The Precocious Mechanization of a Global History: English Cotton Textile Production from John Kay (1733) to Richard Roberts (1822)*

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> 'Dining in a public room, Cartwright became deeply interested in a conversation which was started on the subject of the remarkable inventions of Arkwright and others, and that the consequent extension of manufactures in the neighbourhood and throughout the country. It was urged, however, by one gentleman that Arkwright's cotton-spinning machinery was not an unmixed blessing, seeing that we should soon be making more yarn than our weaver could work up, with the result that it would have to be largely exported to the Continent, and might there be woven into cloth so cheaply as greatly to injure the English trade. At this point, Dr Cartwright ventured the remark that the only remedy for such evil would be to apply the power of machinery to the art of weaving as well as to that of spinning. The notion was set down as absurd; some Manchester gentlemen, who were presumed to have special knowledge of the subject, being more emphatic in its condemnation, contending that such a contrivance was impossible, on account of the variety and intricacy of the movements in weaving. Against this Cartwright instanced the automaton chess-player, a curiosity then attracting much attention, and argued that a skilful application of mechanism could surmount every difficulty. They were not convinced, but he was; and when he returned home he could think of nothing else. After much brooding, he bent all his energies to the task of constructing the model of a power-loom, working incessantly in his rough and awkward way for several months, but steadily improving step by step, until at last, in April 1785, he took out a patent for the first of all power-looms.'
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> Margaret Strickland, *A Memoir of the Life, Writings and Inventions of Edmund Cartwright* (ed. by K.G. Ponting, Bath: Adams and Dart, 1971, p.56

Cotton Textiles as a Global Industry

Current discussions about the chronology and origins of the 'Great Divergence' between Europe and Asia, as well as recent debates on the status of the First Industrial Revolution as a seminal episode or provincial in global economic history, return us to the contrasts across Eurasia that can be located either in histories of technology or histories of industries. For chapters of reconstructed metanarratives on differences between Europe and Asia there is a corpus of historical research on a leading global history and on the famous machines that

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transformed possibilities for the production of cotton textiles in England that might conceivably help to clarify and settle parts of the argument.

By the time of the Great Exhibition of 1851, a predictable sequence of improvements to classic inventions that emerged between 1733 to 1822 had led to: relocation of the cotton textile production from east to west, to an extraordinary acceleration in the growth of its output and to pronounced declines in the costs of producing first cotton and thereafter woollen, linen, silk and many other mixed varieties of yarn and cloth. The story of the precocious transformation of England's cotton textile industry (endlessly told since the reign of Queen Victoria) has never been satisfactorily concluded, because both economists and historians lack a theory of technological progress that might explain this first and paradigm case of mechanization.

Meanwhile, and on all the indicators that have been reconstructed to measure the pace and pattern of British economic growth between 1688 and 1851, the First Industrial Revolution turns out to have been a much slower and less dramatic discontinuity than traditional interpretations suggested. Indeed some historians have dismissed it as a misnamed episode in economic and technological history. That seems premature because even the discontinuities at the macro-economic level are still dramatic enough to merit the adjective 'revolutionary'. Nevertheless, the reconstituted data now available to measure the pace of economic change for Britain as a whole (i.e. growth rates in real per capita income, industrial output per head, and in the productivity of labour employed in manufacturing and agriculture) does suggest that the First Industrial Revolution (as a widely diffused national event) did not come on stream until well into the nineteenth century, which is several decades later than canonical social science and Ashton's classic text suggested, or as Deane and Cole's (Kuznetian) attempts at quantification claimed.

Furthermore, this “restored interpretation” insists that where and when productivity improvements occurred, they tended to be located in just a few sectors of the island’s economy. For example, within manufacturing productivity growth which emanated from breakthroughs in technology were apparently confined, before the second quarter of the nineteenth century, to basic metallurgy, to textiles and above all to cotton yarns and fabrics. As late as the 1830s, the on going mechanization of cotton production and the concentration of all the processes involved in the preparation, spinning, weaving and finishing of cotton cloth into steam powered factories, located in towns, still represented an example for other industries (even for other textile industries) to emulate. In this sense, the First Industrial Revolution has been reconfigured as an example of ‘unbalanced growth’.

