From Hand to Machine: How Indian Cloth Quality Shaped British Cotton Spinning Technology

Alka Raman

Abstract: A true history of industrial technology and innovation must factor in the history of labor and skill required to make a specific product. Mainstream perspectives on industrialization in Britain's cotton industry view technological change in spinning as motivated by productivity gains, facilitated by the fortuitous availability of high-quality, long-staple cotton. However, material evidence shows British cotton textiles advanced to converge with Indian cloth quality, suggesting that spinning machinery too evolved apace in pursuit of product quality. This article demonstrates that alongside the cotton staple, spinner's skill and dexterity determined final cloth quality. The three main spinning machines were technically path dependent, with mechanized spinning of fine cotton based on the original Indian jersey wheel technology. Technological innovations were foremost focused on improving product quality, with mechanization a means to bridge the British skill gap in cotton spinning. Therefore, histories of labor and skill are at the heart of innovation.

Introduction

Material evidence suggests that pursuing quality to match benchmark Indian cotton textiles shaped the evolutionary trajectory of the British cotton industry's products. It also suggests that the pursuit of product quality shaped the evolution of its spinning machinery.[1] If quality-led imitations of Indian cotton textiles motivated mechanization, then what is the technological connection—if any—between mechanized British cotton spinning and preexisting Indian spinning technology?

Improving product quality is arguably the primary motivator for technological innovations, followed by the pursuit of productivity gains. This article interprets "quality" as a

[1] Raman, "Indian Cotton Textiles."

measurement of cloth fineness based on thread per inch count. It demonstrates that an external catalyst—Indian cotton cloth—motivated British entrepreneurs to pursue innovations in spinning machinery. The development was prompted by the absence of local spinning skills matching Indian artisans.[2] It examines the changing relationship between people and machines and traces how each successive mechanical invention moved toward increased automation. For entrepreneurs, quality-led mechanical innovations made rational economic sense. They enabled British manufacturers to compete with the vast qualities and varieties of Indian cotton goods in global markets. Establishing the relationship between the final cotton products and the development of machines to create their market-approved characteristics set by benchmark Indian cottons offers a new perspective on the significance of the India connection. This connection is important, in the first instance, for unpacking the evolution of spinning machinery, but ultimately it presents a new perspective for understanding the causes of industrialization in Britain.

Situating the First Industrial Revolution within the global tradition of technological evolution is not a novel idea. Historians of technological innovation have articulated the global linkages through trade, migration, and exchanging knowledge of ideas and artifacts.[3] Economic historians on the other hand often view new techniques as signifying critical breaks from the past, underscoring disconnections and divergences rather than continuities and linkages.[4] The

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[2] Raman, "Indian Cotton Textiles."

[3] Riello, *Cotton*, 224–27; Parthasarathi, *Why Europe Grew Rich*, 103–13; Beckert, *Empire of Cotton*, 64–65; Basalla, *Evolution of Technology*, 29–30; White, "Tibet, India, and Malaya," 6.

[4] For continuity in the history of technology: Singer et al., *A History of Technology*; Derry and Williams, *A Short History of Technology*. For technological change as a shift or divergence from the past: Pomeranz, *The Great Divergence*; Allen, *The British Industrial Revolution*; Broadberry and Gupta, "Lancashire, India, and Shifting Competitive Advantage."

economic and social changes as a result of the Industrial Revolution may have been large scale enough to justify the idea of a break from the past, yet a closer examination of the British cotton industry's history of mechanization reveals well-documented continuities with techniques in Asia and other parts of Europe. Mainstream economic historians offer a neat rationale for mechanization in the British cotton industry via an induced-by-factor-prices logic for technological innovation. They credit high wages combined with cheaper local energy sources for generating the demand for labor-saving, fossil-fuel, and capital-intensive production methods, as well as faster rates of technological improvements.[5] Productivity-based arguments assume, despite a lack of corroborative material evidence, that prior to mechanization, Britain could spin all qualities of cotton yarn—albeit at an uncompetitively high cost.[6] This scholarship does not account for the factor of product quality, overlooking that Britain's cotton manufacturers were aiming to match characteristics of preindustrial Indian cotton textiles.

A productivity-focused lens is commonly adopted to view sequential mechanization in cotton spinning in Britain. The conventional reasoning for technological change in British cotton spinning is the "challenge and response" model related to John Kay's flying shuttle invented in 1730. By speeding up weaving, this shuttle put pressure on spinners to deliver more yarn, inducing a "wave of innovations" in spinning.[7] However, studies find no clustering of innovations around particular stages of production and the argument overlooks preshuttle attempts to improve spinning through mechanization.[8] The shuttle's impact, moreover, was too

[5] Allen, *The British Industrial Revolution*, 15, 33; Broadberry and Gupta, "Lancashire, India, and Shifting Competitive Advantage."

[6] Raman, "Indian Cotton Textiles."

[7] Baines, *History of the Cotton Manufacture*, 116.

[8] Wadsworth and Mann, *Cotton Trade*, 121–24, 413–15.

circumscribed to be realistically deemed responsible for subsequent technological advances.[9] In 1760, John Kay's son Robert noted local weavers' hostility toward the shuttle due to their inexperience with the new mechanism, many discarding it even before learning how to use it.[10] Historian of science Christine MacLeod shows that patentees' two strongest motivations for their inventions were improving product quality and saving capital.[11] The motivation was import substitution until 1769, increasingly rationalized through quality improvements since 1760, indicating a distinct overlap between import substitution and product quality.[12] According to economic historians Patrick O'Brien, Trevor Griffiths, and Philip Hunt, based on patents, 43 percent of inventors were motivated to improve the quality of new and import-substituted foreign products.[13] Their findings confirm the value of examining the shift in spinning technology through the lens of quality improvement by comparing cotton products of the period.

In his classic work dating back to the early 1980s, Nathan Rosenberg suggested that any analysis of technological change should heed the specific characteristics of the technologies involved. He argued that productivity growth is a slow and painstaking process involving "almost invisible accretion of individually small improvements in innovations."[14] Economic historians Peter Maw, Peter Solar, Aidan Kane, and John Lyons have recently corroborated Rosenberg's claim showing how productivity gains from the initial transition from hand to machine spinning have been overstated and that the post-invention improvement

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[9] O'Brien et al., "Technological Change during the First Industrial Revolution," 163–64.

[10] Wood, "The Inventions of John Kay," 73–86.

[11] MacLeod, *Inventing the Industrial Revolution*, 159.

[12] MacLeod, *Inventing the Industrial Revolution*, 160.

[13] O'Brien et al., "Technological Change during the First Industrial Revolution," 164.

[14] Rosenberg, *Inside the Black Box*, vii, 62.

phase delivered larger gains.[15] Their important finding suggests a different stimulus for "macro inventions" than increasing productivity.

Assessing post–Industrial Revolution adoption of spinning technology in Europe and America, economic historian Joan Rosés shows that technological choice is influenced by the availability of local "skilled" labor developed over time through familiarity and experience with the machinery.[16] Early modern historians Liliane Hilaire-Pérez and Catherine Verna argue that skills and techniques are always embedded within specific communities, in their habits and territories, and that "geography mattered."[17] Recently, Paola Bertucci, historian of science and technology, has argued that a history of machines is inadequate without a history of labor, since artisanal skill is embodied in the worker as well as in the immovable environment where this skill develops.[18] This is an important finding, and this paper finds evidence in support of the argument. Further, economic historian Tirthankar Roy contends that skill embodied in the artisan is a form of capital.[19] Consequently, the lack of a specific skill would equate to a missing production factor, paving the way for change in production methods. This article argues that mechanization in the British cotton industry was a necessary intervention to bridge the skill gap between highly skilled Indian cotton spinners and unskilled British cotton spinners.[20]

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[15] Maw et al., "After the Great Inventions."

[16] Rosés, "The Choice of Technology," 140–42.

[17] Hilaire-Pérez and Verna, "Dissemination of Technical Knowledge."

[18] Bertucci, "Spinners' Hands, Imperial Minds."

[19] Roy, *The Crafts and Capitalism*, 16.

