Technological Evolution in Cotton Spinning, 1878-1933

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The international diffusion of cotton textiles production is one of the dramatic stories of modern economic history. The historic Lancashire industry came under competitive pressure from emerging low-wage Asian producers in the late nineteenth century; yet Lancashire retained its international pre-eminence until World War I, only to suffer irreversible decline during the interwar period. Within the United States, competition between the older New England center and the rising branch in the South had a similar timing and character. But while the experience of the industry in England and New England was broadly parallel, the trajectories of the newly industrializing nations of that era show considerable variety (Table 1). An extensive literature has drawn both bilateral and multilateral comparisons on such dimensions as choice of technique, modes of labor organization and performance, product quality and variety, and the contribution of capital markets and other forms of infrastructure.[1] As the first global industry, cotton textiles offers unique opportunities for tracking the roots of international differences in productivity and in rates of progress through time.

Some years ago we contributed to these discussions by reporting new evidence on

[1] On labor systems and performance, see Gary Saxonhouse and Wright, 'Two Forms of Cheap Labor in Textile History,' in Saxonhouse and Wright (eds.), *Technique, Spirit and Form in the Making of the Modern Economies: Essays in Honor of William N. Parker, Research in Economic History*, Supplement 3, 1984, 271-300; Gregory Clark, 'Why Isn't the Whole World Developed? Lessons from the Cotton Mills,' *Journal of Economic History* 47 (1987), 141-173; Susan Wolcott, 'The Perils of Lifetime Employment Systems: Productivity Advance in the Indian and Japanese Industries, 1920-1938,' *Journal of Economic History* 54 (1994), 307-324; Susan Wolcott and Gregory Clark, 'Why Nations Fail,' *Journal of Economic History* 59 (1999), 397-423. On vertical integration and product variety in Germany, see John C. Brown, 'Market Organization, Protection and Vertical Organization: German Cotton Textiles Before 1914,' *Journal of Economic History* 52 (1992), 339-352; and 'Imperfect Competition and Anglo-American Trade Rivalry: Markets for Cotton Textiles before 1914,' *Journal of Economic History* 55 (1995), 494-527. On capital markets and other institutions, see Stephen Haber, 'Industrial Concentration and the Capital Markets,' *Journal of Economic History* 51 (1991), 559-580; and Brian A'Hearn, 'Institutions, Externalities and Economic Growth in Southern Italy: Evidence from the Cotton Textile Industry,' *Economic History Review* 51 (1998), 734-762.

investments in ring and mule spinning capacity between 1878 and 1920, drawn from the records of six British producers of textile machinery, the primary suppliers to the world cotton industry outside of the USA.[2]

[2] Saxonhouse and Wright, 'New Evidence on the Stubborn Mule and the Cotton Industry, 1878-1920,' *Economic History Review* 37 (1984), 507-519; 'Rings and Mules around the World: A Comparative Study in Technological Choice,' in *Technique, Spirit and Form*.

Although British persistence in mule spinning has often been cited as an example of technological inertia and entrepreneurial failure, the new data demonstrated that the mule was the preferred choice in many other countries as well, at least until 1900 and in many cases well into the twentieth century. Mule spinning descended from the Industrial Revolution of the eighteenth century, and reached its most advanced development in Edwardian Lancashire. Ring spinning on the other hand, originated in early industrial New England, and in many ways epitomized the standardized, low-skill, energy-intensive 'American System' of manufactures. Faced with these two polar choices, the various national industries displayed a remarkable range of responses to the same technological alternatives (Table 2). Such disparate nations as Brazil, Mexico and Japan followed the U. S. lead and developed almost exclusively with the ring; but mules were stubbornly preferred by such unlikely bedfellows as Germany, Russia, France, India, Italy, Austria and Canada.

Consistent with the trend in modern scholarship, our reading of the evidence was that on close examination, there was no simple right or wrong choice on this issue prior to the technical breakthroughs in ring spinning known as 'high drafting' that came in after 1913. Until that time, the divergent choices may be rationalized in terms of such variables as labor skills, product demand, the quality of local cotton varieties, or proximity to major cotton markets.[3] In light of the impressive profit levels and export performance of the British industry down to 1913, it is difficult to sustain a case that the choice of the mule was economically irrational at that time.

[3] Early studies along these lines were Lars Sandberg, 'American Rings and British Mules,' *Quarterly Journal of Economics* 83 (1969), 25-43, and C. K. Harley, 'Skilled Labour and the Choice of Techniques in Edwardian Industry,' *Explorations in Economic History* 11 (1974), 391-414, contrasting American rings and British mules. William Lazonick reached the same conclusion -- that the British choice of mules was economically rational -- but only because of the constraints imposed by the lack of vertical integration between spinning and weaving. See 'Factor Costs and the Diffusion of Ring Spinning in Britain Prior to World War I,' *Quarterly Journal of Economics* 96 (1981), 89-109, and 'Stubborn Mules: Some Comments,' *Economic History Review* 40 (1987), 80-86. We disputed this view in 1987, and our position has recently received support from the work of Timothy Leunig, 'New Answers to Old Questions: Explaining the Slow Adoption of Ring Spinning in Lancashire, 1880-1913,' *Journal of Economic History* 61 (2001), 439-466.

Looking back over this discussion, however, we may observe that little of the evidence shed light on the evolution of the underlying textile technologies themselves during the era under scrutiny. This subject was not entirely neglected. We were able to place the ring-mule choice in the context of a long-term competition between two basic strategies of cotton spinning: continuous spinning (the ring) and intermittent spinning (the mule). Further, we could identify the technological boundaries at both ends of the Victorian-Edwardian era: the epoch was launched with the final demise of the hand mule and the introduction of high-speed ring spindles from America in the 1870s; it came to an end with the Casablancas system of fibre control, invented in 1913 and diffused into general use during the 1920s. Between these dates, we suggested that both ring and mule technologies had their adherents as the predictive dominant choice for the future. In support of this claim, we reported data on the diffusion of paper tubes as an alternative to heavy wooden bobbins on rings, an adaptation to the transport-cost advantage of mules over rings when the industry was not vertically integrated. The dearth of interest in paper tubes on the part of British buyers (in contrast to orders from the Continent) confirmed to us that Lancashire was not particularly interested in preparing the way for a transition to ring spinning.