In many ways that “new” interpretation of the First Industrial Revolution reads like a very old story in which textiles in general, and cotton in particular had been represented as cases of precocious mechanization. Of course, the reconfiguration has been contested, especially by historians, whose research on regions, proto-industrialization and transformations in the organization of numerous traditional handicraft techniques and processes leads them to construct narratives dominated by more rapid and broadly based sequences of improvements to industrial technologies and product innovation. Debate continues, but for purposes of this essay, the ‘cliometric painting’ of the Industrial Revolution (together with the unsatisfying attempts of economic theory to ‘endogenize’ explanations for technological breakthroughs) provides a justification for focusing again on cotton textiles and for re-examining that famous sequence of machines, processes and improvements that emerged on the Island between the times of John Kay and Richard Roberts. So many of the pre-conditions posited for modern economic growth were established within the cotton industry. They were so concentrated within a period of six or seven decades in the eighteenth century, that productivity growth in the manufacture of consumer goods that subsequently became pervasive during the Regency and Victorian periods, can now be analysed as the elaboration of engineering, chemical and kinetic knowledge brought to maturity much earlier, albeit within the confines of a single industry that was global before it was mechanized to become the exemplary case and Britain's leading manufacturing industry.

Writing about cottons in 1835, Edward Baines recalled "that all those inventions have been made within the last seventy years" and proclaimed, "that the cotton mill presents the most striking example of the dominion of human science over the power of nature of which modern times can boast." If historians and economists could offer some kind of general explanation for the inventions and improvements that transformed the manufacture of cotton cloth over the century, following the appearance of Kay's Flying Shuttle in 1733, then they might be en route to communicating some understanding of a "prime mover" behind British and European industrialization and (to be ambitious) offer insights into the industrial origins of the 'Great Divergence' between West and East which emerged rather late in the 18th century and became stark by 1914.

The Destruction of Three Familiar Theories of Technological Change

Innovations in cotton textiles comprehend all new techniques introduced to manufacture an imported organic material (cotton fibres) into finished (i.e. bleached, dyed and printed) cloth. Between 1733 and 1822 the list of innovations that became available to effect that transformation was long. Only a fraction of technological improvements introduced into the cotton textile industry over that century is now recoverable from sources which include: patent specifications, published accounts of the famous machines, industrial and business histories, records of the Society of Arts and other public institutions. Countless other adaptations were adopted by firms that are now lost to historians seeking to reconstruct the entire flow of technological knowledge, applied through time. Nevertheless, familiar taxonomies have been imposed on surviving data to divide 'product' from 'process' innovations and, with more difficulty to differentiate 'macro inventions' from 'improvements' concerned to modify machines or chemical processes, in order to bring them into efficient day-to-day use.

As we study the sequence of major inventions and the full range of adaptations, which ultimately revolutionized four separable processes involved in the manufacture of cotton textiles, we observe that they appeared haphazardly over a century of time. By the time Baines wrote his eulogy, the production of cotton cloth had been revolutionized from a handicraft proto-manufacture (using some crude machinery, powered by muscles, water and animals) into a mechanized, steam-driven, factory-based, urban industry. Over millennia of global history, since craftsmen and women had been engaged in making cloth from organic fibres, the uplift in productivity occurred in so short a span of time, the rate of transformation within and across all stages of production became so rapid, the original locus so geographically contained in one kingdom and its initial applications so concentrated upon a single fabric, that the 'British revolution in cotton textiles' continues to recognized as a seminal episode in the global history of technology.

But can we explain the revolution within a general communicable and satisfying narrative? Only this paper will insist, firstly be an elaboration of the geopolitical and political context within which the industry shifted from east to west and became mechanized initially in Britain; secondly, by way of tightly focused historical research upon the machines and the men who 'conceived', 'assembled' and 'developed' them and thirdly, by an obdurate refusal to incorporate the transformation of this industry within theories of technological change which posit that its mechanization and reorganization depended either upon the growth of consumer demand, or inelastic supplies of labour, or upon sequences of challenge and response. Since all three theories pervade the literature I propose to begin by deconstructing them as underspecified and as lacking empirical foundations.