[20] The paper conducts a novel comparative assessment using mechanical and material evidence alongside data for productivity and cost estimates. Writings of contemporary observers, manufacturers, and stakeholders who textually painted the picture of Britain's eighteenth-century cotton industry are used to chart the mechanical evolution of key British spinning machines: the jenny, the waterframe, and the mule. Material evidence in the

Many scholars agree on the relationship between the staple of raw cotton and final cloth quality. Long-staple Sea Island cotton from the Caribbean and the Americas was considered high quality. In contrast, short-stapled Surat or Smyrna cottons from India were considered lower quality, resulting in lower grades of yarn and final cloth.[21] The qualitative superiority ascribed to long-staple over short-staple cotton refers to mechanized spinning, which was not possible with short-staple cotton fibers. According to Andrew Ure, one of the earliest observers of the British cotton industry who wrote about it as it evolved, "When they are short, and consist of rather broad and flimsy ribands, they will be ill adapted to machine spinning, though still susceptible of being spun by the tact of delicate fingers. We can thus understand how the Hindoo women manage to spin fine yarn from the Dacca cotton, which is the growth of an unequable wool consisting of flimsy ribands, like most of the Indian cottons."[22] Quoting William Roxburgh, the Scottish botanist who worked extensively in India during the late eighteenth and early nineteenth centuries, Ure notes, "The most intelligent manufacturers at Dacca think that the great difference between the Dacca muslin and that of other places, lies in the spinning, and allow little for the influence of the soil, or the variety of the *Gossypium herbaceum*, which is cultivated in Dacca."[23] The final quality of cloth is down to the technology

form of textile samples from the Barbara Johnson Album (1746–1823) at the Victoria and Albert Museum, London, is used to demonstrate quality of final cloth corresponding to evolving spinning machinery. Data from McConnel and Kennedy and other experts' evidence has enabled comparisons between product quality and productivity as well as between yarn cost and price. Customs records from 1777 to 1806 are used to show the growing volumes and varieties of cotton goods exported from Britain.

[21] Baines, *History of the Cotton Manufacture*, 293–99; Ure, *Cotton Manufacture*, 1:93; Styles, "The Rise and Fall of the Spinning Jenny." On the material differences between staples: Lakwete, *Inventing the Cotton Gin*, 1–16.

[22] Ure, *Cotton Manufacture*, 1:83.

[23] Ure, *Cotton Manufacture*.

combined with the spinner's skill. Material and scientific evidence show that compared to the highest quality British and French muslins, Indian muslins were the finest and the strongest. These qualities were thanks to the more robust short-staple cotton's filaments, which Indian spinners with their highly refined skills could impart the greatest number of twists, resulting in the finest cotton yarns.[24]

Skill of Spinning—and Early Innovations

A spinner's skill in handling technology has always been at the heart of spinning, which constitutes the foundation of cloth making.[25] The earliest ways humans manipulated fibers to form twisted lengths of yarn were by using the spinner's two hands. One hand held the mass of the fiber while the other pulled and twisted stretches of fiber, turning them into yarn. Only short lengths of yarn can be spun this way.[26] Such short lengths created the problem of spinning continuous and relatively longer lengths of yarn. One solution was attaching a weight called a whorl at the other end of the spindle. This tool is the drop spindle.[27] A small length of hand-spun yarn tied to the spindle would spin because it was attached to the whorl. Suspended above the ground, the whorl spun round through gravity, once set in motion. The spinner held the loose bunch of fibers attached to the spindle in one hand and guided the stretch of fibers with

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[24] Raman, "Indian Cotton Textiles."

[25] Cloth is woven using two distinct types of spun yarns—warp and weft. Warp is attached vertically or lengthwise to a loom and remains under tension throughout the weaving process. Weft is inserted through the stationary, taut warp in an over-under-over pattern to create simple cloth. Different conditions on the loom require specific characteristics in warp and weft. For a fine calico or muslin, the warp must be a finely spun yarn but also have substantial tensile strength.

[26] Morton and Wray, *Introduction to Spinning*, 133–34.

[27] There is evidence of a wooden spindle from Kahun in Egypt, dated 1900 BCE. Derry and Williams, *A Short History of Technology*, 79.

the thumb and forefinger of their other hand by gently pulling on the roving to bring required lengths of fiber into the twist provided by the spinning whorl.[28] The spinner's significant skill is in guiding or drawing out the fibers from the loose bunch, a process known as drafting, and ensuring the twist is adequate—too much would create patches with scarce fibers, resulting in breakage; too little and the yarn would not be strong enough for weaving.[29]

The earliest mechanical innovations for spinning still required the spinner's skill. The spinning wheel was invented and circulated in India between 500 and 1000 CE.[30] It is a wooden frame with a wheel at one end and a spindle at the other. Using the handle, the spinner rotates the wheel, which in turn rotates the spindle. This wheel is suitable for spinning all short-staple fibers—wool or cotton.[31] The main difference between spinning on the drop spindle or on the Indian spindle, or jersey wheel as it became known in Europe, is the drafting mechanism. Unlike the drop spindle, where the drafting is straight in line with the spindle, with the jersey wheel it is at an angle to the spindle, depending on the twist needed in the yarn. The higher the twist required, the higher the angle the spinner drafts the roving to spin into yarn.[32] This skill-intensive process requires carefully calibrated judgment of the thickness of the roving, the length of drawing, and the extent of twist inserted via the spindle, all the while ensuring a

[28] Technically, a bunch of cotton was first combed or "carded" to form a "roving" to spin yarn, but loosely spun yarn for spinning finer yarns is also known as roving.

[29] Indian spinners, typically women, regulated this by resting the lower end of the drop spindle in a smooth shallow shell to ensure the right drafting tension. Morton and Wray, *Introduction to Spinning*, 135.

[30] Ure, *Cotton Manufacture*, 1:195; Marsden, *Cotton Spinning*, 194–95; Morton and Wray, *Introduction to Spinning*, 135.

[31] Ure, *Cotton Manufacture*, 1:195.

[32] Morton and Wray, *Introduction to Spinning*, 139.

uniform and appropriate twist. Once the yarn has the required twist, it is wound back onto the spindle to form a "cop," a process known as "backing off."[33]

FIG. 1 Basic Spinning Mechanism. The Indian spinning wheel, commonly known in Europe as the jersey wheel, was the basic technology for spinning cotton yarn in the preindustrial period. Its two processes, drafting-twisting the fibers then winding the spun yarn back on the spindle, each require well-honed skills to handle the wheel and short-staple cotton fibers. As the image shows, the spinner's body is a key part of the mechanism, her skill integral to the yarn-making process and her mind-hand-apparatus connection fundamental to working the spinning wheel. (Source: Drawing by Frederick William Alexander De Fabeck, 1860–1890, V&A Museum)

Spinning on the jersey wheel was therefore a two-stage process—first drafting and twisting the fibers to make the yarn, then backing off and winding the spun yarn onto the spindle. This two-staged process was the chief technology for spinning yarns in Asia and Europe till the sixteenth century. A shift to continuous spinning came about in 1530 with an innovation by Johan Jurgen in the German town of Brunswick.[34] The saxony wheel, also known as the flyer or long-fiber wheel, spun the longer fibers of flax, hemp, or wool, combining the principles of spinning and winding on.

[33] Morton and Wray, *Introduction to Spinning*, 141.

[34] Usher, *A History of Mechanical Inventions*, 273.

The spindle in the saxony wheel was attached to a wooden whorl, set in motion by a foot treadle. The yarn was wound onto a bobbin mounted on the spindle shaft, flanked on two sides by the flyer that attached the spindle. Drafting involved the spinner using both hands to direct the fibers into an opening at the tip of the spindle through to the hooks on the flyers guiding the yarn onto the bobbin.[35] Each revolution of the flyer around the spindle shaft gave the length of yarn one twist.

For continuous spinning on the saxony wheel, the spinner had to take care to maintain a constant twist of yarn on the bobbin. Otherwise, each revolution would increase the bobbin's diameter, leading to less twist in the yarn, and consequently increasingly softer yarn as spinning continued. The problem was solved by adjusting the tension on the band connecting the large wheel to the spinning device.[36] Assessments indicate that the saxony wheel's mechanism impedes making fine yarn, even by a skilled and experienced spinner, because the centripetal force of the bobbin pulls strongly on the yarn. It is technically impossible, therefore, to spin fine yet loosely twisted yarn on this type of wheel.[37] Thus, although the saxony wheel doubled productivity and was adopted in Germany, Switzerland, and Belgium for spinning longer fibers, it remained a complementary mechanism to the jersey wheel.[38]

Continuous spinning and the idea of perpetual motion underlying the saxony wheel technology are important developments in the history of mechanization in textile manufacturing. According to Lynn White in his classic 1960 study, this concept came to Europe from India. He traced it to 1150 CE and credited Hindu astronomer and mathematician

[35] Morton and Wray, *Introduction to Spinning*, 50.

[36] Morton and Wray, *Introduction to Spinning*, 151.

[37] Hills, "Hargreaves, Arkwright, and Crompton."