In all of this, we did not bring to bear systematic evidence on relative rates of technical improvement in rings and mules, despite the fact that the same firm records of the British machinery manufacturers contain a wealth of information on technical specifications of these machines over time, between 1878 and 1933: on machine size, speed, yarn count, bobbin type, twist versus weft, and many other more specialized details. Assembling the data for analysis has been a long-term project, with numerous relapses and pitfalls. But this task has now been essentially completed, giving us an opportunity to move the research agenda onto new and perhaps more fundamental questions. The present paper constitutes a preliminary report.

The Transoceanic Migrations of Continuous and Intermittent Spinning

Both mule and ring spinning are direct descendants of spinning processes that date from the earliest days of the Industrial Revolution.[4] Invented (but not patented) by Samuel Crompton in 1779, the mule embodied the same principle of intermittent spinning that underlay both the spinning wheel and the Hargreaves jenny. Mule spindles rest on a carriage that travels on a track a distance of five feet, while drawing out and spinning the yarn. On the return trip, as the carriage moves back to its original position, the newly spun yarn is wound onto the spindle, in the form of a cone-shaped cop. As the mule spindle travels on its carriage, the sliver which it spins is fed to it through rollers geared to revolve at different speeds to draw out the yarn. As its name suggests, the mule was a hybrid form, combining the mechanized features of the jenny with the rollers of Arkwright's water frame. Its versatility ended a period of complementarity between cottage-produced weft yarn and factory-produced warp; by 1790, large mule spinning machines with metal rollers and wheels, fitted with hundreds of spindles and powered by waterwheels, were being used in large factories to spin both warp and weft yarn.

The late-nineteenth-century ring machine also rested on better than 100 years of development of continuous spinning. The mule spindle does not spin while the yarn is being wound; by contrast, the ring – like the water frame – is spinning all the time, the frame being fixed in place. On each ring spindle is a little wire called a traveler, and around each spindle is also a steel ring. After the thread is drawn through rollers similar to those on the mule, it passes through the traveler onto a wooden bobbin placed on the spindle. As the spindle revolves, this traveler is drawn around the ring, receiving its

[4] This description of technological development draws upon Saxonhouse and Wright, 'Rings and Mules around the World,' 272-275. For more detailed technical accounts, see Harold Catling, *The Spinning Mule* (Great Britain: David & Charles,1970); M. T. Copeland, *The Cotton Manufacturing Industry of the United States* (Cambridge, Massachusetts: Harvard University Press, 1912); W. Scott Taggart, *Cotton Spinning* (London, 1920); and G. N. von Tunzelmann, *Steam Power and British Industrialisation to 1860* (Oxford: Clarendon Press, 1978).

impetus from the yarn. By revolving a little more slowly than the bobbin, the yarn receives twist at the same time that it is wound on the bobbin. In order to secure uniformity in winding, the frame of rings moves up and down slowly.

While both the ring and mule were clearly recognizable descendants of 18th century machines, the pace of their development in the intervening 100 years was quite uneven. Mule spinning meant the demise of Hargreaves' jenny, but it did not mean the end of spinning by continuous methods. The water frames, and later the throstle, by twisting and drawing the yarn simultaneously, could produce a coarse yarn faster and cheaper than the mule, so continuous spinning retained a niche in this segment of the yarn market. This coexistence was threatened by the rise of the self-acting or automatic mule, invented by Robert Roberts of Manchester in 1825 and gradually diffused across the next several decades. The self-actor reduced the brute strength required for pushing the mule back and forth on its carriage, allowing a significant increase in the size of individual frames. The innovation also simplified the hand-eye coordination required for the delicate process of guiding the yarn into a precisely-shaped conical package. Despite these reductions in skill requirements, the ascendancy of the self-actor coincided with the crystallization of Lancashire mule spinning as a skilled, all-male quasi-craft occupation. Under this system, the mule became the all-but-complete basis for British domination of the world market for cotton goods in the nineteenth century.[5]

Across the Atlantic, technological evolution had moved onto a different trajectory as of the 1820s if not earlier. Because written forms of technological dissemination were not available prior to the 1830s, the first phase of American textile development was largely the work of skilled British immigrants – official restrictions on emigration notwithstanding. Almost immediately, however, textile producers selected among

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[5] The interaction between industrial relations and diffusion of the self-actor is considered by Lazonick, 'Industrial Relations and Technical Change: The Case of the Self-Acting Mule,' *Cambridge Journal of Economics* 3 (1979) and by Mary Freifeld, 'Technological Change and the "Self-Acting" Mule,' *Social History* 11 (1986).

techniques in order to adapt to American conditions. New England cotton yarn manufacturers, for example, tended to use throstles rather than mules, because of their higher productivity per spindle for coarse and medium yarns. When indigenous machinists began to explore possibilities for improvements, their attention focused on continuous spinning. American patents on ring and cap spinning were issued in 1828, to John Thorp and Charles Danforth respectively. The key step was dispensing with the U-shaped "flyer" fixed at the top of the spindle. Cap spinning substituted a conical cap mounted over the spindle, to guide the yarn to the bobbin below. Ring spinning replaced the flyer with a "c"-ring traveling at a high speed around a grooved circular raceway mounted on a plate, which in turn traveled up and down the spinning bobbin. These improvements meant dramatic increases in output per spindle, with less labor and no increase in energy required. By the 1850s average speeds on ring machines reached 5,500 rpm, and there were already reports at this time of successful ring spinning of coarse yarn at 9,000 rpm. Because of these developments, ring spinning was never eclipsed by the self-acting mule in the United States; by the 1860s the American industry had almost as many ring as mule spindles.[6]

Reasons for this national differentiation are not difficult to identify; indeed, they have been the subject of an extensive literature following in the wake of H. J. Habakkuk's classic 1962 work on the impact of labor scarcity on American technology. At the time of its early industrial surge in the 1820s and 1830s, the United States had no stock of skilled mule spinners to draw upon, and preferred machines that could be operated by inexperienced female and child labor. Further, ring spinning was well suited for long-staple American cottons that were used in the relatively power-intensive

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[6] The standard account of early transatlantic textile diffusion is David Jeremy, *Transatlantic Industrial Revolution* (Cambridge, Massachusetts: The MIT Press, 1981). See also the articles collected in Jeremy, *Artisans, Entrepreneurs, and Machines* (Aldershot: Variorium, 1998). A detailed review of the development of the American ring frame in competition with the self-actor may be found in John William Lozier, *Taunton and Mason* (New York: Garland Publishing Company,1986), chapter IV. The rpm figures are from Copeland, *Cotton Manufacturing Industry*, 122.

production runs of standardized yarn and cloth for the domestic market.[7] By contrast, the mule was better adapted to variations in cottons and yarn counts, and thus allowed Lancashire to take advantage of its proximity to the world's largest cotton market in Liverpool, and to produce for diverse buyers all over the world. Thus, the initial divergence between the two countries had a reasonably clear economic logic.