The Rise of Material Culture

Demand-led explanations for technological innovation has continued to flourish long after Rosenberg analysed their inconsistencies and listed the empirical evidence required for their validation. Surely the existence of a desire for knowledge that will generate cheaper, more saleable or higher quality products was something approximating to a constant for centuries of Eurasian history? Alternatively, if (as the growth of consumer demand thesis implicitly posits) some intensification of pressures to spend occurred prior to the technological breakthroughs of the 18th century, are social historians not required to demonstrate that the propensity to buy cottons rose perceptibly through time or somehow became stronger in some countries, regions or markets compared to others? Responding to that challenge, more than a decade ago cultural historians developed a general thesis about "the rise of material culture", and made the valid point that there is more to consumption than incomes and prices. Economic growth required households who were not only able but became "willing" to consume more of the "superfluities" of the day, to diversity their diets, to admit novelties to their homes, to fashion their attire, to emulate the consumption patterns of their betters, to maintain expenditure in the face of adverse fluctuations in real incomes and even to convert leisure into industrious work in order to find the were-with-all to consume more goods. Most Anglo-American historians are disposed to English exceptionalism, but some of us are not convinced that the rise of material culture came conveniently on stream shortly after the Restoration or that radical shifts in consumer behaviour (even if that could be dated) can be represented as quintessentially English or Protestant or even Dutch. Furthermore, the period selected for a "reordering of consumer culture" on the Island which falls (unsurprisingly like much else in Tory historiography after a deplored Republican Interregnum) coincides (alas inconveniently for any testable version of the thesis) with several supply side forces; including higher rates of net investment in transportation and distribution networks, a really marked uplift in expenditures by the state on naval power for the protection of oceanic commerce and an upswing in agricultural productivity, which came on stream around the same time, and thereby also operated as separable "supply side" components of an explanation for the integration and widening of markets for British manufactures.

More nuanced versions of demand-led theories of technological progress that depend more upon changes in tastes, desires and fashions initiated by consumers as their own collective and widespread response to an influx of imported cottons largely from India are heuristic to contemplate. Nevertheless, the creation widening deepening as well as the protection of the kingdom's domestic and imperial markets for cotton textiles by the Navy must also be included as part of any explanation for the shift of cotton textile production from east to west.

Producers certainly recognizeded the tensile strengths, lengths and other properties of cotton fibres (for purposes of carding, roving, spinning and weaving) as favourable compared with other natural fibres. Merchants and finishers of cotton cloth recognized that it absorbed and retained colours and prints more effectively than silks, woollens and linens. Cottons could be adapted to a greater variety of uses, conditions and climates than cloths made from other natural fibres.

Although cottons had been available in Europe for centuries, for reasons that are still not clear, Western consumers came to appreciate and learn more about the qualities and properties of cottons over the second half of the 17th century when the pace of substitution for other fabrics accelerated and demand curves shifted to the right. Demonstration, bandwagon and fashion effects certainly flowed from the increasing volume of imports flowing in from the East that shifted the volume of cotton consumption up to levels where incentives became strong enough to promote a familiar process of import substitution. Thereafter, domestic production of cloths embodying mixtures of cotton and other yarns attained scales and levels of know-how that created conditions for mechanization. But how far some initial and autonomous a shift in tastes, for novelties, fashion goods and luxuries associated with cottons (without protection from Indian imports and their mechanization) might have carried the production of English cotton textiles is not seriously addressed by historians emphasizing separable and significant roles for the appeal of exaction from the Orient and for consumers during the early stages of the industrial revolution. Baines acknowledged the steam powered mechanized cotton mills of his day (1835) as the dominion of human science and technology over nature and shifts in the traditional view that the supply curve mattered far more than shifts in demand for the sustained rise of the English cotton textile industry, has been qualified, but not seriously undermined by recent histories of the rise of material culture.

Labour Saving Machinery

Shortages of labour may warrant greater weight in narratives about the rise of the cotton textile industry. Businessmen had complained for decades before the emergence of Kay's labour saving machine for weaving in 1735 about the high levels of wages paid to English, compared to Irish, French and other workforces. Still incomplete, programmes of research on wage rates paid to builders, labourers and craftsmen (measured in grams of silver per day) suggest that wages were discernibly higher in London than other large cities on the mainland and across Eurasia. Furthermore, and since the mid-seventeenth century they had risen sharply relative to price indices for capital goods (wood, iron, nonferrous metals and bricks).

Higher wages and cheaper energy (coal) seem to have been outstanding features of the British economy from the late 17ht century onwards. Nevertheless there is no statistical evidence that supplies of industrial labour for textile production in Northern England became increasingly inelastic between the times of Kay and Roberts. On the contrary, the anxieties of Anglican clergymen, parish officials and the writings of many mercantilists confront problems of unemployment among the poor. After mid-century when population growth accelerated and food prices began their upward climb, the supply curve for "hands" presumably became more elastic as women, children, Celts and other migrants moved in ever larger numbers onto industrial and urban labour markets. We know almost nothing about the supply curves or wage rates for specific categories of labour employed in the manufacture of textiles.