[38] Catling, *The Spinning Mule*, 16; Usher, *A History of Mechanical Inventions*, 273–74.

Bhaskara with the idea of gravitational *perpetua mobilia*, which in White's view was rooted in the "Hindu belief of the cyclical and self-renewing nature of all things."[39] From here it was picked up by Islam, followed by Europeans. White wrote, "We may thus be sure that about AD 1200, Islam transmitted the Indian concept of perpetual motion to Europe, just as it was transmitting at the same moment Hindu numerals and positional reckoning: Leonard of Pisa's *Liber Abaci* appeared in 1202."[40] White noted that once the Indian concept of perpetual motion arrived in Europe, it was greeted with widespread practical and mechanical interest, unlike in the Hindu and Islamic traditions where it remained a theoretical concept.[41]

Attempts to mechanize the process of spinning wool and cotton had limited success after the invention of the saxony wheel but before that of the spinning jenny in 1764. Silk throwing, however, was already successfully established in Britain by 1720, with knowledge clandestinely acquired from Italy. Thomas Lombe's silk mill set up in Derby in 1721 was the first mechanized textile production facility, a trendsetter not only for silk manufacturing in Britain but also for other fibers.[42] Alfred Wadsworth and Julia de Lacy Mann's classic study referred to a handful of attempts in the late seventeenth and early eighteenth centuries by enterprising individuals to mechanize spinning in Britain. According to the authors, these were typical of the time's two main preoccupations: providing relief through gainful employment of the poor and "enrichment of the nation by the establishment of new industries." Two attempts, one in 1678 by Richard Dereham and Richard Haines for a machine that could operate between six and a hundred spindles with a manual wheel and crank mechanism, and another in 1723 by

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[39] White, "Tibet, India, and Malaya."

[40] White states that *Liber Abaci* was one of the first European texts to delineate the Hindu-Arabic numeral system with symbols in line with modern Arabic numerals.

[41] White, "Tibet, India, and Malaya."

[42] Warner, *The Silk Industry of the United Kingdom*, 199–201.

Thomas Thwaites and Francis Clifton to manufacture a yarn from a mix of wool, flax, cotton, and silk, using "several engines by certain multiplying of wheels," aimed at employing destitute hands in England's workhouses.[43]

Another attempt at mechanization was by Elias Barnes between 1720 and 1724. This time, the inventor clearly stated that his motivation to spin cotton, especially fine cotton, was to rival Indian muslins in global markets. Barnes's invention was only a slight modification to the jersey wheel, without adding extra spindles or applying inanimate power. What Barnes did achieve was a refined spindle-and-whorl mechanism enabling speedier and more uniform spinning. The Board of Trade and Plantations, where Barnes submitted his invention hoping for an award, circulated the spinning machine among manufacturers and other experts who gave favorable feedback. However, the slow response from the Board led Barnes to look to the Continent for opportunities. A school in Paris and subsequently various provinces in France adopted his machine. Though Wadsworth and Mann dismissed Barnes's improvement to facilitate spinning finer yarn because it was not launched in industry owing to the lack of multiple spindles and inanimate power, his endeavor was one of the first to recognize that the problem with replicating Indian cotton goods in Britain hinged on the quality gap.[44]

Wadsworth and Mann show how improving the quality of spun yarn was the central motivation for all three early spinning inventions.[45] Recognizing the yarn-quality problem, inventors sought to resolve this while simultaneously gaining additional justification for their instruments to deliver employment and relief for the poor. Machines to employ jobless hands were much sought after.[46] Contrary to the argument that skilled labor facilitated

[43] Wadsworth and Mann, *Cotton Trade*, 413–15.

[44] Wadsworth and Mann, *Cotton Trade*, 122–24.

[45] Wadsworth and Mann, *Cotton Trade*, 416.

[46] Dossie, *Memoirs of Agriculture*, 93–94; MacLeod, *Inventing the Industrial Revolution*, 159, 161.

industrialization, scholars have offered evidence suggesting an abundance of unskilled labor and institutional efforts to provide gainful employment.[47] The first major commercially oriented attempt to mechanize wool and cotton spinning was by duo Lewis Paul and John Wyatt in the 1730s, with a successful patent for yarn spinning using rollers in 1738.[48] However, their newly developed carding mechanism to obtain the required quantity of carded cotton remained mechanically troublesome.[49]

Following Paul and Wyatt's debacle, the general feeling about the prospects for mechanized continuous spinning was pessimistic. It is widely reported that the Society of Arts, later Royal Society of Arts, offered support and encouragement by way of premiums and awards for inventions and innovations in Britain.[50] However, after 1759, the Society only offered premiums for improvements to the spinning wheel like the kind Barnes had already achieved by 1724. It stopped encouraging machine spinning, convinced that such a mechanism was not feasible.[51]

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[47] Parthasarathi, *Why Europe Grew Rich*, 104–5; O'Brien et al., "Technological Change during the First Industrial Revolution," 886, 888.

[48] French, *Life and Times of Samuel Crompton*, 223.

[49] Wadsworth and Mann, *Cotton Trade*, 426–27.

[50] O'Brien et al., "Technological Change during the First Industrial Revolution," 886.

[51] Wadsworth and Mann, *Cotton Trade*, 447–48. In his *Memoirs*, Dossie observes, "They attempted to improve the practice of this art in England, and to introduce the spinning of those finer kinds of threads, or cotton yarn, which we are at present furnished with from foreign countries. But the most efficacious, and proper means, by which they essayed to encourage spinning, were the efforts to procure improvements in spinning wheels, and the other instruments subservient to spinning: such as reels for winding, twisting, etc." Dossie notes, "The Society offered three kinds of premiums, respecting the perfection of spinning-wheels, and the operations subservient to spinning. The first was the greatest improvements in the common spinning-wheel, either for wool, cotton, flax, or silk. . . . These premiums were continued to 1766: and then omitted, to make way for fresh objects." Dossie, *Memoirs of Agriculture*, 94.

Technological Path Dependence

The historical narrative on the "wave of innovations" in Britain's cotton industry overshadows a basic fact: preexisting technology in the form of the spinning wheel and spinner's skill was readily available to British spinners, indeed to anyone aiming to replicate Indian cotton products. What then explains the sequential mechanization in cotton spinning? Were these machines connected to the Indian method of spinning cotton yarn, signifying path dependence on Indian technology? Surveying the working mechanisms of the jenny, the waterframe, and the mule tests the mechanical path dependency on the Indian spinning wheel.

The spinning jenny was invented by James Hargreaves in 1764, though he did not apply for a patent until 1769.[52] It was a simple mechanism whereby one wheel moved multiple spindles, replicating the spinner's hands. The entire mechanism was encased in a horizontal rectangular frame. A smaller frame containing bobbins filled with roving was attached to a bar that moved it up and down the rectangular frame from one end up to three-quarters of the way to the other end. A sliver from each bobbin was attached to a corresponding spindle at the other end of the rectangular frame, set at an angle inclined toward the spinner. The slivers passed through rails holding them in place. The spinner drafted the rovings by moving the bar attached to the bobbin frame toward them while turning the main wheel to turn the spindles. Once the rovings had enough twist, the spinner moved the bar forward while slowly turning the spindles to wind the yarn back onto them. The spinner could then use a faller wire to guide the yarn being wound by depressing a lever.[53]

[52] Mann, "Textile Industry," 278; Aspin and Chapman, *James Hargreaves and the Spinning Jenny*, 13.

[53] Hills, "Hargreaves, Arkwright, and Crompton," 26.

The jenny was a straightforward development of the short-fiber wheel or jersey wheel, both with exactly the same drafting and twisting principles.[54] Ure explains the common jersey wheel mechanism, "This is the ancient spinning implement of Hindostan. The first mechanical invention regularly employed with profit upon a manufacturing scale for spinning cotton in England was constructed upon this principle; several spindles, at first eight, afterwards eighty, being made to whirl by one fly-wheel, while a movable frame, representing so many fingers and thumbs as there were threads, alternately receded from the spindles during the extension of the thread, and approached them in its winding on. This multiplying wheel, called a spinning jenny, was invented by James Hargreaves, about the year 1764, at Stand-hill, near Blackburn, in Lancashire."[55]

According to historian—and founding curator of the Museum of Science and Industry in Manchester—Richard Hills, there were several physical, structural, and technical problems with the jenny. It was difficult to draw out an even yarn while broken yarn needed constant piecing attention. Technically, the jenny was only suitable for weft since the mechanism allowed some yarn to run loose from the tip of the spindles to the clasp in the bar, letting the twist run up into the new portion of roving. Yarn spun on the jenny was only softly twisted and of lower counts. As Hills points out, while the jenny could be improved, it was fundamentally limited in the type of yarn it could produce.[56]

Gravenor Henson, who recorded the oral testimony of Nottingham's framework knitters in the early 1830s, noted, "The cotton yarn spun by Hargraves [*sic*], though much superior to the Nottingham [hand] spinning, was still a poor article, being full of tender thin places, 'bumps and burs' and was with difficulty wrought in stockings." According to Henson,

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[54] Morton and Wray, *Introduction to Spinning*, 142.

