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Can profitable arbitrage opportunities in the raw cotton market explain Britain's continued preference for mule spinning?

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Can profitable arbitrage opportunities in the raw cotton market explain Britain's continued preference for mule spinning?[1]

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Abstract

In an influential article Saxonhouse and Wright argued that the quality of local cotton was the single most important factor in explaining national preferences for ring or mule spinning. For Britain, they argue that mills using more flexible mule spindles could exploit arbitrage opportunities between different types of cotton in the Liverpool market, reducing the incentives to adopt rings. We use newly assembled price data to show that such cost-reducing arbitrage opportunities were small. We argue instead that the primary determinants of Lancashire's technological choice were demand factors, but that the availability of good raw cotton did determine technological choice in emerging cotton industries.

[1] I would like to thank Diana Weinhold for helpful comments, Arlene Crossett, Lisa Joyce, the late Betty Lessard and John Mayer of the Manchester Historic Association, New Hampshire, for outstanding service and hospitality, Judith Allen for excellent research assistance in preparing the data set, and the University of Oxford's George Webb Medley Fund for financing the data collection. The remaining errors are my responsibility.

Introduction

This paper brings evidence to bear on a plausible but untested hypothesis set out by Saxonhouse and Wright to answer that much-asked question: why did Britain continue to use so many mule spindles to spin cotton a century ago? Saxonhouse and Wright argue that the starting point to understanding differential international rates of ring and mule use is to look at how the two machines treated raw cotton. They note correctly that mule spindles were less fussy than ring spindles as to the quality of cotton required to operate successfully. In particular, compared with rings, mules could use a greater variety of different lengths of cotton fibres (known as the "staple") to spin yarn of any given fineness (known as the "count").[2] There is much evidence to support this proposition.[3] Saxonhouse and Wright then go on to argue that those countries with access to high quality raw cotton, such as the United States and Brazil, used rings, while those nations that used lower-quality, shorter staple cotton, such as Britain, India and Russia, preferred mule spindles.[4]

It is worth noting that the case of Britain is different to that of other low-quality cotton using nations, such as India or Russia. These nations use of shorter staple cotton was caused by a reliance on domestic cotton that was invariably shorter staple. Britain, in contrast, imported its raw cotton, mainly from the United States. Since United States cotton growers were as willing to sell to British as to American manufacturers, British cotton firms had equal access to good quality cotton as did American firms. Saxonhouse and Wright note that although this is true, British firms also had unique access to the Liverpool market, from where they could purchase every type of cotton conceivable. They argue that 'only the mule allowed these spinners to make maximum use of this market.'[5] We shall argue, in fact, that this was not the case. Instead we argue that the existence of 'the world's best-developed spot market in raw cotton' meant that British firms could rely on being able to buy all types of cotton at

[2] Gary R. Saxonhouse and Gavin Wright, "New Evidence on the Stubborn English Mule and Cotton Industry, 1878-1920," Economic History Review 37.4 (1984)., p. 514.
[3] See for example Melvin Thomas Copeland, The Cotton Manufacturing Industry of the United States, Harvard Economic Studies ; 8 (Cambridge (Mass): Harvard University, 1912)., pp. 65-74, especially in this context p. 72.
[4] Saxonhouse and Wright, "New Evidence.", p. 514.
[5] Saxonhouse and Wright, "New Evidence.", p. 515.

consistent prices that reflected their relative worth. As such, there were fewer opportunities for arbitrage than would have been the case with a thinner, less well-developed market. We will argue that Britain's undeniable use of lower quality raw cotton is a simple outworking of the Rothbarth-Habakkuk hypothesis, whereby the relatively higher ratio of raw cotton to labour costs in Britain encouraged firms to use raw cotton more parsimoniously, at the expense of using more labour, than their American counterparts.

In order to test Saxonhouse and Wright's hypothesis, we need detailed staple-specific raw cotton price data. This would allow us to test whether the price premium of a given staple of cotton fluctuated relative to other types of cotton – creating an arbitrage opportunity for the mule spinner that a ring spinner could not exploit. No such data exist for the Liverpool market, nor for the New Orleans market. We have, however, found staple-specific price data in the cotton orders book of New Hampshire's Amoskeag Mill, for the period September 1928 to March 1935. Although it would clearly be better to have British data for the period 1900-1913, these data have the singular advantage of existence.[6] They allow us, for the first time, to measure the magnitude of relative price movements, and to see how a ring spinning mill – the Amoskeag – coped with the fluctuations that did exist. We shall show that the fluctuations were relatively small, and will argue that the fluctuations in this data set represent an upperbound on the likely size of the fluctuations that would have existed in the Liverpool market. Furthermore, we find that even though a ring spinning mill such as the Amoskeag could not arbitrage across cotton staples, it could and did arbitrage over time, buying more cotton when prices were advantageous.

We proceed as follows. We begin with a concise survey of the literature, setting forth the various hypotheses and evidence that different authors have used to try to explain Britain's relative attachment to the mule spindle. We then set out and describe the data. We use that data to assess the extent of short-term fluctuations in the price premium of one staple of cotton versus another, and to calculate the corresponding

[6] The Amoskeag cotton order records do go back to 1906, but the order books do not list the staple before 1928. The records are housed as Amoskeag Series 75 in the Manchester Historic Association, Manchester, New Hampshire, see Alan M Schwartz, Guide to the Records of the Amoskeag Manufacturing Company at the Manchester Historic Association (Manchester, NH: Manchester Historic Association, 1985).

size of the saving that a hypothetical mule spinner could have made. We show that this saving was small, at around 2 per cent of total expenditure on raw cotton.