Challenge and Response

The ever popular Challenge and Response Model (repeated in countless books, lectures and undergraduate essays, since it was mentioned in a memoir about Edmund Cartwright (1859), suggested in a biography of Samuel Crompton (1859) and elaborated by Thomas Ellison's book, *The Cotton Trade of Great Britain* (1886)), draws ultimately upon standard early nineteenth century histories of the cotton industry by Guest (1823), Baines (1835) and Ure (1836). Ellison's book includes a brief overview of technological progress, which differs, however, from earlier accounts by making explicit links between the advent of the shuttle and the challenge posed to and solved by mechanical engineers who confronted a subsequent sequence of imbalances in production processes. Ellison asserts that the "imbalance between hand spinning and hand weaving worsened significantly after the invention of the Fly Shuttle … a contrivance which enables the weaver to turn out twice as much cloth as before in a given space of time", and he cites Guest's *Compendius History of the Cotton Manufacture* (1823) in support of his claim.

Ellison's book exemplifies a tradition of explanation for the sequence and timing of innovation across all four major processes in the production of cotton cloth. His "model" implicitly posits that the diffusion of a new technique by affecting one stage of production sets up pressures for responses (either down or upstream) to deal with intensified demands for inputs or (as the familiar story about Cartwright's invention of the power loom shows) with increased incentives to utilise cheaper supplies of intermediate outputs.

Ellison's original account of a sequence of technological progress ends with Cartwright's loom, but begins and becomes linear with Kay's Shuttle. His narrative, repeated in coutless textbooks, as been "emplotted" to persuade us that the Shuttle intensified demands from weavers for yarns, satisfied after a lag of more than three decades by means of machinery invented by Hargreaves, Arkwright and Crompton. Their inventions then produced a surfeit of yarn, which prompted a search for powered looms, "solved" in engineering terms by Edmund Cartwright in 1785 and "resolved" commercially (after a protracted period of learning and development extended over several decades) by Roberts in 1822, who sized the warp and placed the loom in an iron frame.

Yet for Ellison's model to work as a progression of technical challenges and successful responses, the narrative should logically proceed from an initial state and on through several subsequent sequences of disequilibrium. Furthermore, changes in the scale of material inducements required to initiate a serious search for new technologies need to be specified if the story is to remain credible. No assurances can be provided that the Shuttle (which was virtually confined in its initial applications to bays and only after further development increased the productivity of weavers of broadcloth, by 30% and weavers of narrower and fancy cloths, by between 10% and 17%) could have launched the powerful sequence posited by simplistic versions of the story. For years the Shuttle's competitive advantages seem to have resided more in its capacity to upgrade the smoothness and quality of narrow cloth, rather than in labour saving properties that could have led to anything like a doubling in industry-wide demands for yarn. Kay's loom did not, moreover, appear in the cotton industry much before mid-century and its diffusion around that time coincided with the development and production of high quality cotton velvets and velveteens prominent among rising exports for Guinea and which substituted for light cotton fabrics previously supplied for the African trade by Indian producers.

Apart from the familiar problem of long and unexplained lags, patents and other data provide no statistical support for the idea that the search for innovations shifted systematically in any clear direction following the invention and introduction of the Flying Shuttle. On the contrary, arithmetic shows that the proportion of recorded innovations which can be classified as designed to raise the productivity of labour engaged in the preparation of fibres and the spinning of yarn for weaving declined from (an unweighted) 46% of the total before the appearance of Kay's Wheeled Flying Shuttle, 1720-33, to 23% between 1734-53. Furthermore, and just three years before patenting his Shuttle, Kay developed a machine to spin and dress worsted thread, suggesting a desire on his part to address mechanical problems in general rather than any perceptions of profitable opportunities arising from any widely perceived need to relieve bottlenecks in weaving.

Even sophisticated manipulators of statistical techniques would be hard put to manufacture convincing representations drawn from admittedly imperfect data sets (which includes registered patents and submissions to the Society of Arts) for "systematic clustering" denoting the sort of patterns of search and success in inventive activity posited by conceivable version of a challenge and response model. Data sets for textile innovation display no discernible tendencies to "cluster" around preparatory processes following the invention and diffusion of major breakthroughs in weaving. Nor is there evidence for the concentration upon manufacturing processes (concerned either with the weaving or the finishing of cloth) over the years that succeeded the diffusion of spinning jenny, water frame and mule.