[55] Ure, *Cotton Manufacture*, 1:195–96.

[56] Hills, "Hargreaves, Arkwright, and Crompton."

the very development of manufacturing stockings was based on the use of imported fine Indian cotton yarn in Nottingham, as domestic attempts at hand spinning similarly fine cotton yarn were unsuccessful.[57]

One key change that the spinning jenny brought about was transferring the skill embedded in the spinner's fingers into the machine's mechanisms. Although a basic device, the jenny disconnected the feel, control, and dexterity of the spinner's fingers from the jersey wheel's spinning process. Multiplying the number of spindles joined to the prefilled bobbins of rovings attached to a large wheel eliminated the spinner's skill in manipulating the yarn to a required degree of fineness. While the spinner, now more aptly described as a basic mechanical device operator, exercised some discretion through the number of twists they imparted to the stretched rovings, this was determined by the machine's capacity, not the spinner's skill. As historian H. C. Cameron noted about the jenny's significance, "For the first time in the making of cloth something which constituted a machine was freely available. A machine is more than a tool in the hand of the workman; it is itself an artificial hand, made by the engineer to reproduce automatically the results of the skilled and dexterous manipulation of the craftsman."[58]

Following closely on the heels of Hargreaves's jenny came Richard Arkwright's waterframe in 1767. Unlike the jenny, the waterframe stood in a vertical rectangular frame with a horizontally placed wooden frame on top holding the bobbins containing the rovings. The rovings from each bobbin passed through two pairs of rollers, with the second pair moving faster than the first, ensuring the rovings were stretched further. A flyer arm guided the yarn onto the spindle at the base of the machine. The bobbins, standing on the spindle shaft toward the lower half of the rectangular frame and flanked by the flyers, had the yarn thus wound onto

[57] Henson, *History of the Framework-Knitters*, 366.

[58] Cameron, *Samuel Crompton*, 48.

them. The waterframe's spindle-and-bobbin mechanism is based entirely on the saxony wheel's continuous spinning model.[59] Finally, continuous spinning was mechanically possible with the twin spinning and winding-on processes completed simultaneously.[60]

Drafting the fibers using rollers was a crucial new solution, and in large measure responsible for the success of Arkwright's machine, despite using the same type of rollers as Paul and Wyatt. The differing speeds of the sequential rollers and attached weights were Arkwright's novel contributions and some of the small tweaks that made a significant difference. The waterframe, initially driven by horsepower, quickly shifted to waterpower at the Cromford Mill in 1771, producing "water-twist" yarn.[61] The waterframe spun a strong and well-twisted yarn suitable for cotton warp as well as hosiery. It was a smooth, wiry, and less hairy yarn, unlike the jenny's loose and soft yarn.[62] It was technically usable as warp for all manner of cotton goods such as calicoes, fustians, cords, and sewing thread, though its wiry character and limits with fineness meant it was unsuitable for finer calicoes or muslins.

Overcoming the jenny's key limitations in spinning cotton warp, the waterframe enabled for the first time large-scale manufacturing of all-cotton goods in Britain. However, Ure notes complaints about the quality of yarn from the waterframe as well as its successor, the throstle, claiming an estimated 40 percent more throstle yarn was used on the loom compared to the soft warp from the common throstle's improved successor, the Danforth throstle invented in America in 1829.[63] The waterframe was also unsuitable for spinning short-

[59] Mann, "Textile Industry."

[60] Cameron, *Samuel Crompton*, 53.

[61] Wadsworth and Mann, *Cotton Trade*, 484.

[62] Mann, "Textile Industry"; Hills, "Hargreaves, Arkwright, and Crompton."

[63] Ure, *Cotton Manufacture*, 2:141.

staple wool, and weavers complained of the rough worsted yarn it spun.[64] The waterframe, under the name "throstle," was still used for well over a century, with few structural changes. It survived alongside the mule in cotton spinning but was eventually adapted for flax, jute, and worsted spinning.[65]

The waterframe further distanced the spinner from the process of spinning. It required no specialized spinning skills. The operator's job was to refill the rovings, piece together broken yarn ends, and remove the bobbins full of spun yarn. Unskilled women and children commonly worked on the waterframe.[66] Hills notes that the skill involved in spinning cotton yarn was transferred to the machine builders and fitters and to the producers of rovings.[67] The inability of the waterframe to produce finer yarn, however, points to the significance of skill for the making of quality goods.

A New Skill for Spinning

In 1779, Samuel Crompton showed the public his new spinning invention, the mule. A weaver by training, he had been devising his spinning machine since 1772, after, in his now famous words, he was "Grieved at the bad yarn I had to Weave."[68] Combining the rollers of the waterframe with the jenny's movable carriage in a rectangular frame, he put the spindles on the carriage and the rollers at the end furthest from the operator. The spinner drew out the carriage with the slivers stretching for a short length till the rollers acted like the jenny's clasp and the carriage moved back slowly, continuously twisting the yarn on the spindles. Once

[64] Aspin and Chapman, *James Hargreaves and the Spinning Jenny*, 56.

[65] Morton and Wray, *Introduction to Spinning*, 155.

[66] Pinchbeck, *Women Workers in the Industrial Revolution*, 183.

[67] Hills, "Hargreaves, Arkwright, and Crompton."

[68] Crompton letters, in Daniels, *The Early English Cotton Industry*, 159.

drawing was complete, the yarn was disengaged by turning the spindles backward and further stretched and twisted. The carriage was then pushed in again to wind the yarn into a cop, with the help of a faller wire as in the jenny.[69]

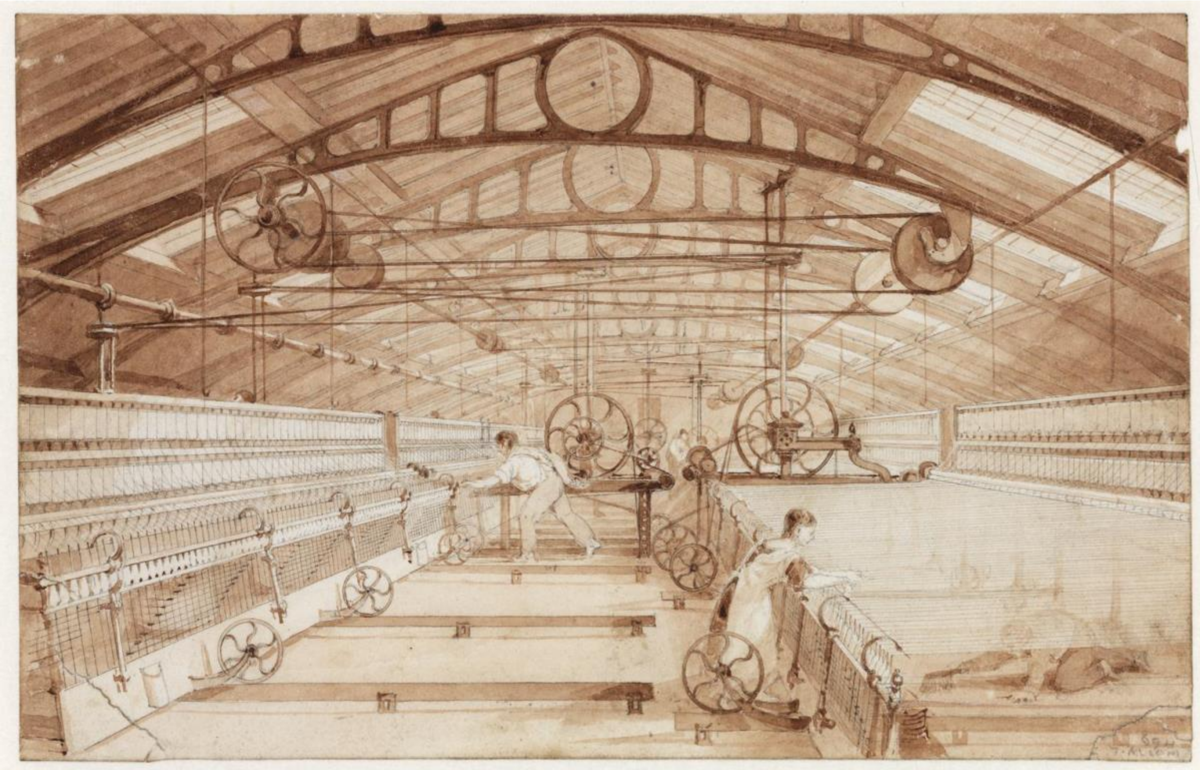

FIG. 2 Mechanized Spinning. The mule or muslin wheel specifically invented by Samuel Crompton in 1779 enabled Britain to manufacture fine cotton goods like muslins. The mule was a refined spinning jenny, operated by mule spinners. As the image shows, human interaction with the mule's mechanism had shifted from bodily engagement to mechanical calibration. The machines made the yarn while the mule operators ensured smooth operations and consistent yarn quality. (Source: Drawing by Thomas Allom, 1834, Museum of Science and Industry).