What is perhaps less obvious is that the logic of national divergence became *more* compelling over time, because of positive feedback from choice of technique to patterns of factor expansion and learning. Contrary to the long standing caricature of the self-actor as a "deskilling" technology, mule spinning required an extended period of informal apprenticeship and observation, during which an aspiring spinner learned how to adjust the quadrant nut in order to form the cop; to monitor the product for quality flaws; and to maintain and repair the mule itself, over which he maintained personal responsibility. These skills were passed along to new generations of mule spinners, through an informally structured program comprising "migration" (moving from machine to machine, or from factory to factory), "following-up" (attaching a young person to an experienced worker), and "picking up" (an even less formalized mode of learning by observation).[8]

The American industry, on the other hand, began with an unskilled labor force and replaced it many times over with new generations of immigrants. The dexterity and stamina of this factory workforce undoubtedly improved over time, but the primary locus of technical knowledge and advancement resided in mill managers and mechanics. A clear illustration of distinct industrial dynamics is the fate of the mule spinners who migrated to America, recounted by Isaac Cohen. Although they were able to practice their skills in the mule-using branch of the American industry, the immigrants were never

[7] Jeremy, *Transatlantic Industrial Revolution*, 65, 101, 115, 182.

[8] Charles More, *Skill and the English Working Class, 1870-1914* (London: Croom Helm, 1980), 107-130; Freifeld, 'Technological Change.'

able to establish British-style control over their machines and their piece rates, and Fall River, Massachusetts, was a center of contentious disputes until American mule spinning virtually disappeared by the turn of the century.[9]

Thus it was that American ring spinning technology continued to progress, reaching new performance levels in the "spindle revolution" of the 1870s. The new Sawyer spindle was reduced in weight, and its point of support was changed to an elevated holster. Light-weight, self-centering spindles cut wobble and top-heaviness, thereby reducing power costs and allowing faster machine speeds. The average speed of rings in operation reached 7,500 rpm by the mid-1870s. The late 1870s saw the introduction of the Rabbeth spindle, and within a few years average spindle speeds were as high as 10,000 rpm. In this advanced form, continuous spinning re-crossed the Atlantic in the 1870s, as British textile machine makers began to produce ring spinning machines under license from American companies – not because of a shift in *domestic* demand, but because the industry itself had become international, and the chief suppliers of capital equipment were the British. Within a few years, several British companies were proudly promoting their own advanced versions of ring spinning machines.[10] No fewer than 408 British patents for ring spindles were granted between 1867 and 1892, including 117 during the crucial period 1881-84 when all the leading machinery firms began to market the new frame.[11] Subsequent advances in ring technology therefore owe as much to their British re-borrowers as to their origins in the American environment.

The Textile Machinery Industry

The emergence of specialized machinery producers was a distinguishing feature

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[9] Isaac Cohen, *American Management and British Labor* (New York: Greenwood Press, 1990).

[10] See the articles on 'Ring Spinning' at the 1887 Manchester Jubilee Exhibition, *Cotton Factory Times*, 24 June and 1 July, 1887.

[11] Douglas Farnie, *The English Cotton Industry and the World Market, 1815-1896* (Oxford: Clarendon Press, 1979), 154.

that differentiated the United States and Great Britain from other 19th century textile centers. Supported initially by the size of the domestic textile industry, such specialization made possible the extreme adaptation of technology to distinct national conditions in these two cases. Other countries, beginning later and relying on imported machinery, typically had to choose between one or the other of the two dominant national models. As Kristine Bruland has emphasized, late industrializing countries such as Norway did not just buy spinning machinery on the international market, but more commonly an entire "package" of ancillary services, including technological information and supplementary machines, often accompanied by expert advisors and even skilled laborers.[12] As the century progressed and British firms developed expertise in ring spinning, countries were increasingly able to compromise, dividing their investments between rings and mules. But they still relied heavily on British advice in doing so.

In both the U. K. and the U. S., machinery producers played an active, initiating role in disseminating new technology to new producing centers. American textile-machinery manufacturing had important linkages to other branches of the machine tools industry. As early as the 1830s, machine shops that were initially attached to textile mills began to diversify their product lines into steam engines, turbines, locomotives, and other machine tools. In contrast to the bifurcation across national boundaries, a tendency towards standardization within the country was observed very early, promoted both by long-distance sales of specialty firms and by the high geographic mobility of 19th century mechanics. Towards the end of the century, New England machinery firms actively promoted textile development in the southern states, offering discounted machinery prices, technical advice, and even investment capital at times.[13]

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[12] Kristine Bruland, 'Skills, Learning and the International Diffusion of Technology,' in M. Berg and K. Bruland (eds.), *Technological Revolutions in Europe* (Cheltenham: Elgar, 1998).

[13] The standard histories of the U. S. textile machinery industry are George S. Gibb, *The Saco-Lowell Shops* (Cambridge, Massachusetts: Harvard University Press,1950) and Thomas R. Navin, *The Whitin Machine Works Since 1831* (Cambridge, Massachusetts: Harvard University Press,1950). The critical role of these firms for the development of American machine tools is analyzed by Nathan Rosenberg, 'Technological

In Britain, specialized machinery producers also sprang up with the rise of Lancashire in the first half of the 19th century, but quickly adopted a more expansive and outward-looking posture than did the parent industry.[14] These firms were among the leading advocates of lifting the mercantilist restrictions on machinery exports, and took full advantage of their opportunities when that effort succeeded in 1843. The industry leader, Platt Brothers of Oldham, was the largest engineering firm in the world as of the 1850s, and foreign sales accounted for nearly two-thirds of its receipts over the entire period 1873-1913.[15] The pioneering British ring producers were Samuel Brooks (1872) and Howard & Bullough (1878); but by the 1880s, Platt Bros. and other firms were producing a full range of rings, mules and ancillary machinery. The Chairman's annual report to the stockholders of Platt Brothers for 1888 noted that the company was by far the largest producer of ring frames in the world, that its machines were unsurpassed for excellence and speed, and that they were scarcely able to keep up with demand.[16] But all the major firms drew upon expertise accumulated over most of the 19th century; the only significant new entrant after 1870 was Tweedales and Smalley, in 1891. By 1913, British machine makers supplied 87 percent of world trade in spinning and preparatory machines.[17]

Change in the Machine Tools Industry, 1840-1910,' *Journal of Economic History* 23 (1963) and Lozier, *Taunton and Mason*.