To construct any kind of "pattern" embodying pretensions to be statistical from the sources, historians of technological change cannot avoid reading the detail contained in patent specifications. On inspection there is some tendency for innovations to appear prima facie as improvements to, or substitutes for, macro inventions. For example, several minor adaptations to the Shuttle appeared in the 1740s, while a seemingly concerted surge of innovations for the manufacture of yarn followed hard upon Arkwright's all inclusive carding and spinning patent of 1775. Over the next four years 15 spinning machines appeared, of which eight were patented. In the late 1770s Samuel Crompton developed the Mule in order to deal with the problems he encountered in producing yarn of the requisite quality, either on a spinning jenny or by rollers. This stimulus also followed from the registration of Edmund Cartwright's designs for prototype power looms. Within a decade 16 "improvements" to his machinery appeared and eight of them were patented. Opportunities for profit presented by the emergence into an industrial domain of machines that worked in engineering terms prompted the search for further improvements and/or stimulated the development of differentiated technologies in order to undermine a patentee's monopoly rights, seem to have been more powerful inducements to innovation than perceived shortages of inputs or surpluses of outputs.

Political and Geopolitical Contexts for the Mechanization of English Cotton Textile Production

Theories purporting to explain the rise of English cotton textile production are not merely too parsimonious to account for the complexity of the process, but are usually devoid of references to the political and geopolitical contexts within which the mechanization and reorganization of the industry occurred.

Unless the appearance and diffusion of machinery and factories could just as easily have emerged on a spectrum of European locations then there must have been some distinctive features of the Island's economy, politics and culture – that made England a "more likely" site for innovations in cotton textiles between the Treaties of Utrecht (1713) and Vienna (1815) than, say, Holland, France, Saxony, Spain, Switzerland and (as postcolonial research has latterly made us aware) of several proto-industrial regions in India, China and Japan as well. Indeed no less than five potential contrasts between Britain and other regional candidates can be elaborated to suggest why the location and timing for the technological breakthroughs that occurred in English industry between 1733-1882 cannot be represented as merely random.

Firstly, both the scale and scope of textile production located within the realm was already relatively large by the late seventeenth century and the industry continued to expand and diversify its output over the following century. By 1660 Britain and Ireland manufactured most the entire range and qualities of textiles: woollens, linens, silks, cottons and an astonishing variety of mixed yarns and cloths, including fustians.

Secondly, by the time of Kay the English workforce may have embodied a higher proportion of relevant skills and knowledge in metallurgy, carpentry, precision engineering, tool making, machine design, etc., than workforces elsewhere on the European mainland (or in East Asia). Josiah Tucker thought so and asserted 'we may aver with some confidence that … parts of England … exhibit a specimen of practical mechanics scarce to be paralleled in any part of the world.' How, when and why the English economy accumulated the human capital required to make and sustain improvements in mechanical engineering is still not understood either in theoretical or historical terms. An investigation into a sample of traceable names who registered patents to process inventions or for differentiated products for the British textile industry between 1688-1851 does not suggest, however, that this significant segment of the country's skilled workforce can be represented as a distinctive human resource, separable from the population at large. Names of traceable patentees claiming and paying for legal protection for property rights to innovations for the textile sector do not emerge as a sub-group in terms of their social status, education, residence, religion, politics or linkages to networks for the exchange of scientific and technological information. Although available samples of names who could be represented as innovative are small and their description is no substitute for prosopographical analysis, they seem, nevertheless, to be a rather predicable cross-section of the kingdom's urban population.