Since Crompton had plain spindles like the jenny, without the flyers, he therefore had to use the jenny's mechanism of drawing out a length of roving, spinning, then winding it back on. Hence the need for a movable carriage. Improving the jenny mechanism first involved arranging the gearing to allow for calibrated movement between the rollers releasing the rovings and the carriage turning down. The spindles were rotated just enough to give the yarn sufficient twist to stay intact without the fibers disentangling. The next phase started with the second improvement to the jenny mechanism. First, the yarn was disengaged from the rollers.

[69] Mann, "Textile Industry"; Catling, *The Spinning Mule*, 33–34.

Then it was further stretched by drawing it out of the carriage, which meant the yarn was drawn out against the twist. Spindles were then turned to add more twist and strengthen the yarn.[70]

The mule is described within the large literature on the British cotton industry's history as a combination of the waterframe and the jenny—the very name is a nod to its hybrid character.[71] However, the only waterframe mechanisms that found their way into the mule were the rollers. The rest of the structure and yarn-making process remained the same as the jenny, though improved. As a successor of the jenny, the mule was continually plagued by the jenny's main problem—winding the yarn back on to the spindle to make the cop. At the end of the second draw and twist, the spinner had to turn the spindles backward to unwind the yarn until it reached the tip of the cop, where the yarn was wound. The spinner then had to guide the yarn onto the cop, with the help of the faller wire as in the jenny, at the same time pushing in the carriage. This required the mule operator's good judgment and mechanical skill in coordinating the assembly of the yarn on the cop alongside the carriage's movement.[72]

The transfer of cotton-spinning skills from the hands of Indian spinners, predominantly women, to the machine, beginning with the jenny and solidified by the waterframe, acquired a new component with the mule.[73] It demanded a new skill in the machine operator—astute mechanical ability to navigate the intricacies of the yarn-making process on the mule, or to operate larger and more complex machines. While operating the mule required physical

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[70] Hills, "Hargreaves, Arkwright, and Crompton."

[71] Ure, *Cotton Manufacture*, 1:262; Baines, *History of the Cotton Manufacture*, 197–98.

[72] Ure, *Cotton Manufacture.*

[73] Spinning was largely women's work in India. Though not the focus of this article, a gendered lens would highlight that traditional Indian women's spinning skills were transferred to a machine operated predominantly by British men, making it a mechanical, male skill.

strength and mechanical ability, the spinner's skill in the form of dexterity with fibers had been successfully removed from the spinning process.[74]

What was the entrepreneurial motivation for the mule if the jenny, the waterframe, and successors had already mechanized cotton warp spinning and enabled the manufacture of all-cotton goods? In order to establish fine cotton and muslin manufacturing in Britain, a mechanism was needed within the industry to supply the fine yarn, in the absence of skilled local labor capable of spinning fine cotton yarn. The mule provided this technology. George Daniels describes the arrival of the mule as the "rise of a new cotton manufacture" of fine cottons or muslins.[75] According to journalist, parliamentarian, and one of the earliest historians of the British cotton industry Edward Baines, once Crompton had made fine yarns on the mule, he obtained 14s. per lb. for spinning and preparing No. 40 yarn (weighing 40 hanks to the pound), 25s. for No. 60, and 42s. for the small quantity of No. 80 spun to test the market demand.[76] Baines explains, "These prices were commanded by the unrivalled excellence of the yarn; and it affords a criterion to estimate the value of the machine, when it is found that the price of yarn No. 100 is at present day only 2s. 3d. to 3s. per lb. including the cost of raw material, which is 10d. or 1s., this surprising reduction having been effected chiefly by the powers of the mule; and that, whereas it was before supposed impossible to spin eighty hanks to the pound, as many as *three hundred and fifty* hanks to the pound have since been spun, each hank measuring 840 yards, and forming together a thread a hundred and sixty-seven miles in length!"[77] These prices indicate the strong demand for fine quality yarn in Britain.

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[74] Hills, "Hargreaves, Arkwright, and Crompton."

[75] Daniels, *The Early English Cotton Industry*, 113.

[76] Baines, *History of the Cotton Manufacture*, 200. For reference: s. = shillings, lb. = pounds, d. = pence.

[77] Baines, *History of the Cotton Manufacture*, 200. Italics in original.

Baines was quick to recognize the significance of the mule (popularly called the "Muslin wheel") because it heralded a particular type of fine cotton manufacture in Britain after 1779. He noted previous unsuccessful muslin manufacturing attempts in Lancashire and Glasgow, despite using Indian hand-spun warp. The resultant cloth could "not be made to compete with those of the East." Underscoring the competitive and comparative origins of this new manufacture, he noted, "Bengal, which for some thousands of years stood unequalled in the fabric of muslins, figured calicoes, and other fine cotton goods, is rivalled in several parts of Britain."[78]

How much were these technological advances influenced by the pursuit of quality versus productivity? A comparison of the three key spinning machines and self-acting mule establishes their productivity, quality of spun yarn, and what types of fabrics these yarn categories could produce.

Fig. 3: Comparative assessment of cotton spinning machinery in Britain, 1764-1830

Machine	***Year***	***Technical ancestor***	***Key new mechanism***	***Spindles per machine***	***Productivity (hanks per day, per spindle)***	***Productivity (hanks per machine)***	***Range Yarn Count***	***Quality of yarn***	***Suitability***	***Type of fabrics***
Cotton hand spinning	Since antiquity	Indian spinners	Small tools/ Jersey wheel	1	8 (80s)	8	All	All	Warp + weft	All cottons
Cotton hand spinning	17th century	British spinners	Small tools/ Jersey/Saxony wheel	1	6.5-8 (16s)	8	Coarse	Coarse	Weft	Coarse fustians, linen-cottons
Jenny	1764	Jersey wheel	Multiplication of spindles	16	1.6 (16s)	25.6	Less than 30s	Coarse, loose, breakable	Weft	Coarse fustians linen-cottons
Water frame	1767	Saxony wheel + rollers	Improved drawing and continuous spinning	48	1.6 (24s)	76.8	Less than 60s	Wiry, smooth, tightly spun	Warp	Fustians, cords hosiery, sewin threads
Mule	1779	Jenny + water frame	Controlled, 2-stage drawing for finer yarns	48	1.25 (40s)	60	20s -300s	Soft, downy, strong	Warp + Weft	All-cottons, fin cottons, muslins
Self-acting Mule	1825	Hand-operated mule	Labor inputs largely eliminated via automation	298	3 (40s)	894	20s - 300s	Like Mule, more uniform	Warp + Weft	All-cottons, fin cottons, muslins

[78] Baines, *History of the Cotton Manufacture*, 202, 334–35.

Source: Ure, *The Cotton Manufacture of Great Britain, Vol I*; Baines, *The History of the Cotton Manufacture in Great Britain*; Chapman, *The Cotton Industry in the Industrial Revolution*; Wadsworth and Mann, *The Cotton Trade and Industrial Lancashire 1600-1780*; Catling, *The Spinning Mule*; von Tunzelmann, *Technology and Industrial Progress: The foundations of economics growth*; Mann, The Textile Industry: Machinery for Cotton, Flax, Wool, 1760-1850, in, Singer, *A History of Technology Vol IV: The Industrial Revolution c.1750-c.1850*; Maw, Solar, Kane and Lyons, After the Great Inventions: technological change in UK cotton spinning, 1780-18

Figure 3: **Quality vs Productivity**. This comparison of cotton yarn spinning techniques' product quality and productivity illustrates that multiple spindles gave machines their advantage over hand spinning. Both the waterframe and the mule were invented to recreate specific characteristics and qualities of cotton yarn, producing first the all-cotton cloth, and then the fine all-cotton cloth that Britain needed to rival India in the global cotton textile market.