[14] Christine MacLeod, 'Strategies for Innovation: The Diffusion of New Technology in Nineteenth-Century British Industry,' *Economic History Review* 45 (1992).

[15] Robert Kirk, *The Economic Development of the British Textile Machinery Industry ca. 1850-1939,* Ph.D. Thesis, University of Salford (1983), 425; Farnie, *English Cotton Industry*, 151.

[16] General Meetings Minute Book, DDPSL 90/1, 12 July 1888.

[17] Robert Kirk and Colin Simmons, 'Engineering and the First World War,' *World Development* 9 (1981), 774. The smaller percentages reported by Farnie ['The Textile Machine-Making Industry and the World Market, 1870-1960,' in Mary B. Rose (ed.), *International Competition and Strategic Response in the Textile Industries Since 1870* (London, Frank Cass, 1991)] refer to all types of textile machinery, as opposed to spinning. Firms in Alsace, Switzerland and Saxony began to impinge upon Lancashire's monopoly after 1906, but chiefly in weaving machinery.

Hypotheses and Evidence

The business records of the major British textile machinery firms are now available at the Lancashire Public Records office in Preston. Over many years time, we have assembled what we believe to be the most complete data set available on production and sales of spinning machines by these firms, covering the years 1879 to 1933. During most of this era, Lancashire was the world's dominant supplier to every country outside of the United States. The records thus offer a rare opportunity to trace the evolution of world spinning technology across this entire period, not only as it was embedded in machines, but as it was implemented in culturally and geographically diverse parts of the world.[18]

What do we hope to learn from a review of the specifications of textile machinery across fifty years of history? At least three types of questions present themselves:

1. Was there any positive technological progress in textile machinery? Technical or engineering-based studies of technological change in history are comparatively rare. Most economic studies try to infer "technological progress" from some form of productivity index, a procedure that frequently conflates technical change with other forms of economic adjustment. The late nineteenth-century textiles industry is frequently classified as "mature," not subject to additional rapid improvements; indeed, this maturity is often linked to Britain's more general problem of maintaining world industrial and technological leadership. Yet we know that textiles technology experienced explosive change both before 1880 and after 1913. Do we actually see a hiatus of thirty years or more, or do the data show more gradually emerging trends? If progress occurred, along what technical dimensions and with what implications for international competition?

2. Did rates of technical improvement differ between rings and mules? We know that the

[18] The textile machinery records have been utilized effectively in the past, most notably by Farnie *(English Cotton Industry*, 'Textile Machine-Making Industry') and Kirk (*Economic Development*). By assembling a more comprehensive data set, we hope to take a broader overview of the both technology and its global diffusion.

pace of change between continuous and intermittent spinning was highly uneven across two hundred years. But was the gradual expansion of the ring relative to the mule between 1880 and 1913 driven by continuing unevenness in the pace of advancement? Such a finding would have interesting implications for our thinking about the nature of technological change and biases in the flow of technological progress. A full understanding of these issues calls for more than conventional measures of productivity. At any point during their coexistence, rings and mules maintained market niches based on their known relative advantages and disadvantages. The test of their relative progress, therefore, would involve an attempt to measure the boundaries of these market niches and to trace their movement over time.

3. Were there significant differences between nations in their capacity to absorb advances in technology? The technical specifications of machinery purchased are not "pure" reflections of supply-side developments in machinery production. Such indicators as machine size and machine speed, for example, partly reflect advances in the machines themselves, but they also involve greater demands on the skill and effort-level of the textiles work force. Comparative studies show striking differences between national industries in levels and growth of productivity, even where the capital goods were coming from the same handful of British companies. It has been plausibly argued that these differences arose from varying success in recruiting and retaining a good work force, and in mobilizing the labor force to supply greater effort. Indeed, it may be difficult to identify the source of technical improvements, between these two general types. But the chance to examine an array of international cases may be very helpful in distinguishing changes that were common to all countries, versus those that were only experienced by the most advanced or the most successful national industries. In this regard, our data may enable us to address two specific issues that have been debated by economic historians:

3A. British Productivity Growth. An early study by Jones found no productivity growth in British textiles at all, between 1870 and 1913.[19] This conclusion has been disputed by Sandberg and on different grounds by Lazonick.[20] In both cases, the results turn crucially on appropriate measures of product mix and quality, and on input mix and quality. Productivity measures in this context generally suffer from problems of aggregation bias and inadequate measurement of quality. A better alternative is to look for evidence of changes in input-output relationships within a broad spectrum of technically specified parameters.

3B. Japanese Exceptionalism. Among all the newly industrializing countries of this era, Japan stands out for having broken out from the pack of poor countries of the Third World. Japan's record in cotton textiles was distinctive too, in that the country made the switch from mules to rings very early and very completely, and in defiance of the rules of thumb then prevailing in the industry: ring spinning technology arose in the high-wage context of the United States, yet Japan was relatively labor abundant; and ring spinning was most successful where the cotton fibres were medium- to long-staple, yet Asian cottons tended to be short staple. In our earlier work, we cited contemporary sources to the effect that the key to the Japanese switch was an innovative reconfiguration of major components of the production package. The Japanese industry, we argued, was able to deploy its largely female labor force to the task of judiciously blending imported and domestic cottons, making it possible to operate ring spindles at speeds up to 10,000 rpm without having frequent yarn breakages undermine efficiency.[21] If this account is correct, we ought to be able to find evidence for it in the relationships among the choice of rings, machine speeds, yarn count and fibre length in Japan.

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[19] G. T. Jones, *Increasing Returns* (Cambridge: Cambridge University Press, 1933).

[20] Sandberg, *Lancashire in Decline* (Columbus: Ohio State University Press, 1969), chapter 5; Lazonick, *Competitive Advantage on the Shop Floor* (Cambridge, Massachusetts: Harvard University Press, 1990), chapter 6.

[21] 'Rings and Mules around the World,' 289-290.