We conclude by returning both to the debate on the reasons for Britain's continuing use of the mule, and to the applicability of Saxonhouse and Wright's hypothesis for other countries. We argue that the primary reason for Lancashire's dependence on the mule was demand. Lancashire produced large amounts of fine count yarn, and yarn for export: both sectors that were trivially small in the United States, and for which the ring was inherently less well suited. In addition, the combination of Lancashire's use of power looms, and Lancashire's factor costs, meant that almost all weft yarn was spun using mules. Finally, we note that Saxonhouse and Wright's insight that the different treatment of cotton by mule and ring spindles does explain why Lancashire spinners were less likely to use rings for very coarse counts (sub-20) than for coarse counts (20s): the mule was able to work well with waste cotton, in a way that the ring was not. Finally, we argue that although it is not the primary cause of Britain's continued use of the mule, the international evidence for Brazil, India and Russia assembled by Saxonhouse and Wright in favour of their hypothesis is compelling: access to reasonable cotton was a pre-requisite for using ring spindles.

Literature

In his original article and subsequent book, Lars Sandberg argued that Lancashire's greater use of mule spindles, and correspondingly lower use of ring spindles, c. 1900, was readily explicable in a neo-classical context, without the need to accuse Lancashire manufacturers of technological conservatism or entrepreneurial failure.[7] He characterised observed investment behaviour in three ways. First, Lancashire manufacturers generally chose rings when buying new machinery to spin coarse (sub-40 count) yarn. Second, firms did not scrap but instead continued to use existing mules spinning coarse yarn, and third, that mules remained the choice for new machinery to spin medium and fine yarns (counts over 40 and 80 respectively). In

[7] Lars G. Sandberg, "American Rings and English Mules: The Role of Economic Rationality," Quarterly Journal of Economics 83.1 (1969)., Lars G. Sandberg, Lancashire in Decline : A Study in Entrepreneurship, Technology, and International Trade (Columbus: Ohio State University Press, 1974).

contrast United States manufacturers were more likely to scrap existing coarse mules, and to purchase rings to spin medium and even fine cotton.

He argued that this observed investment behaviour was in line with different cost conditions in the two countries. In particular, skilled mule spinners were relatively abundant in Lancashire and relatively scarce in the United States. This meant that the wage premium commanded by mule spinners over their unskilled ring counterparts was lower in Britain than in the United States, and, as a result, British firms were more likely to find that the unit costs for mule spinning were lower than those for ring spinning. This had two implications. First, British manufacturers found it economic to keep existing well-functioning coarse mules while United States manufacturers found it cheaper to scrap them, replacing them with new ring spindles. Second, British firms found it rational to purchase new mules for medium count yarns while United States firms found it rational to purchase ring spindles to spin the same counts.

These different cost patterns generated different optimal ratios of rings to mules in each country for any given count of yarn, with Britain more likely to find mules advantageous. This difference in favour of the mule at each count in Britain was then compounded at the aggregate level by different demand structures. Whilst United States firms produced almost exclusively coarse yarn (counts below 40), British firms produced cotton of all types, including substantial amounts of medium and fine yarns. This increased the proportion of mules in the British total capital stock because although ring spindles and mule spindles were good substitutes for low count yarn, rings were less well suited to medium and particularly to fine counts of cotton.

Sandberg concluded that since observed investment behaviour matched his assessment of the cost conditions faced by entrepreneurs in the two industries, British entrepreneurs continuing use of mule spindles was not in any sense irrational, or conservative, but rather an optimal response by successful entrepreneurs to the cost and demand conditions that they faced.

There have been two major critiques of Sandberg's work, the first by Lazonick, the second by Saxonhouse and Wright. We look briefly at Lazonick's work, before moving on to look in more detail at that of Saxonhouse and Wright, whose arguments are the focus of this paper.

Lazonick used new and better data to argue correctly that Sandberg had overestimated both the incentives and the extent to which Lancashire adopted rings for coarse yarn production.[8] These corrections left Sandberg's conclusions essentially unaltered: manufacturers responded rationally to the costs that they faced. More importantly though, Lazonick introduced a major additional consideration into the debate: market structure.[9] He provided evidence that the transport costs of moving yarn from independent spinner to independent weaver were higher for ring than for mule spun yarn. As a result, Lancashire's unusual reliance on vertically specialised spinners and weavers slowed the adoption of ring spinning. In addition, he showed that there existed technical complementarities between new technologies in spinning and weaving, namely between rings and automatic looms. Vertical integration would have allowed the co-ordinated and earlier introduction of both technologies.

Leunig shows that Lazonick is right that vertical specialisation increased transport costs and lowered ring adoption rates, but that the effect is modest.[10] Just over half of all coarse spinning specialised firms had weavers nearby, and ring adoption rates in those firms equalled those of integrated firms: co-location proved a good substitute for vertical integration. Leunig also shows that automatic looms were not viable at all under British cost conditions and so the issue of technological inter-relatedness was not of practical relevance in Britain.