Figure 3 shows that each new spinning machine improved the quality of yarn and enabled the manufacturing of new, finer cotton goods than were possible with the previous mechanism, except the self-acting mule. Thus, the complexity of each successive machine, until the self-acting mule, is fundamentally related to increased quality of the yarn spun. Recent research by economic historians Maw, Solar, Kane, and Lyons shows that initial productivity gains came from increasing the number of spindles, not through improved spinning mechanisms.[79] Evidence shows that pursuing quality in the first instance, and productivity in subsequent mechanical refinements, drove the evolution of machinery. The greatest substantive differences in machine outputs are the diverse qualities and varieties of yarns that could be spun on each one, despite an initial drop in productivity per spindle. The jenny could spin coarse, loose, and breakable weft of less than 30s count, suitable for making coarse fustians with linen as the warp. The waterframe could spin a wiry, smooth, and tightly strung warp of less than 60s count, suitable for fustians, cords, hosiery, and sewing threads. The mule drastically increased the potential for spinning counts for both warp and weft ranging from 20s to 200s. It resulted in a soft, downy, and strong yarn suitable for all cotton fabrics, including fine cottons and muslins. The move to the self-acting mule did not add a quality increment to the evolving machinery.

[79] Maw et al., "After the Great Inventions," 47.

Its biggest contribution was automating the mule's mechanism. It thus eliminated the input of skilled mechanical labor.

The mechanical evidence helps determine to what extent each new spinning machine improved the quality of yarn. Dated samples from the wardrobe of middle-class English woman Barbara Johnson, from her album compiled between 1746–1823, now situated at the Victoria and Albert Museum, are used to estimate the mechanical evolution in spinning alongside the material evolution of the final textile products.[80] The samples Barbara Johnson collected do not supply manufacturer information that could indicate the technology used. The dates on the fabric swatches, however, give some indication of the type of base cloth and yarn produced by each new spinning technology.

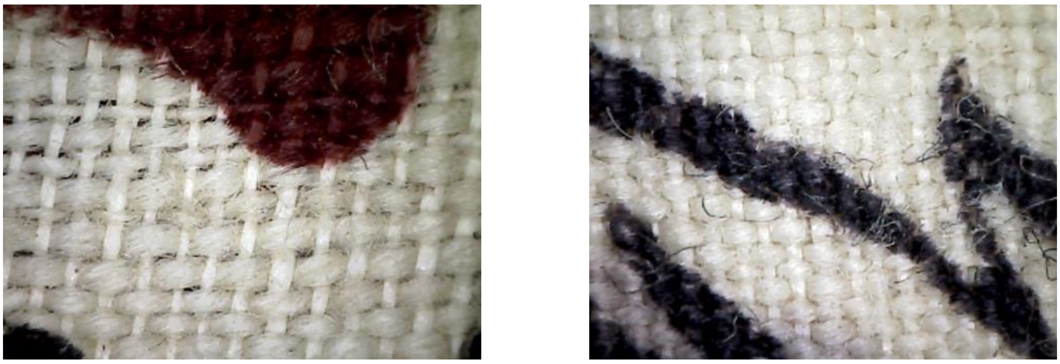

FIG. 4A, 4B Initial Cloth Quality. These are magnified images of fabrics used by a middle-class English woman, Barbara Johnson, in 1746 and 1768, to imitate Indian printed and painted cottons. Magnification shows that the warp is linen. In sample 4a, the weft is coarse and highly uneven, indicating the low quality of British cotton cloth predating the mechanization of spinning. The fabric has a low thread per inch (TPI) count of 115. Sample 4b is more uniform, possibly spun on the spinning jenny. The fabric has an improved TPI of 141, showing that the very first mechanization of cotton spinning improved yarn quality.

Figures 4a and 4b from the Barbara Johnson Album are magnified images of textiles used by Johnson in 1746 and 1768 respectively. The printed textile in 4a is definitively from the pre-jenny era, going by the quality of the yarn, and more significantly, the linen warp for making linen-cotton cloth. Both warp and weft are hand spun. Given that it took one to two

[80] The Barbara Johnson Album, T.219-1973, V&A. On using these textile samples as material evidence in comparison with Indian samples: Raman, "Indian Cotton Textiles."

years from yarn spinning to selling printed cloth in the market, the sample in 4b is likely to be pre-waterframe, with weft made on the jenny. The yarn is more uniform than the hand-spun sample immediately above, and the warp is again made of flax, further affirming the estimate that this fabric is pre-waterframe.

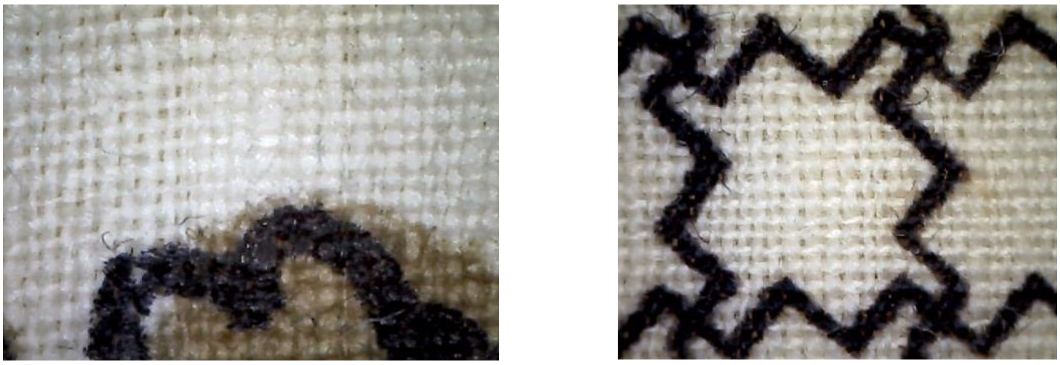

FIG. 5A, 5B Improving Cloth Quality. Magnified images of fabric used by Johnson in 1778 and 1803. Given the twelve-year gap between the invention of the waterframe (1767) and the mule (1779), and the warp's tightly spun, wiry nature, sample 5a was presumably made on the waterframe, with a better TPI of 192. Sample 5b demonstrates even higher quality. Though it is not possible to definitively confirm if the warp and weft were made on the waterframe or the mule, the fine yarn's downy nature suggests mule spinning. The fabric has a high TPI of 227, indicating that materially sequential mechanization improved yarn quality. (Source: Barbara Johnson Album, V&A)

Figures 5a and 5b are from fabrics that Johnson used in 1778 and 1803 respectively. Since the sample in 5a was consumed in 1778, it is safe to conclude that it is pre-mule, and presumably the cotton warp—on account of its stringy and wiry nature—was spun on the waterframe. The downy nature of the weft, on the other hand, suggests it was spun on the jenny, though this cannot be confirmed. The sample in figure 5b is described by Johnson as a "purple and white gown" giving no clues to its technical origins. Its timing sits neatly between the advent of the mule in 1779 and the self-actor in 1825. The yarn could have been made on the mule or the waterframe as the two coexisted in Britain's cotton industry for several years, though the fine yarn's downy texture suggests it was spun on the mule.

The material evidence suggests that the improved quality of the spun yarn is closely connected to the improvement in final cloth quality and types of products manufactured in Britain. From the ability to make a coarse linen-cotton cloth in 1746 to a fine calico in 1803, new machinery and incremental improvements in mechanized spinning facilitated the manufacture of new and finer cotton textile products.

Economic Rationale for Quality-Led Mechanization

Both material and mechanical evidence suggest that incremental improvements in mechanized spinning pursued product quality. Is there an economic rationale for quality-led innovations? Each successive machine in the British cotton industry between 1764 and 1779 improved the quality of the yarn produced until then within the industry. The quality motivation, as discussed, originated from competing against, and learning from, Indian cotton goods.