New Evidence: Machine Size and Machine Speed

Table 3 confirms the finding of a protracted period of coevolution between ring and mule, culminating in the near-total triumph of the ring by 1920 (Britain, France and Germany being the last bastions of mule holdouts).[22] During 1878-1883, no country purchased more ring frames than mules. Clearly there was a global trend toward rings thereafter, but the pace of this shift was by no means uniform. Indeed, the share of mules in the world total actually increased during 1899-1906, compared to the previous period. This surprising temporary reversal of the trend largely reflects the prominence of Lancashire itself in the Edwardian textile construction boom, but not entirely so; a parallel reversal may be detected for Alsace, Canada and Spain. In 1907-1914, the mule's downward share continued, but even at that late date many countries (not just Great Britain) made large purchases of new mule spinning capacity, the most conspicuous being Austria, Canada, France, Germany, India and Russia. The mule shares for the Continental countries may exaggerate the persistence somewhat, if German-made machines were mainly rings. Even so, it is undeniable that purchases of new mules were substantial in many countries, down to the very eve of the Great War.

Tables 4A and 4B compare the growth of spindles per frame, for rings and for mules. If staffing ratios per frame were relatively fixed, the rise in spindles per frame is a form of increased labor productivity.[23] Most notably, the tables do not show a decisive

[22] For ease of viewing, the countries listed are limited to the fifteen largest in total spindles in place, minus the United States on the grounds that U. S. imports of spinning machinery were an insignificant and unrepresentative component of its total national stock. The world totals include exports to smaller countries not listed separately; 'Non-GB' deducts Great Britain from the total.

[23] Studies of the Lancashire industry argue that this was indeed the case, and that the codification of piece-rate payments in regional lists encouraged both firms and spinners to increase the size and speed of mules: 'Extending the length and improving the timing and speed of spinning mules were the principal means by which employers adjusted to the lists...In coarse spinning, the nature of the list meant that workers and firms shared the benefits of the new investments...The continued investment of firms was based on their expectation that increased labor effort on these new longer mules would cover the rise in fixed expenses' [Michael Huberman, *Escape from the Market: Negotiating Work in Lancashire* (Cambridge: Cambridge University Press,1996) 143, citing Jewkes and Gray, *Wages and Labour* (Manchester: Manchester University Press,1935).]

performance difference between the two types of machinery. Both ring and mule frames increased in size between 1878/83 and 1907/14, the global average increase for mules actually outpacing that for rings slightly, 192 added spindles versus 92. (The increase for rings was slightly higher in percentage terms, because mules were three to four times larger at the beginning of the period.) Perhaps more notable than the global averages are the patterns for different countries. As one might expect for a skill-based technology, the international dispersion in machine size for mules was significantly higher than that for rings. Spindles per mule frame in Britain led the world in every decade, the only exceptions being anomalous observations for Canada in 1891-98 and Japan in 1907-14. Similar conclusions emerge when we examine patterns of *change* in machine size: for rings, the country observations cluster narrowly around the average increase of 30 percent; for mules, increases range from virtually zero in India and Russia to better than 50 percent in Austria, Italy, and Belgium. These figures suggest that for countries that were well adapted to the mule, productivity growth was clearly possible with that technology. By contrast, the growth in spindles per ring spinning frame was more uniform among nations. And in contrast to her world leadership in mule size, British rings were actually smaller than the world average, for every time period from 1878/83 to 1907/14.

Table 5 displays a remarkably similar pattern for machine speed. Average speeds in ring spinning were somewhat below the U. S. norm, as Copeland reported. But ring speeds did increase over time, from an average of 8,100 rpm in 1884/90 (the first period in which ring speeds are recorded) to 8,900 in 1907/14. However, the same was true for mules; in fact, the overall increase in machine speed for mules actually exceeded the increase for rings. In the majority of cases for which comparisons are possible, mules were faster than rings. True, the increase in world average speed for mules came to an end in 1914. But it is interesting to note that those countries with the most persistent commitment to the mule (Britain, India, and Russia) were also countries where mule speeds outpaced those of rings. Again we find that dispersion in mule speeds was far higher than dispersion in ring speeds, as visually displayed in Figure 1. This contrast suggests that progress with mules was largely a matter of expertise and experience, whereas progress with rings had more to do with technical improvements in machine quality.

As measured by mule speed, Great Britain was the world leader in 1878/83. Thereafter, British speeds were sometimes matched by other countries, notably Russia. But Britain remained at or near the top in mule speed, while British ring speeds were not much different from the average. If we multiply Britain's 17 percent increase in mule size by her 20 percent increase in mule speed, the implied productivity increase is more than 40 percent over thirty to thirty-five years (a growth rate somewhat better then 1.0 percent per year). By no means is this figure a rigorous estimate of productivity growth; but one may also say that it is by no means symptomatic of a stagnant, unprogressive national industry.

Dividing and Conquering the Markets: Trends in Yarn Count

Table 6 displays the average yarn counts for which spinning machines were designed, pairing rings and mules by country as in the Table 5. But the two tables are not really analogous. Whereas size and speed are open-ended performance characteristics, the distribution of yarn counts by machine type is a representation of the division of the product market between the two processes. In Britain and some other countries, higher-count production was dominated by mules, rings entering mainly at the low end of the distribution. In that context, equal increases in yarn counts for rings and mules may not reflect 'neutrality,' or equal progress by both methods. A more plausible interpretation would be that rings were gradually broadening their commercially viable product space, while mules were retreating to a higher but smaller market niche. However, the overall distribution of counts in world markets was governed by a complex process that balanced relative costs against relative demands, interacting with uneven rates of technological change. We cannot hope to capture that global analysis here; and because the figures in Table 6 refer only to installations of new machinery rather than to the entire active stock in each year, it would be a mistake to infer market trends from these data alone.

To add to the complication, the division of the market in other countries was often different. Because a chief advantage of the mule lay in its gentler and more flexible handling of fibers, it was sometimes observed that mules were preferred both for extremely fine spinning and for extremely coarse spinning -- in the latter case, the true correlation being with the shortness of the cotton fibers used in coarse spinning. Thus we find, for the earliest period in our sample (1878-1883), that rings in India, Austria, and Belgium were designed for counts *higher* than the average for mules. Thus, in the absence of a complete model of the cotton market, we have to interpret the count data with caution, focusing only on the most visible and persistent trends.

The evidence in Table 6 does show an increase in average ring counts over time, but for the world as a whole, the extent of that increase was surprisingly limited prior to the 1920s: the global average was 25.9 in 1878/83, and had reached no higher than 29.8 by 1907/14. One gets a different impression, however, by tracing the course of average ring counts in individual countries. Between 1878/83 and 1907/14, the average count for which new rings were designed increased by 20 percent or more in Britain, France, Italy, Russia, Spain, and Alsace, as well Japan and Mexico. Average counts for mules increased as well, but as just discussed, this probably reflected a decline in market share rather than an enhancement of the mule’s productive range. Thus the country-by-country patterns do not appear entirely consistent with the aggregate.