In their 1984 article, Saxonhouse and Wright use new data from Lancashire's textile machinery manufacturers to show that Lancashire's preference for mules was more extensive than either Sandberg or even Lazonick had claimed.[11] They show that firms continued to purchase large numbers of new mule spindles, and that mules were the dominant choice even for coarse yarns, right until the outbreak of the first world war.

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[8] William Lazonick, "Factor Costs and the Diffusion of Ring Spinning Prior to World War I," Quarterly Journal of Economics 96.1 (1981).

[9] William Lazonick, and Mass, William, "The British Cotton Industry and International Competitive Advantage: The State of the Debates," Business History 32.4 (1990), William Lazonick, "Industrial Organization and Technological Change: The Decline of the British Cotton Industry," Business History Review 57.2 (1983).

[10] Timothy Leunig, "New Answers to Old Questions: Explaining the Slow Adoption of Ring Spinning in Lancashire, 1880-1913," Journal of Economic History 61.2 (2001).

[11] Saxonhouse and Wright, "New Evidence.", see also William Lazonick, "Stubborn Mules: Some Comments," Economic History Review 40.1 (1987), Gary R. Saxonhouse and Gavin Wright, "Stubborn Mules and Vertical Integration: The Disappearing Constraint," Economic History Review 40.1 (1987).

They use this evidence to argue against the earlier claim that Britain's continued reliance on mule spinning was caused by the importance of medium and fine yarns in the output mix. Taking advantage of the fact that British machinery manufacturers supplied textile machinery to other nations' cotton industries, they show that the ratio of rings to mules across countries does not correlate well with the count of yarn spun. Instead, they argue 'that the quality of local cotton was the single most important factor in explaining national preferences for ring or mule spinning' – those countries with ready access to good cotton used rings, those countries without such access used mules, 'a machine whose *forte* was getting the most out of low-quality cotton.'[12]

Britain, of course, grows no cotton, and most of the raw cotton used by British spinners to make coarse yarn came from the United States. If the quality of available raw cotton was indeed the single most important factor explaining national preferences for ring and mule spinning, we would start from the *a priori* expectation that British and United States ring adoption rates would be similar. Saxonhouse and Wright argue against this, however, noting that British spinners had access to the Liverpool cotton market, 'the world's best developed spot market in raw cotton'.[13] The mule could use a wider range of raw cotton to produce any given output than could the ring. As a result, Lancashire mule spinners – but not Lancashire ring spinners – could take advantage of fluctuations in the price of one type of raw cotton against another. This in turn increased the advantage to mule spinning in Lancashire. Saxonhouse and Wright note that Sandberg provided no data on the fluctuations in the price of one type of cotton versus another, and instead assumed that there was no such variation. They note the existence of qualitative evidence in the contemporary literature that such fluctuations existed, although on closer inspection neither author was referring to fluctuations in staple price premiums within seasons.[14] Saxonhouse

[12] Saxonhouse and Wright, "New Evidence.", Abstract and p. 514.
[13] Saxonhouse and Wright, "New Evidence.", p. 514.
[14] Winterbottom, refers to changes in the price premium from one season to another, which do not hold open opportunities for arbitrage. Chapman gives no evidence of price fluctuations, but rather a theoretical example of the limits to which risk could be removed by cotton spinners through the raw cotton futures market. James Winterbottom, Cotton Spinning Calculations and Yarn Costs: A Prictical and Comprehensive Manual of Calculations, Yarn Costs, and Other Data Involved in Adapting the Machinery in All Sections, and for All Grades, of Spinning and Doubling, second ed. (London:

and Wright do not offer quantitative evidence as to the magnitude of these fluctuations, or the likely savings that a mule spinner could make over the year. This paper aims to fill that gap, and so to test their hypothesis.

Data and analysis

Cotton is classified in two ways, by grade, and by length of staple. Grades ranged from "ordinary" to "middling fair", with sub-grades (barely, strictly and fully) giving intermediate grades.[15] Grades cover the purity and consistency of the cotton, the percentage of foreign matter, such as leaves, seeds and so on, and was equally important to ring and mule spinners alike. Staple literally measures the length of the cotton fibres, which, for American grown yarns that were most important in the Liverpool market, varied from a little below one inch to 1.5 inches, at intervals of one-sixteenth or one-thirty-second of an inch. Ring spindles demanded a higher and, critically, a more precise staple length than mule spindles. Here, then, is the potential advantage for mule spinners: rather than being forced to buy a particular type of raw cotton, whatever its price, they are able – within reason – to buy whichever type of cotton is priced most advantageously on the day. Of course, buying lower staple cotton is not costless: the yarn will break more often during manufacture, lowering both labour and capital productivity and so raising costs. But if lower staple raw cotton is *disproportionately* cheap, its purchase will still be advantageous to the manufacturer.

As we noted earlier, neither Sandberg nor Saxonhouse and Wright give evidence as to the size of fluctuations in the cotton market, either in Liverpool or elsewhere. It appears that no market data exist, either for Liverpool or for New Orleans.[16] This paper, however, uses new data gathered from the company records of the world's largest mill, New Hampshire's Amoskeag Manufacturing Company. The data cover

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Longmans, Green and Co., 1921)., pp. 232-7; Sydney John Chapman, The Cotton Industry and Trade (London: Methuen, 1905)., pp. 47-8.