By mechanizing the production process, the entrepreneur was investing in the machine, a fixed-capital asset for creating the product. Investing in machinery to improve quality made rational economic sense as it enabled monopolistic competitive gains from manufacturing a low-volume, high-price product—the fine cotton yarn. Herein lay the motivation for the mule: spin fine yarn and make the finest cotton fabric—muslin. Between the years 1778 and 1816, weft and warp prices show that the higher the count, the higher the market price of yarn, indicating higher net margins. Prices for counts ranging from 18 to 200 show that while the bulk of the industry was concentrated in the middling ranges from 40 to 100, prices for yarn counts above 100 were much higher. The 200s count yarn went for ten times the 18s count yarn.[81]

[81] Von Tunzemann, *Steam-Power and the Cotton Industry*, 181

It also cost more to produce higher counts of yarn. Estimates from 1819 at McConnel and Kennedy, a fine cotton yarn-spinning firm in Manchester, show that the total cost of producing 210 over 100 count yarn increased rapidly by 413 percent.[82] An assessment of the cost to produce various yarn counts versus profit margins for each count shows that the profit margins for higher counts were also significantly higher. While the data for net profit is from two different sources, assuming the numbers are representative, net margins for 170s count yarn were 1,062 percent more than for 60s count yarn, indicating substantially higher profit.[83]

Although the bulk of domestic and overseas demand came from the cheaper and lower count yarns for calicoes and even cheap and coarse muslins, the highest profits were in spinning fine yarns for fine muslins.[84] McConnel and Kennedy are quoted in an 1806 letter as saying, "Spinning numbers below 80 at present price is really such a threadbare trade that there is scarce any room to give way in price."[85] While cheaper yarns, and consequently cheaper cloth, were subject to the constant pressure of price reduction, finer yarn was used to make fine, luxury cloth, for which the market behaved differently and price was not the primary concern.[86] Obtaining authentic luxury goods, of high quality and in line with the fashion of the period, were more important concerns than price for the luxury market segment.[87] Indeed, Rudolph Ackermann, a leading London shopkeeper who, through his illustrated periodical published

[82] McConnel and Kennedy, *A Century of Fine Spinning*, 53.

[83] McConnel and Kennedy, *A Century of Fine Spinning*, 53; Edwards, *The Growth of the British Cotton Trade*, 127.

[84] Edwards, *The Growth of the British Cotton Trade*, 29–30, 44–46.

[85] Edwards, *The Growth of the British Cotton Trade*, 127.

[86] Edwards, *The Growth of the British Cotton Trade*, 128.

[87] Ackermann, *Repository of Arts, Literature and Commerce*, 52–53.

from 1809 to 1828, influenced English tastes in fashion, art, and architecture, warned discerning customers in the market for luxury cottons that British muslins were being peddled in leading shopping areas as Indian muslins and guided them to shops where the real goods were available.[88]

Finer goods may have been desirable, but were they also cost competitive against Indian cottons? A comparison with Indian production costs for diverse yarn counts shows that the British advantage of relative production costs over Indian production processes increased as the yarn count improved. The highest cost advantage over Indian yarns was in the fine 120–150 yarn count categories, with a 64 percent advantage over Indian production costs for the same yarn count. Beyond that, it declined as a direct consequence of the mechanically skilled labor required for making finer yarn on the mule. Although different in nature, labor skills in both the Indian and British settings were still significant enough to impact final production costs as well as yarn quality.

The advancement in fine spinning in Britain enabled diversification of final cotton goods and successful competition with the wide varieties and qualities of Indian cottons. A statistical analysis of customs data on exports from Britain shows that the variety of cotton goods increased as mechanization evolved. This wider range was thanks to improved yarn quality and hence connected to Indian cottons. Making finer yarn enabled the production of diverse finer textile goods in line with those from India.

[88] Ackermann, *Repository of Arts, Literature and Commerce*, 52–53.

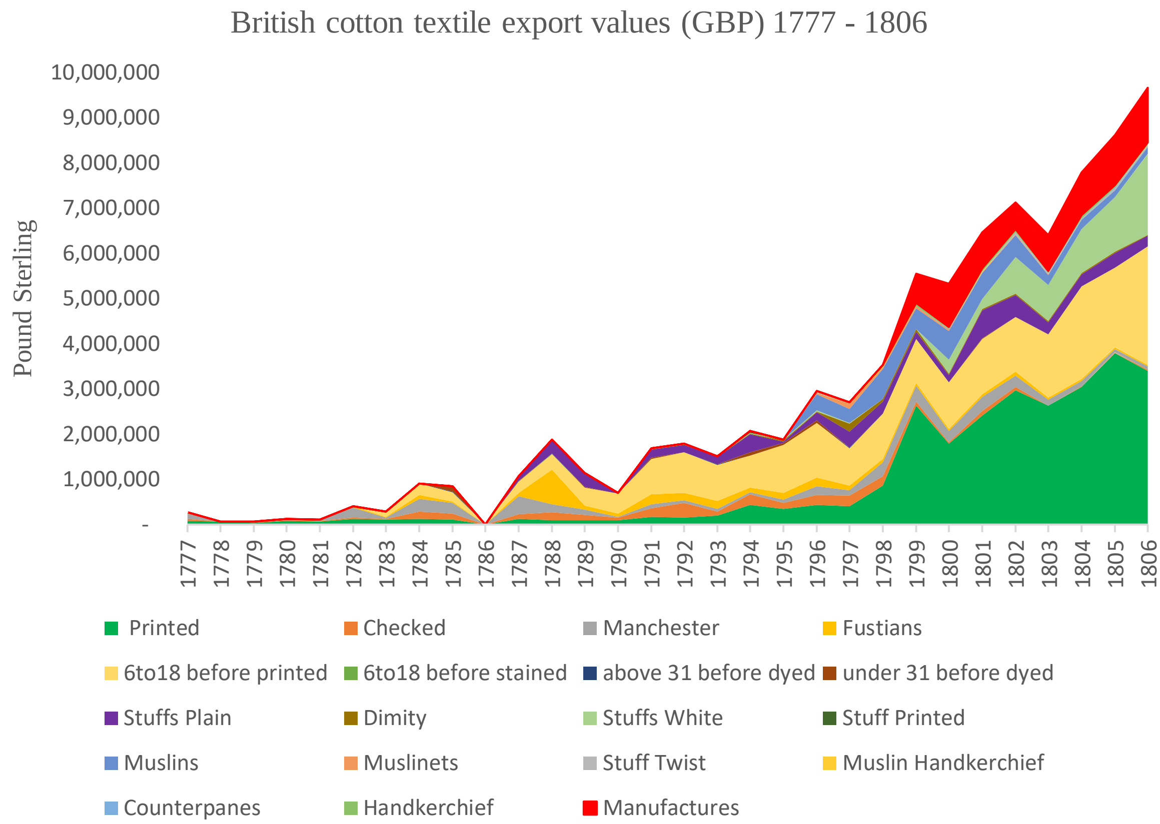

FIG. 6 Critical Diversification of Products. This graph shows the critical diversification within the industry—new products like muslins, muslinets, counterpanes, and stuffs were only manufactured after the invention of the mule. The resulting improved yarn quality allowed the industry to diversify its range of goods and serve diverse global markets at multiple price points. (Source: CUST17, TNA)

The export value of cotton goods sent to the rest of the world grew from £266,181 in 1777 to £9,665,644 in 1806, a thirty-six-fold increase. Figure 6 shows that this increase was not only thanks to greater quantities of printed cotton cloth but also greater diversification of cotton products. Evolving spinning technology enabled the manufacture of a large variety of cotton goods previously impossible, such as muslins, muslinets, muslin handkerchiefs, counterpanes, and an opaque category of manufactures.[89] Mechanization enabled British manufacturers to successfully overcome the skill deficit within the local labor force to compete globally against the vast varieties of cotton goods from India.

[89] CUST 17, Volumes. 5-30, TNA.

Mechanization and the Skill Gap

Skill is defined as the "capability of accomplishing something with precision and certainty; practical knowledge in combination with ability; an ability to perform a function, acquired or learnt, with practice."[90] It implies the existence of knowledge and expertise in performing a set task. For making cotton cloth, the fundamental primary task is making adequate cotton yarn successfully, and hence this skill is crucial. Skill is also a form of capital, present or absent, that can be expanded or contracted through investing time and effort.[91] The technology-and-skill combinations for any non-Indian economy seeking to replicate Indian cotton goods were:

1. Adopt Indian technique = jersey wheel + skilled spinner
2. Adopt European technique = saxony wheel + skilled spinner
3. Modify Indian technique = modify jersey wheel or spinner's skill
4. Modify European technique = modify saxony wheel or spinner's skill
5. Invent an entirely new technique = a new way of spinning cotton yarn
6. Invest in developing local labor force's skills through training, possibly by inviting expert Indian spinners to lead this, resulting in option 1.

The historiography of technology shows that option 5 did not materialize, as we can trace the clear ancestry of all machines. Further, there is no historical evidence of option 6 in Britain; indeed, the focus on finding a mechanical solution to spinning cotton yarn indicates a trend in opposition to option 6. Therefore, the only realistic options were 1–4.