There are several reasons why the global trend does not have to reflect the typical experience of individual countries. The average count for rings declined between the first and second periods, as Japan and India learned to adapt the ring to short-staple Asian cottons, substituting rings for mules in low-count production. Over a somewhat longer period, the increase in the global average ring count was held down by compositional change, specifically the growing market share of low-count producers – China as well as India and Japan – even while European countries were pushing the use of rings into the 30s and 40s for the first time. Thus the evidence in Table 6 is consistent with the view that a major frontier for ring-mule competition was an improvement in the ring's range of commercially viable counts.

What forces drove this process? Clearly one ongoing factor was the effort by machinery producers to extend their markets. The mule might match the ring in productivity growth for any given yarn count. But the mule's primary protection was its "preserve," the range of counts and qualities that a skilled mule spinner could achieve, beyond the reach of the ring at a point in time. Once the ring moved into new territory, matching productivity growth was not enough to save the mule, and competition in the machinery industry propelled advances precisely along these lines.[24] In support of this view, we note that the 75th-percentile ring count (the count level below which 75 percent of the country's orders fell) increased in every case under study, an indication that intrinsic machine capacities were improving. As a 1909 observer put it, the self-acting mule was 'a beautiful piece of mechanism for performing one of the prettiest of operations;' but in modern mills, 'the roving is of such even thickness that ring yarn is practically perfect, and what more can mule yarn be?'[25]

At the same time, the extension of the ring's domain was not purely a matter of technical progress in machine making; it also reflected the success of user countries in adapting their procedures and their labor force along this path. As noted, dispersion in performance measures using the ring was much lower than for the mule. But the data

[24] Consider this quotation from a Platt Brothers memo headed 'Rings for Fine Spinning': 'Please note that in the future all Ring Frames for fine spinning (say over 40 counts) should have rings specially finished and accurately gauged as recently supplied to Bolton Mills' 28 September 1899. DDPSL/1 85/32 ('Memos on Technological Change').

[25] William H. Booth, 'The Modern Cotton Spinning Factory,' *Cassier's Magazine* 35 (1909), 364, 582

nonetheless provide support for a measure of Japanese exceptionalism. After starting with mules in the 1870s, Japan's switch to rings was earlier and more complete than that of India, at a time when British and Indian opinion was distinctly divided on the merits of the two technologies. Alone among the emerging third-world textile countries, Japan quickly moved towards the top of the world distribution in the size and speed of its rings. And while still using a large proportion of short-staple Asian cottons as raw material, the average count of Japanese yarn advanced so rapidly that it was actually ahead of the world average as early as 1899-1906. In contrast, China's textile industry remained concentrated on coarse yarn production throughout the 1920s. The performance problems of India's textile industry are well known, analyzed most recently by Wolcott and Clark. Whatever else the contrast between India and Japan may have represented, it did not derive from any difference in their access to world-class spinning machinery.

Thus it fell to Japan to "break the mold" of the pre-existing global division of the textile market, extending the reach of an American technology into a setting whose factor costs and market opportunities could not have been more different from those in the USA. Perhaps surprisingly, the closest parallel to the Japanese performance prior to 1914 is Mexico. Despite its proximity to the United States, and despite a lively debate over the comparative merits of American versus British technology, the Mexican textile industry was supplied almost entirely by Lancashire ring spinning machines prior to 1918. Mexican mills were almost completely electrified by 1905, running their machines at speeds that matched the leading countries of the world (Table 5). During the same period, average Mexican yarn counts increased even more rapidly than those of the Japanese, from 12.0 in 1878/83 to 27.8 in 1907/14 (Table 6). This record is confirmed by careful econometric studies, showing extraordinary rates of productivity growth in Mexican textiles through 1914.[26] Thus Mexico provides another illustration of the

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[26] Armando Razo and Stephen Haber, 'The Rate of Growth of Productivity in Mexico, 1850-1933,' *Journal of Latin American Studies* 30 (1998).

democratizing potential of ring spinning, for countries with appropriate social and political characteristics, and access to growing markets. Unfortunately, the realization of that potential was interrupted by the Mexican Revolution, and the retreat to protectionism on both sides of the Rio Grande in the 1920s.

Conclusion

The cross-section panel data provided by the records of the British textile machinery firms offers a new perspective on the dynamics of technological change and diffusion during an important half-century of world industrial history. Rather than seeing an older "mature" technology supplanted by a more advanced modern form, we observe two technological paradigms in competitive coexistence, each one capable of supporting ongoing productivity growth, through complementary improvements in machinery, organization and workforce skills. The era saw the final phase of a longer competition between the principles of continuous and intermittent spinning. But behind this technical differences lay a deeper contrast between systems: a "British" craft-like technology, in which the machinery drew upon the personal skills of the operators, versus an 'American' approach in which improvements in the machinery reduced skill requirements and extended its range along other dimensions. At the same time, the diversity of experience among newly emerging industries makes it clear that progress was a two-sided affair, a mutual adaptation between machines and local conditions. Not all countries tapped into the ring's potential, and no other country matched Japan's success in adapting the 'American' principle to an entirely different economic and cultural environment.

From this vantage point, criticism of Lancashire's failure to switch more rapidly to the ring appears misguided. The mule was a skill-based technology, and in this competition, British mule spinners were the best in the world. Under machine-based ring technology, British productivity was not much better than the world average. Thus, it was *only* with the mule that the pioneer country could hope to retain its place in world markets. Once the mule itself ceased to be viable, no feasible choices could have staved off the collapse of the historic Lancashire cotton industry.

Table 1. Spindles in Place by Country, 1878-1930
(in thousands)

	1877/1882	**1907/1908**	**1930**
United Kingdom	44,207	52,818	55,207
United States	10,600	23,200	34,031
Germany	4,700	9,192	11,070
Russia	4,400	7,562	7,624
France	5,000	6,609	10,250
India	1,610	5,280	8,907
Austria	1,558	3,584	NA
Italy	880	2,868	5,342
Spain	1,865	1,850	1,875
Japan	8	1,540	7,045
Brazil	42	1,000	2,775
Belgium	800	1,200	2,172
Canada	NA	894	1,277
China	NA	756	3,829
Mexico	249	733	804

Source: USA (1880): M.T. Copeland (1909), p. 128; India (1880): Sung Jae Koh (1966), p. 365; Mexico (1878, 1908, 1930): Armando Razo and Stephen Haber (1998), Table 4; all others from Brian Mitchell, International Historical Statistics: Europe, 1750-1988 (New York: Stockton Press, 1992); Asia and Africa (New York: Stockton Press, 1995); The Americas and Australasia (Detroit: Gale Research Company, 1983).