[15] Winterbottom, Calculations., p. 237.

[16] The *Liverpool Daily Report*, for example, does not record staple premiums, and, as one author notes of the Liverpool market, 'the whole business of the spot market is conducted in private by individual bargaining, and the last thing that either seller or buyer would think of is to tell anyone the price agreed on. J.A. Todd, The Marketing of Cotton from the Grower to the Spinner (London: Pitman and Sons, 1933)., p. 213.

all raw cotton purchases made by the mill between 5th September 1928 and 5th March 1935. In over 98 per cent of cases, the data give the date, price, staple, grade, and any distinguishing characteristics, such as discolouration. In total we have 2583 useable observations, covering 428,815 bales, with total expenditure of $27,929,250.[17] Of course, insofar as the interesting question is the continued use of mules in Britain c. 1900, it would be better were the data to be for the market itself, rather than for one company, for the right country and for the right time period. But as we have noted such data do not appear to exist, so this data have the overwhelming advantage of existing.

Saxonhouse and Wright criticise Sandberg for using United States data in his unit cost calculations.[18] They note, for example, that United States and UK staple classifications differ, so that what passed as 1" in the United States would be classified as 1 1/16" in Liverpool. That criticism is not relevant to this paper, however, because we make no attempt to match the actual staples of cotton bought in the United States with the types of yarn that were produced in Britain. Instead we look at whether the premium on one staple of cotton over another was consistent over time. We will return later to the issue of whether our results can be taken as applicable to Lancashire before 1913.

As we have noted, the Amoskeag data are extensive, covering seven seasons, and purchases costing $28 million. The price per pound averaged 12.35 cents with a standard deviation of 4.6. The most common length was 1", making up 36 per cent of purchases, with 7/8" and 1 1/32" also common at 22 per cent and 14 per cent respectively. 31/32", 1 1/16" and 1 1/8 per cent each represent between 7 per cent and 9 per cent of purchases, while the remaining staples, 13/16", 15/16", 1 3/16" and 1 1/4", were relatively rare, between them making up fewer than 5 per cent of observations. In terms of grade, the mill generally bought reasonable cotton yarn. Only 9 per cent of purchases were of good ordinary grades and below (of which 4 per cent were good ordinary, and 5 per cent strictly good ordinary), whereas 44 per cent were lower middling grades (of which 42 per cent were strictly lower middling) and

[17] Assuming standard 500lb bales.
[18] Saxonhouse and Wright, "New Evidence.", p. 515.

47 per cent were middling or better (42 per cent middling, 5 per cent strictly middling). 5 per cent of cotton was discoloured in some way, some spotted, some tinged, some coloured grey-blue.

The price paid varied considerably both because the raw cotton being purchased varied considerably, but more importantly because the period was one of tremendous macro-economic disruption. The consumer price index fell from 100 in 1928 to a low of 76 six years later, before rebounding a little to 78 in 1934.[19] The price falls for raw cotton were much larger, with figure one showing that the price of a standardised grade of cotton (1", good ordinary) falling 78 per cent from an average price of 16.1c in the 1928/29 season to a low of just 3.5c in 1931/32, before recovering somewhat to 10.0c in 1934/35. These extreme price movements are characteristic of agricultural prices in this period more generally, reflecting the heavy impact of the depression on agriculture.[20]

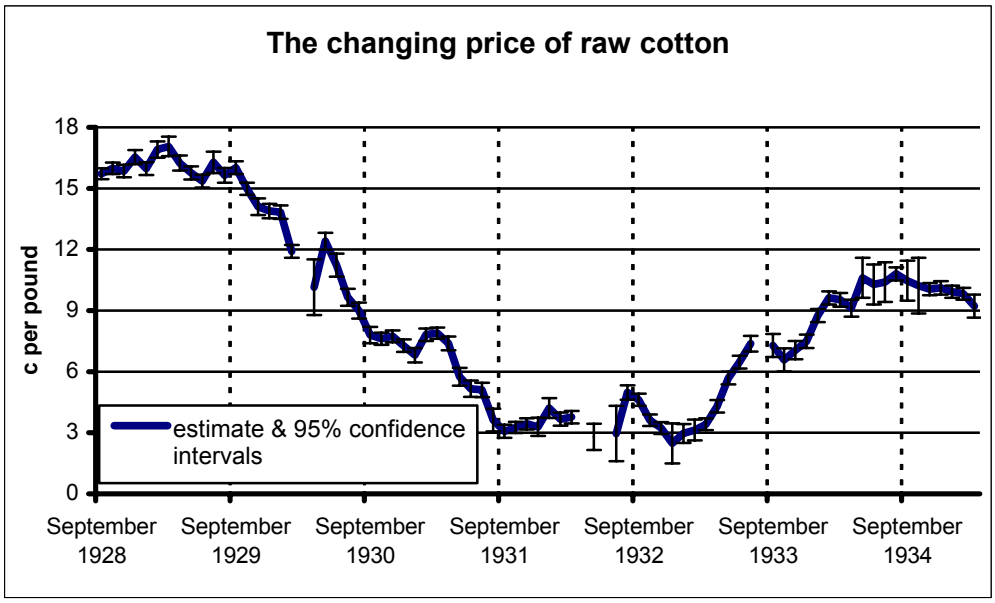

Figure 1

Note: Price is for 1" good ordinary non-discoloured cotton. Gaps indicate months with no observations.