British entrepreneurs, merchants, spinners, and other stakeholders explored options 1 and 2 during the early phase of substituting Indian cotton imports. Studies show that this imitation phase demonstrated the local workforce's inability to spin an adequate quality of

[90] https://www.oed.com Oxford English Dictionary, accessed 10 May 2021.

[91] Roy, *The Crafts and Capitalism*, 16.

cotton warp using the jersey or saxony wheel.[92] Since the quality of the yarn spun through these techniques was not competitive, British entrepreneurs next tried options 3 and 4, moving away from skilled labor toward mechanization of existing spinning technology. Option 3 is the jenny and its successor the mule, through the modification of the jersey wheel and reduced skill required by the spinner. Option 4 is the waterframe and its successor, the throstle, through modifying the saxony wheel and the skill required by its spinner. If Indian yarn quality had to be matched, however, any technique based on option 4 would be unfeasible because it was technically impossible to spin fine yarn using the saxony wheel, later deployed in the waterframe. Therefore, the only viable options were 1 or 3. British entrepreneurs adopted 3 because this was the only way to imitate Indian quality successfully; option 1 was not possible owing to the lack of skilled labor.

The skill gap in Britain was a technical problem. Historical unfamiliarity with cotton fiber meant British spinners struggled to meet the required fineness and strength specifications. Significantly, fine cotton yarn for hosiery manufacture was spun domestically by erstwhile wool spinners who were adept at Spanish short-staple wool and became "tolerably expert in spinning cotton."[93] In contrast, most of the British trained in spinning long-staple wool could not adapt to the short-staple cotton, even with moderate skills.[94] Individual highly skilled wool spinners or "tolerably" skilled cotton spinners could not meet the growing demand for fine yarn in Britain.

Cotton's characteristics as a fiber differ from wool, flax, or silk. Artisans' traditional materials and methods to process cotton fundamentally shaped local skills.[95] Over centuries,

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[92] Raman, "Indian Cotton Textiles."

[93] Henson, *History of the Framework-Knitters*, 358–59.

[94] Henson, *History of the Framework-Knitters*, 358–59.

[95] Bertucci, "Spinners' Hands, Imperial Minds."

Indian spinners had honed the skill to spin fine yet strong cotton yarn within a very specific family and caste-based vertically integrated system of cloth production.[96] Arguments regarding training costs pale in significance compared to traditional skills developed over time and within entirely distinct socioeconomic contexts. Equally, relative British and Indian wages are irrelevant when the skill to achieve a set standard was nonexistent in one setting.[97]

Baines contended that using simple tools alongside an "acute and delicate" sense of touch, Indian spinners produced yarn that was much "finer and much more tenacious than any machine spun yarn in Europe."[98] Explaining the delayed development of European cotton manufacture, Baines noted, "Owing to the rudeness of the spinning machinery, fine yarn could not be spun, and of course fine goods could not be woven."[99] His claims present an inherent contradiction: simple tools sufficed for Indian spinners to spin fine cotton yarn but not for European spinners. This contradiction brings into sharp focus the issue of skill. Replacing Indian spinners' "acute and delicate" sense of touch, essentially their skill of spinning, with machinery provides the critical connection between Indian spinning technology and the motivation for mechanization in the nascent British cotton industry.

The issue of skill also underscores the motivation to develop Richard Roberts's self-acting mule. This mule was the first example of industry leaders commissioning a mechanical invention with the specific and stated aim of replacing labor, following widespread and determined strikes by unionized male mule spinners.[100] Prior to the development of Roberts's

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[96] Roy, "Knowledge and Divergence."

[97] Parthasarathi, "Rethinking Wages."

[98] Baines, *History of the Cotton Manufacture*, 68.

[99] Baines, *History of the Cotton Manufacture*, 102.

[100] Catling, *The Spinning Mule*, 63.

self-actor in 1825, spinning on Crompton's mule reportedly required great skill and care.[101] Despite its mechanized process of spinning yarn, the mule still required significant operator input in terms of attention and mechanical ability. Specifically, to build a good strong stable cop of spun yarn on the spindle for the backing-off process, the operator had to apply a combination of skills: physical strength and calibrating the speed of the retreating shaft in line with the speed of the yarn accumulating on the spindles.[102]

An analysis of the skill required to spin fine yarn compared with preexisting Indian and modified British technology leads to the "hand-mind connection" concept.[103] The feedback loop comprising the coordination between the spinner's hand and their brain's constant reaction to each hand movement for twisting yarn is central to the skill required for spinning. Both Indian and British fine-yarn spinners have been described as artisans, yet they applied very different skill sets and embodied knowledge for spinning yarn. Indian spinners, typically women, were skilled artisanal makers of cotton yarn, using basic tools and their hands and minds as integral components of the yarn production process. To manipulate yarn, the spinner's fingers registered an instant feedback signal in the brain pertaining to the nature and quality of the twist. The spinner was then able to calibrate every successive draft and twist action in line with this feedback. This method of intelligent spinning could produce any yarn count commissioned, as long as the spinner, through training and investment in countless hours of experience, had developed sufficient skills to manipulate the yarn in a tightly controlled environment: one hand moving the wheel, the other drafting, twisting, and winding on, engaging body and mind in a constant feedback loop. The higher the yarn count, the greater attention to detail required for each part of the process. Arguably, the skilled spinner could

[101] Catling, *The Spinning Mule*, 147–64.

[102] Marsden, *Cotton Spinning*, 224–25; Lazonick, "Industrial Relations and Technical Change."

[103] Roberts, "Workshops of the Hand and Mind."

allow their attention to wander when spinning coarser counts, or a less-skilled spinner could suffice for the lower counts; but attention and skills needed to be at their highest levels for the finest yarns.

In the British context, the artisan was commonly a male mule operator—a mechanic, as well as an assessor of yarn quality. The machine required periodic calibration in order to spin different counts. The spinner's knowledge and skill in setting up the machine to achieve this calibration was indispensable. In addition, the mule spinner's skill was required for successful backing off and winding the yarn into a cop. The actual spinning was done by the machine, and since the spinner was not using their hands to do the spinning, the constant feedback loop with the mind functioned differently. The spinner had to watch and assess the quality of the yarn being spun, look out for irregularities or broken parts, and at the same time be aware of the machine's mechanical operations. The large mule may have replaced the small spinning wheel, but the mule spinner still had to pay close attention to the spinning-process details. This attention had not yet moved into the overseer category, which only materialized with the arrival of the self-acting mule.

Conclusion

This paper has revised the history of technological change in the British cotton industry by analyzing the materials and skill at the heart of the debate – cotton textiles and the skill required to make them. It has connected the British cotton industry to its inspirational source, the Indian cotton industry, and in so doing, has shown the technological and material connectivity and points of departure that mark technological change. It has demonstrated that to fully understand the structural shift characterized by industrialization in the British cotton industry, it is essential to decipher the Indian and European roots of the technical knowledge enabling this shift. For the British cotton industry, technological change in spinning represents continuity with the traditional Indian jersey wheel technology of cotton spinning, albeit with significant adaptations to compensate for a skill deficit. Evidence reveals not only technology deeply rooted in the past, but also in the ways in which techniques functioned alongside human skills within two entirely distinct socio-economic contexts. Recognition of British spinners' lack of adequate spinning skills motivated the move to mechanization, in order to match the quality of cotton products created and perfected over centuries by anonymous and highly skilled Indian artisans.

The paper demonstrates the importance of material evidence alongside other mainstream sources commonly used for historical investigations. It refutes the long-held view of long-staple cotton's qualitative superiority over short-staple cotton and demonstrated that short-staple cotton produced the finest and most robust cotton textiles in tandem with highly skilled spinning adapted to short-staple cotton in India. This revision has thrown fresh light on the close connection between technique, materials and the artisanal skill. Product analysis shows that a combination of all three factors determines cloth quality, not the staple of cotton in isolation. Histories of labor, materials and techniques are, therefore, essential for a comprehensive understanding technological transfer and why technologies persist, alter or become obsolete. In the British cotton industry, while culturally, geographically and organizationally Britain's mechanization of cotton spinning appears distinct from India's traditional yarn production processes, it remained path dependent on preceding Indian and European techniques.

Alka Raman is Hallsworth Fellow at the University of Manchester's Department of History. She has a Ph.D. in economic history from the London School of Economics and is currently tracing the impact of Indian cotton textiles on industrialization in the British cotton industry. She would like to thank Tirthankar Roy, Joan Rosés, Linda Eaton, Beverly Lemire, Prasannan Parthasarathi, Liliane Hilaire-Pérez, John Styles, and referees.

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