Table 2. Ring and Mule Distribution by Country, 1908-1920								
	1908		**1910**		**1913**		**1920**	
	%Mule	**%Ring**	**%Mule**	**%Ring**	**%Mule**	**%Ring**	**%Mule**	**%Ring**
UK	83.6	16.4	83.4	16.6	81.3	18.7	78.7	21.3
USA	17.7	82.3	17.6	82.4	13.1	86.9	9.2	90.8
GE	55.8	44.2	52.9	47.1	45.8	54.2	44.4	55.6
RU	50.2	49.8	48.4	51.6	41.3	58.7	NA	NA
FR	60.0	40.0	58.5	41.5	54.3	45.7	47.3	52.7
IN	28.0	72.0	30.0	70.0	27.5	72.5	18.6	81.4
AU	61.0	39.0	57.0	43.0	51.0	49.0	NA	NA
IT	26.6	73.4	33.5	66.5	24.7	75.3	24.7	75.3
SP	40.0	60.0	41.1	58.9	40.0	60.0	38.9	41.1
J	3.3	96.7	1.5	88.5	2.3	97.7	1.2	98.9
BR	3.0	97.0	NA	NA	NA	NA	0.3	99.7
BG	51.5	48.5	41.6	58.4	33.2	66.8	28.8	71.2
CN	46.0	54.0	48.3	51.7	45.2	54.8	30.5	69.5
ME	4.0	96.0	NA	NA	NA	NA	7.4	92.6
CH	NA	NA	NA	NA	NA	NA	0.0	100.0
WORLD	55.8	44.2	54.4	45.1	49.5	50.5	44.6	55.4

Source: Master Cotton Spinners Manufacturers’ Association, Official Reports of the International Congress, 1908-1920.

Table 3. Total Spindles Ordered (in thousands)

	1878-1883		1884-1890		1891-1898		1899-1906		1907-1914		1915-1920		1921-1928		1929-1933	
Country	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**
AL	3.2	0.5	25.1	125.9	79.9	113.6	78.0	80.7	35.4	63.1	2.0	9.0	24.4		7.8	
AU	41.4	220.1	67.1	482.8	100.6	624.7	347.4	391.9	597.8	382.7			53.7			
BG	3.6	33.0	18.6	111.4	72.2	79.2	112.4	102.7	260.4	82.4	8.1		113.7	30.6	43.7	
BR	1.7	1.4	67.2	0.7	86.3	3.4	115.9	3.4	323.0	3.8	54.9	0.9	458.7		23.5	
CH			42.4		245.9		47.8		196.4		415.0		357.1	4.0	534.7	2.7
CN	1.3	6.5		17.5	10.3	49.5	34.6	46.4	152.8	73.9	107.1	5.5	21.0		23.6	
FR	32.8	114.6	45.5	448.3	309.0	1073.2	835.4	770.6	936.6	645.0	512.4	302.6	315.8	126.4	104.2	12.3
UK	73.4	5634.9	627.0	8134.4	830.2	5555.6	2260.7	17900	2743.5	10200	1540.2	1956.3	818.0	1963.7	125.4	106.6
GE	28.4	115.8	78.5	736.7	329.8	1002.8	461.2	891.2	330.0	426.0			246.1	54.0	17.7	4.2
IN	90.4	415.0	708.0	863.5	1302.7	601.6	1158.0	265.9	1287.0	223.3	951.4	98.9	1242.0	59.8	1397.5	
IT	85.3	153.8	123.9	111.4	265.2	300.8	1312.4	255.4	558.4	68.1	25.1	2.2	251.0	2.3	68.3	
J		12.5	189.7	62.4	808.1	73.8	374.7	12.8	1001.1	2.6	1091.1	11.3	1164.1	10.8	441.6	
ME	12.7	19.1	38.8	1.0	134.5	1.8	155.1	6.2	118.5	0.8	1.2		39.6		11.2	
RU	240.1	705.2	406.2	649.0	1749.3	1122.4	1104.1	624.2	1623.8	545.9	175.4	7.2	1302.0	85.6	205.4	16.7
SP	4.3	59.2	44.2	27.0	80.5	32.3	102.8	30.3	80.2	19.1	98.6	12.8	107.9	2.4	40.4	
WORLD	685	7935	2586	12800	6693	11800	8930	22300	10700	13000	5160	2478	7448	2396	3331	147
NON-UK	612	2300	1959	4630	5863	6290	6669	4417	7963	3120	3620	522	6630	432	3205	41

Table 4A. Average Number of Spindles per MULE Frame								
Country	**1878-83**	**1884-90**	**1891-98**	**1899-06**	**1907-14**	**1915-20**	**1921-28**	**1929-33**
AL	663.4	828.9	865.1	888.6	908.3	900.0		
AU	666.5	759.3	872.5	927.6	957.5			
BG	809.0	921.4	917.3	1006.4	1152.3		949.8	
BR	825.7	766.7	629.3	784.7	814.3			
CH							675.0	
CN		720.0	1119.5	833.9	930.4	1107.0		
FR	789.6	919.7	986.9	1008.4	1036.0	1101.7	1005.2	786.3
UK	994.5	1084.7	1087.4	1146.4	1173.0	1069.0	1148.2	878.1
GE	808.2	871.4	979.0	988.0	963.2		934.3	1068.0
IN	694.6	763.3	754.6	778.1	794.5	714.2	504.1	
IT	710.1	782.9	818.3	822.3	1067.6	558.1	859.6	
J	700.0	742.8	913.5	768.8	1319.7		304.0	
ME	685.5	360.0	300.0	405.1				
RU	854.0	814.4	813.2	878.8	962.4		1001.3	1048.0
SP	689.4	840.8	735.3	1145.8	841.9	1300.0		
WORLD	929.5	983.7	987.5	1096.0	1122.4	1064.8	1113.0	898.6
NON-UK	786.4	830.6	886.8	928.3	979.9	1056.1	949.7	930.4