[19] Samuel H. Williamson, "What is the Relative Value?" Economic History Services, April 2002, URL : http://www.eh.net/hmit/compare/

[20] Jeremy Atack and Peter Passell, A New Economic View of American History : From Colonial Times to 1940, 2nd ed / ed. (New York: Norton, 1994)., p. 594.

As we noted above, the crucial thing is that a mule spinner – but not a ring spinner – could vary the staple of raw cotton purchased according to which was good value in the market that day. If we are to assess the potential gains to a mule spinner from being able to vary the staple of cotton purchased we would – ideally – like to know what was being spun, the staples of cotton that could be realistically have been used, and the additional (or reduced) labour and capital costs from using a shorter (or longer) staple of cotton than usual. In reality we do not have the data to do this. Instead, we shall make the following simplifying neo-classical assumption: that the average premium of one staple versus another was just sufficient to compensate a mule spinner for changes in other costs associated with that staple of cotton. This implies that if the price premium of one staple of cotton is lower than average in any particular case, then that cotton may be considered 'good value', and vice versa.

Let us consider the plausibility of this assumption a little further by imagining that it does not hold. Imagine instead that the premium on (say) 1 1/8" over 1" cotton is greater than the cost saving from using it. If that were true, then no spinner would buy 1 1/8" cotton, and the price would fall until the premium was equal to the cost savings that the manufacturer could gain from using it, at which point manufacturers would be willing to purchase it. Of course, it is unrealistic to imagine that a mule spinner could have substituted any staple of cotton for any other, and we later consider the case in which a given cotton staple is considered a substitute only for those staples up to 3/16" longer or shorter.

In order to assess which cotton was good value, therefore, we compare the actual staple premium for each and every cotton purchase with the average premium for that staple. We first use regression analysis to calculate the average premium for each cotton characteristic, including different staples and grades. The results are given in table one.

Table 1

13/16” staple	-1.539184	(-15.45)	****
7/8” staple	-0.7565986	(-18.94)	****
15/16” staple	-0.6036653	(-2.02)	**
31/32” staple	-0.1862627	(-2.66)	***
1 1/32” staple	0.4847295	(8.97)	****
1 1/16” staple	1.185309	(13.98)	****
1 1/8” staple	1.177099	(17.48)	****
1 3/16” staple	2.859526	(18.23)	****
1 1/4" staple	7.264984	(53.93)	****
grade: lower middling	3.597917	(54.79)	****
grade: middling+	4.19548	(65.87)	****
discoloured	-0.4471307	(-7.11)	****
constant	15.72244	(115.08)	****

Adj R-squared = 0.9782
Root MSE = .68207
F(86, 2496) = 1346.13
Number of obs = 2583
* significant at the 10 per cent level, ** 5 per cent, *** 1 per cent, ****0.1 per cent

Dependent variable: the price of cotton. All variables are dummy variables. Excluded category is 1” cotton, good ordinary grade, not discoloured, bought in September 1928. Monthly dummy variables included, but not reported in this table. These are given graphically in figure one.

OLS regression, performed using STATA 7.0.

Overall the regression works well, explaining almost all of the variation in cotton prices, with an adjusted R^2 of 0.98. Since this regression forces the staple premium to be constant over the entire seven year period, the small amount of unexplained variation in price tells us immediately that it is unlikely that the staple premiums fluctuate significantly over time and that it is correspondingly unlikely that the potential arbitrage savings were large.

The coefficients on grades and on discolouration work well: the mill was prepared to pay more for better grades of cotton, with a positive premium on lower middling yarn compared to good ordinary, and a larger premium still on middling grade yarn, and a negative co-efficient on discolouration. All of the coefficients on staple lengths are correctly signed and significant. The co-efficient on 1 1/8” yarn should, however, be larger than the co-efficient on 1 1/16” yarn, with a co-efficient of, say, 2 cents being more in keeping with the other results. With that exception the magnitudes are internally consistent, with, as expected, the difference between coefficients larger at

each end of the staple spectrum, and smaller between staples that were more readily substituted, one for another.

The dummy variables for each month capture both the general macro-economic volatility in this period, and the changes in the state of the overall raw cotton market both from year to year and from month to month. For clarity we present the results graphically, showing both the coefficients and 95 per cent confidence intervals. The graph shows the decline in raw cotton prices at the onset of the Great Depression, as well as variation in the market over shorter periods of time.

We now go on to assess which of the Amoskeag's purchases represent 'good value' to a mule spinner, using the methodology outlined above. We calculate whether each purchase was good value by subtracting the actual price paid for the cotton from its assessed value, which is derived from the coefficients in table one. Put simply, if value exceeds cost (a positive result), the purchase was good value, whereas if cost exceeds value, the purchase was poor value. By that we do not mean that the cotton was poor value to the ring spinning Amoskeag Manufacturing Company, but rather that it would have been poor value to our counterfactual mule spinning firm. The distribution of results is given in figure two, which shows that although there were a few examples of cotton that would have been very good or very poor value to a mule spinner, 89 per cent of the cotton was priced within 1c of its fair value.

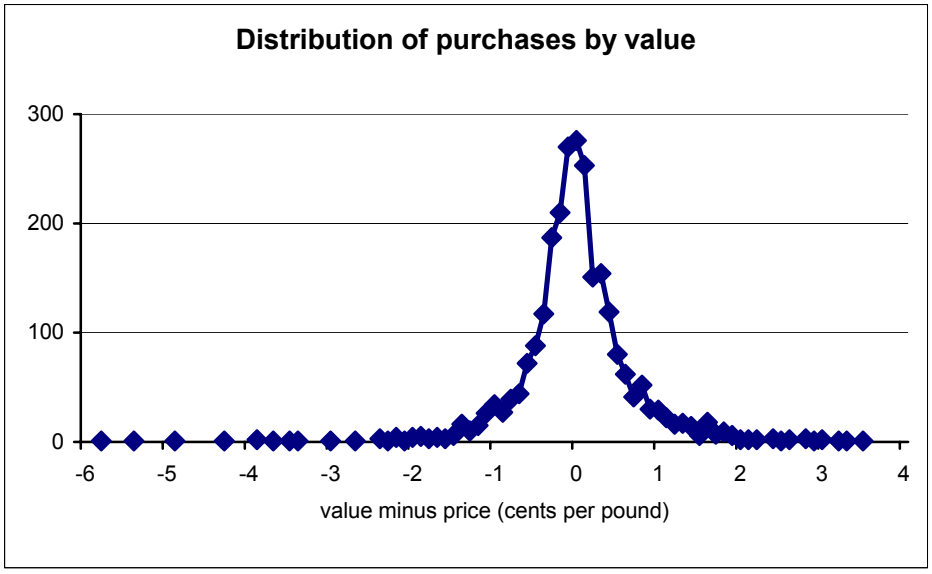

Figure 2

Given the greater flexibility of the mule, a mule-spinning firm could have taken greater advantage of good value cotton and been in a better position to resist buying bad value cotton than a ring-spinning firm would have been. Specifically, we make the claim that a mule spinner would have bought only the best value cotton bought by the Amoskeag each day. Since we make no claim that our counterfactual mule spinner would have been any better able than the Amoskeag mill to predict price trends, we only allow it to arbitrage within each day, and not across days. We quantify the saving made by comparing the value of each actual purchase with the best value purchase for that day. The counterfactual mule-spinning firm would have changed 1691 (65 per cent) of the purchases made by the Amoskeag mill, reducing the price paid per pound on each transaction by an average of 3.1 per cent.

This overstates the total saving available to the mule-spinning firm. The Amoskeag mill was aware that some of its purchases represented better value than others: the average number of bales per transaction was higher when cotton was good value, as measured using the methodology given here. This means that although a mule spinner could have saved an average of 3.1 per cent per transaction, the total saving would have been lower, at 2.7 per cent. A strong financial position meant that the Amoskeag mill was able to arbitrage across time, buying more raw cotton when prices seemed advantageous.

Had our counterfactual mule-spinner, therefore, been able to buy the best value of the Amoskeag's cotton purchases each day, it would have been able to reduce the amount paid for raw cotton by 2.7 per cent. That figure represents an upperbound on the true saving, for two reasons. First, we assume that there were unlimited amounts of the best value cotton available for purchase each day. Second, we assume that the mule-spinning firm could have substituted any staple of cotton bought by the Amoskeag for any other. Neither of these assumptions are realistic, and we now go on to quantify their effects in turn.

In reaching our 2.7 per cent savings estimate we assumed that our counterfactual mule-spinning firm would have been able to replace each day's total purchases with the same number of bales of the best value cotton. This assumption does not hold. 709 of the Amoskeag's purchases – more than one-quarter of the total – were of a staple of

cotton bought at a higher price than that paid the same day for the same staple of cotton. Excluding simple irrationality there are three alternative explanations for the Amoskeag's actions. First, the different purchases of the same staple cotton may have had other differences which were not recorded, but which explain the different prices. Second, the quantities available at the lower price were limited. Third, the price moved during the day. Given the detailed descriptions in the records, the first seems unlikely. The second is plausible – buyers may have sold identical cotton at lower prices if they wanted to shift relatively small amounts of cotton at the end of the day, or, if credit constrained, may have been happy to charge a shade under the market price to ensure that their cotton was purchased first, or simply if they were less good at negotiating price than other sellers. Similarly, it is plausible to believe that the price moved within the day (the time of purchase is not recorded in the records), just as, say, stock prices do today.

All of these explanations imply that a mule-spinning firm would have been just as unable as the Amoskeag to secure unlimited cotton of a given staple at the price of the best value transaction. We therefore make the assumption that where the Amoskeag paid more than one price for the same cotton staple, that a mule-spinner would have been unable to replace the dearer purchase with a larger quantity of the lower-priced identical cotton. This reduces the amount that our counterfactual mule-spinning firm could have saved to 2.0 per cent of the total expenditure on raw cotton.