Table 4B. Average Number of Spindles per RING Frame								
Country	**1878-83**	**1884-90**	**1891-98**	**1899-06**	**1907-14**	**1915-20**	**1921-28**	**1929-33**
AL	286.2	340.0	381.7	407.4	436.7	500.0	454.8	478.7
AU	341.3	380.9	440.7	448.7	465.7	458.7	494.4	465.5
BG	321.0	305.7	378.0	427.6	461.8	441.5	460.9	463.6
BR	300.0	347.8	341.5	349.1	387.5	394.6	462.6	438.5
CH		377.7	343.7	379.4	398.6	388.0	394.1	400.4
CN	235.3		307.7	275.3	393.2	486.2	402.7	259.6
FR	309.9	357.2	394.6	445.2	468.8	478.1	487.7	487.9
UK	348.8	323.5	368.4	385.0	404.3	442.0	420.6	447.6
GE	402.7	399.3	367.0	416.5	451.9	500.0	473.7	433.4
IN	299.8	316.5	327.6	355.1	356.7	366.1	401.0	380.1
IT	396.0	354.1	378.8	434.0	438.8	401.1	480.1	409.3
J		369.1	386.5	416.1	408.1	411.7	407.5	410.8
ME	208.0	351.8	373.1	360.6	389.8	392.4	391.4	405.2
RU	426.5	351.5	372.1	401.4	432.6	474.2	472.1	490.0
SP	352.6	408.2	414.1	432.9	425.1	445.2	469.4	479.5
WORLD	348.9	350.5	370.0	402.9	422.2	416.7	439.6	407.5
NON-UK	348.9	354.1	370.2	408.4	426.0	411.6	441.5	405.6

Table 5. Average Speed of New Investment: Ring vs. Mule

	1878-1883		1884-1890		1891-1898		1899-1906		1907-1914		1915-1920		1921-1928		1929-1933	
Country	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**
AL			8.1	8.4	9.3	9.0	8.7	10.2	9.1	9.8	9.5		9.7		10.0	
AU		6.8	8.5	8.6	8.6	9.3	9.0	9.6	9.4	9.5	9.2		9.2		9.4	
BG		7.5	8.2	8.7	8.4	9.0	8.6	8.8	8.7	9.1	9.7		8.9		7.7	
BR			8.1	8.4	7.1	4.4	7.8	9.7	8.3	8.5	8.5		8.3		8.3	
CH			6.9		6.9		6.8		7.3		8.7		8.4		9.7	
CN				7.2	8.2	7.9	8.0	9.0	8.6	9.1	8.6		7.5		7.3	
FR		7.9	8.6	9.3	8.5	9.6	8.9	9.3	9.1	8.9	8.6		9.0		8.9	
UK		8.1	9.4	8.9	8.6	9.3	8.6	9.7	8.9	9.6	8.8	10.1	8.8	6.8	8.8	4.3
GE		6.6	7.9	8.5	8.9	9.2	8.6	9.2	9.4	8.9	8.5		9.0		9.4	
IN		6.8	7.7	8.9	8.3	8.9	8.5	8.6	8.6	9.8	8.4	7.6	8.7	5.0	9.8	
IT		6.3	8.1	6.9	8.6	8.7	8.9	8.0	9.1	9.4	8.3	7.0	8.4		8.7	
J		6.6	7.0	6.4	7.6	7.8	8.3	5.1	8.3		9.1		9.8		10.6	
ME		7.1	7.9	6.0	8.1	8.1	8.9		8.7		9.0		9.1		9.3	
RU		7.4	8.1	9.1	8.4	9.3	8.5	10.1	9.3	10.4	8.6		9.4	4.3	9.1	
SP		6.7	8.6	7.5	8.6	9.7	8.6	9.6	8.2	8.7	8.2		8.6		9.1	
WORLD		7.7	8.1	8.8	8.6	9.2	8.6	9.5	8.9	9.6	8.7	9.1	9.0	6.6	9.7	4.3
NON-UK		7.1	7.9	8.6	8.6	9.1	8.6	9.2	8.9	9.5	8.7	7.6	9.0	4.6	9.7	

Table 6. Average Count of New Investment: Ring vs. Mule																
	1878-1883		1884-1890		1891-1898		1899-1906		1907-1914		1915-1920		1921-1928		1929-1933	
Country	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**	**Ring**	**Mule**
AL	26.2	67.9	27.2	34.3	30.5	31.1	31.4	46.4	36.2	39.8	30.0	150.0	51.0		37.2	
AU	28.3	25.4	26.6	28.7	28.8	29.6	29.2	32.3	31.8	37.5	37.2		38.0		50.9	
BG	29.4	32.2	44.1	31.5	36.0	26.9	27.5	21.9	29.5	27.6	31.1		29.1	17.7	29.0	
BR	29.5	58.0	30.0	44.3	16.3	15.2	18.2	77.7	24.7	56.0	35.7		29.6		54.4	
CH			20.7		14.5		13.6		14.5		18.9		24.3	7.5	25.8	
CN				21.0	22.8	49.5	16.9	85.0	32.6	70.6	35.1	44.7	28.4		17.8	
FR	28.5	56.2	24.9	50.1	28.4	47.0	32.4	96.8	30.8	80.7	33.5	104.5	37.7	106.0	47.4	66.8
UK	24.8	46.7	28.7	48.4	30.9	47.2	35.2	55.0	33.8	53.2	31.4	59.8	41.0	60.4	40.0	79.4
GE	28.3	23.0	22.2	29.1	22.8	27.8	31.8	29.6	31.0	41.0	18.0		29.7	46.9	22.8	83.0
IN	44.9	20.0	19.6	19.7	20.3	18.1	25.7	17.5	25.3	18.4	24.8	14.3	27.2	4.7	35.8	
IT	20.0	21.6	25.6	22.0	29.9	32.5	28.4	24.6	30.3	31.2	35.5	8.3	34.5	26.8	45.5	
J		18.0	17.0	19.1	19.3	73.9	42.6	42.6	28.2	68.3	35.7		31.4	110.0	28.8	
ME	12.0	22.1	23.7	20.0	25.1	15.0	27.0	3.3	30.9		34.0		35.7		30.1	
RU	29.8	41.9	30.2	33.8	34.3	36.2	32.4	36.2	35.2	44.3	25.1		30.0	50.8	60.8	110.0
SP	18.4	30.0	25.9	27.6	30.3	40.7	33.3	36.5	24.8	24.9	37.3	32.5	31.7		29.6	
WORLD	25.2	43.4	24.9	42.4	25.9	41.6	31.0	53.4	30.5	53.1	30.6	71.1	31.3	60.9	34.9	86.1
NON-UK	25.2	36.1	24.2	33.1	25.4	36.0	29.7	48.2	29.8	52.8	30.5	94.0	30.4	63.6	34.6	96.6

Figure 1: Speed by Ring/Mule, Mean
For 1914