We have assumed until now that the mule-spinning firm could have substituted any raw cotton for any other in the production process. Although the mule was more flexible than the ring in terms of the cotton it needed to spin any given count of yarn, it was not infinitely flexible. For example, 7/8" cotton was best suited to spinning count 20 yarn, whereas 1 1/16" yarn was suitable for spinning counts in the mid-30s, and 1 ¼" cotton count 60 yarn.[21] It is implausible to believe that cotton suited to spinning count 20 yarn could have been used for yarn of counts above 35, or that cotton suited to mid-30s yarn could have been used to make yarn finer than count 60. Similarly, it seems unlikely that 1 ¼" cotton would have offered any productivity advantages over 1 3/16" cotton when spinning coarse yarns for which 7/8" cotton

[21] Winterbottom, Calculations., p. 235.

would have been more normal. If we assume that any staple of raw cotton could be substituted for any other staple up to and including 3/16" longer or shorter than that actually purchased – still a generous interpretation of the mule's flexibility - we find that the saving made by our hypothetical mule-spinning firm falls to 1.7 per cent.

There are reasons to see this figure too as an upper-bound. We continue to assume that the counterfactual mule-spinning firm could have replaced any purchase of a different staple with the best value cotton available that day, even though we have evidence that the quantities available at such a price were frequently limited. Similarly, we allow our counterfactual mule spinning firm to gain from any intra-day price movements, effectively endowing them, unrealistically, with perfect foresight within each day. It is not possible to quantify the size of these effects, but their existence means that all of the estimates presented here overstate the true savings that would have been available to a mule-spinning firm.

As we noted at the beginning, the data used here are for the United States, and for the late 1920s and early 1930s. It is possible that the savings available in Lancashire in the period prior to the First World War were larger. It seems likely, however, that the arbitrage savings would have been smaller before the war, and smaller in the Liverpool market. The period for which we have data, 1928-35, was a period of extreme economic turbulence, in which the price of cotton fell 78 per cent in the first three years, before rising 185 per cent in the next three. This level of economic turbulence was much greater than was experienced prior to the first world war, and we would expect a period of extreme price volatility to increase the gains to arbitragers, compared with one in which prices were more steady. Second, the Liverpool market was the largest and most liquid cotton market in the world. In general, the greater the market size, the closer prices are true values, since any given change in demand could be more easily accommodated within existing supply, directly reducing volatility and the corresponding gains to those able to arbitrage.

Third, there were large numbers of mule spinners in Lancashire, all able and willing to vary the staple of cotton purchased according to what was financially advantageous that day. All would have had approximately the same judgement as to the price premium at which a particular cotton staple was good value compared with another.

Given that there existed a large number of essentially symmetric, well-informed, mule spinners, any deviation from the correct premium, however small, would be arbitraged away almost instantly, so that there were, in equilibrium, never any arbitrage gains to be had by mule spinners in the Liverpool cotton market. These are essentially the same conditions that preclude the existence of bargains in stock markets and foreign exchange markets today.

Against this, it is worth noting that we do not have price data for every staple of cotton every day. It may be that there were types of raw cotton that would have been good value to a mule spinning firm, but which were not purchased by the Amoskeag mill, and so were not included in our assessment of what was available. Although this is possible, it does not seem especially likely. We know that the Amoskeag mill purchased all staples of cotton at different times, and that it was happy to hold considerable stocks of raw cotton if it felt that this was advantageous. It therefore seems unlikely that it passed up the opportunity to purchase cotton at a good price. Instead it is more plausible to think either that the missing staples were unavailable that day, or that the Amoskeag felt that the cotton staples that it did not purchase were not good value. Both imply that our data include all examples of good value cotton.

Finally, we noted earlier that our regression estimated a premium on 1 1/8" cotton that was lower than the estimated premium for 1 1/16" cotton. We argued that a premium of 2 cents rather than the estimated 1.177 cents would be more consistent with the other estimates in the regression. We therefore reran the simulations using this imposed premium for 1 1/8" cotton, leaving the other premiums as estimated by the regression analysis. This change raises the estimated saving that a hypothetical mule spinner could have made by 0.4 per cent, to 2.1 per cent of raw cotton expenditure.

Interpretation

We have shown that the cost reductions that a mule spinner could have made by arbitraging between different staples of cotton were, in the United States market in the late 1920s and early 1930s, limited to around 2 per cent of the value of the cotton purchased. Furthermore, we have argued that this overstates the amount that could been saved by mule spinners in Lancashire before the First World War. We do not,

therefore, think that Lancashire firms' access to the world's most developed cotton market can be the primary explanation of their continued reliance on mule spindles. On the contrary, having access to "an established market for more different growths of cotton than any other market in the world"[22] should have made it easier to adopt rings in Lancashire, since spinners could be assured of the availability of exactly the type of cotton that they needed.

Instead, we argue that Lancashire's reliance on mule spinning can be explained by four principal factors. First, and most importantly, Lancashire spun a far greater amount of medium and fine cotton than did the United States. Saxonhouse and Wright find that a majority of spindles installed in Britain between 1878 and 1906 were installed to spin counts of over 40, whereas, in contrast, such counts represented just 8 per cent of United States output.[23] Those fine count installations represented more than 60 per cent of all mules purchased in Lancashire in this period.

But as Saxonhouse and Wright show, Lancashire spinners were still as likely to pick mules as rings for counts below 40. What can explain this preference? First, Lancashire had a substantial export trade in yarn, accounting for over 10 per cent of yarn output in the pre-war period.[24] Since the mule, unlike the ring, produced yarn in lightweight packages made up of nothing but yarn, the yarn export trade could only be satisfied by mule spinners, however coarse the yarn being spun might be. The United States had no equivalent yarn export trade. Second, Leunig, building on the work of Sandberg, has shown that virtually no Lancashire firm, including integrated firms, used ring spindles to produce weft yarn.[25] The cost of rewinding the yarn to prepare it for weaving on power looms – a stage not necessary if using mule spindles – was prohibitive.

There is one remaining puzzle, however: Saxonhouse and Wright find that although Lancashire spinners were only one-third more likely to pick mules than rings for

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[22] Alonzo B. Cox, Marketing American Cotton in England, Us Department of Agriculture Technical Bulletin, vol. 69 (Washington: Government Printing Office, 1928)., quoted in Saxonhouse and Wright, "New Evidence.", p. 514.

[23] Saxonhouse and Wright, "New Evidence.", US Government, Census of Manufactures, 1905: Textiles, ed. S.N.D. North, vol. 74 (Washington: Government Printing Office, 1907)., p. 48, by weight.

[24] Robert Robson, The Cotton Industry in Britain (London,: Macmillan, 1957)., pp. 332-333.

[25] Leunig, "New Answers.", pp. 455-459

counts in the 20s, they were more than twice as likely to pick mules than rings for counts lower than 20s. This is counterintuitive, since we think of rings as best suited to spinning low counts of cotton. Here Saxonhouse and Wright's emphasis on the different technical capacity of the mule is a useful explanator. There is ample evidence that Lancashire's spinners were more likely than United States firms to re-work raw cotton waste to make coarse yarns.[26] Given that waste cotton was by definition more heterogeneous in staple than bales of sorted new cotton, the mule, 'a machine whose *forte* was getting the most out of low-quality cotton'[27] had an obvious advantage for this sort of work over a machine that needed more consistent cotton to work effectively.

Notice that in the United States such waste would have been more likely to be discarded. Its reworking in Britain – but not in the United States – is a classic example of the Rothbarth-Habakkuk hypothesis: the industry with lower cotton to labour costs (the United States) is wasteful of cotton to economise on labour, whereas the industry with higher cotton to labour costs (Lancashire) is wasteful of labour to economise on cotton. At a wider level, since both the Lancashire and the United States industries used United States grown cotton as their primary raw material, we can view Lancashire's more careful and less wasteful use of cotton as a more general example of a Rothbarth-Habakkuk substitution between labour and raw cotton.

We noted that it was the heterogeneity of waste cotton that made the mule useful for spinning very low count yarn in Lancashire. We can build on this insight by looking again at Saxonhouse and Wright's international evidence. They note that when India and Russia relied on domestic raw cotton, the mule prospered. In the light of the evidence from Britain, it seems likely that it was not simply the shorter staple that made the mule a useful investment in these countries, but the heterogeneity of locally produced bales of cotton. Had the Russian and Indian domestically produced cotton simply been shorter, but baled as consistently as United States produced cotton, then ring spinning firms would have been able to use it perfectly well, albeit to make yarn that was coarser than would have been possible with longer staple cotton imported

[26] Copeland, Us Cotton Manufacturing., p. 72.
[27] Saxonhouse and Wright, "New Evidence.", p. 514.

from the United States.[28] What made the mule useful in these countries was its ability to cope with heterogeneous, as opposed to simply shorter, bales of cotton, of the sort that simply would not have been sold in Liverpool or New Orleans. It is noticeable that mules were used in India to spin very low counts of yarn that could – and given the relative costs of raw cotton and labour in India – almost certainly were made from cotton waste.[29] Saxonhouse and Wright are, then, correct to argue that the different treatment of raw cotton is crucial to understanding international choices between rings and mules, but what is important is not the availability of long versus short stapled cotton, but rather the availability of cotton that is of consistent length and so suitable for spinning on rings. That was true in the United States and in Brazil, where all domestic raw cotton was long enough as to make variation in the staple unimportant. These countries, therefore, and those that imported from them, such as Britain – which, we must remember, was a major user of ring spindles in absolute terms – had the choice of which technology to use. Differing factor costs meant that the United States and Brazil opted for rings, while Britain continued to use mules to a large extent. Countries without dependable cotton supplies, in contrast, were effectively constrained to continue to use the mule by their inability to secure the sort of cotton that was a prerequisite for using ring spindles.

Conclusion

In this paper we have used new data to quantify the gains available to mule spinners from arbitrage across different staples of cotton. We find that the gains were very small, amounting to 2 per cent of raw cotton expenditure, and certainly too small to have been a major determinant in explaining the technological choice of Lancashire's cotton spinning firms. Instead we argue that the more traditional explanations, revolving around the different structures of demand, and different relative factor costs, are more powerful in explaining technological choice in Lancashire. This result for Lancashire in no way invalidates Saxonhouse and Wright's claim that different availability of good raw cotton is an important determinant of ring adoption

[28] Winterbottom, Calculations., p. 237.
[29] Saxonhouse and Wright, "New Evidence.", p. 512.

elsewhere, on the contrary, that hypothesis fits the facts more accurately than any other.

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