Three other political histories behind the rise of cotton textile production within England can be connected to the commercial, colonial and mercantilist policies pursued by the state. Firstly, there is the rather particular (but in outcome functional) reaction of a mercantilist government and parliament to the threat posed to the country's indigenous textile industries from the rapid penetration of the home market by cheaply made and highly desirable cotton cloth imported from India and China between 1660 and 1721. In contrast to the reactions of other European governments, tariffs and other barriers erected to protect woollen, silk and linen industries emerged slowly in England and then evolved into a "functional" framework of legislation that allowed for the expansion of a long established fustian industry out of which the indigenous manufacture of pure cotton textiles eventually emerged. Fustian consisted of a mixed fabric woven from cotton wefts (made in Lancashire)and linen warps (imported from Ireland) and provided an unacceptable substitute for Indian cottons. After the Glorious Revolution and pacification of Ireland. William III and his ministers formulated to contain resentment in England's rebellious Catholic province that included subsidies and other incentives for the Irish linen industry, which they hoped would provide employment for dispossessed peasants and might placate Irish merchants and manufacturers after parliament had passed discriminatory legislation in 1697 to close England's home and imperial markets to Irish made woollen yarns and cloth. Internal colonization worked and for several decades Ireland's cheap labour grew and processed flax and spun warps of linen yarn which they exported to Lancashire to be manufactured into fustian cloth. Eventually inelasticities in imported linen yarn supplies and instabilities in delivery (occasioned by privateering and warfare on the Irish Sea, 1740-48 and 1756-63) gave rise to expectations within the English fustian industry that more secure and profitable opportunities might be realised from the weaving and finishing of cloth made from warps and wefts of cotton yarn spun entirely within Lancashire.

Such expectations could only have been heightened by the extension of cotton cultivation first to British (and captured French) colonies in the West Indies and late on for former Southern colonies on the mainland of the American South that occurred when French competition on European markets for sugar intensified (following the exploitation of fertile plantations on Haiti) which provided the push required to diversity production and Britain's exports from the Caribbean into cotton fibres. Any food or industrial crop that could be grown cheaply on tropical soils in the American colonies (utilising the coerced labour of African slaves) promised profits from investment in plantations, in trade and shipping and from the manufacture of cheaper and desirable cotton textiles. With massive assistance from the Royal Navy Britain moved into a position of leadership among European powers to exploit the commercial and economic potential of the growing Atlantic economy by realizing the opportunity to integrate its domestic cotton textile industry into a network of imperial trade that included multilateral exchanges of British cotton cloth, African slaves and American foodstuffs, shipping and cotton fibres.

From Historical Backgrounds to Necessary and Sufficient Conditions

From Context to Agency

Protected by an effective and well funded Royal Navy, the mercantilist strategy and division of labour between the metropole, the Americas and Africa, realized gains from trade for the British economy and rapidly growing fustian-cum-cotton textile industry that were not available to its competitors on the mainland. England's long tradition of manufacturing a diverse range of textiles especially woollens and worsted, together with the states increasing aggressive support for mercantilism and colonialism helps to explain why an embryo or proto-cotton textile industry in England had by 1733 climbed to a "plateau of possibilities" from where breakthroughs in technology might (at least with hindsight) be regarded as probable.

Alas, any elaboration of context (even when details about the prior accumulation of domestic skills and capital for the manufacture of textiles, as well as the European, Asian, American and African connexions are filled in) could only be represented as necessary, but never as a necessary and sufficient explanation for the technological breakthroughs that occurred in the manufacture of cotton textiles between the times of Kay and Roberts. That is the case, because all macro inventions are conceived and constructed by particular people at given moments of time. Unless and until the fundamental breakthroughs that occurred in technologies and techniques for the manufacture of textiles (or indeed any other innovations for this era of pre-modern economic growth) can be convincingly analysed as a transformation of context into content, historians of technology have nowhere to go, but back to biography. Famous names (macro inventors) have long been associated with macro inventions. Unless we believe with the cynical Dean Inge that "innovation is undiscovered plagiarism" that association must first be verified. Then the argument could move on to reconnect the lives and the work of England's great textile inventors to the specific contexts in which they operated.

The Definition of Macro Inventions

Early in the twentieth century Mantoux and his generation of economic historians recognised that some artefacts, technical designs and machines must be regarded as more important for the long run transformation of the textile industry than others. They wrote about machines in ways that modern engineers would recognise as discontinuities or leaps forward. In his book, *What Engineers Know*, Vincenti has defined "Normal Engineering" as an evolutionary, predictable stream of improvements in contrast to radically new devices that represent "voyages into unknown and unfamiliar conceptual space and mechanical design".

More recently Mokyr relabelled the latter as "macro inventions". His apposite term has been contested by the "imperialist" thrust of modern economics which attempts to explain early modern industrialization within a corpus of anachronistic theory and restrictive data sets which are dominated by variations in factor prices and little else. Mokyr's label is, however, a useful reminder that prototype models provided "foundations" for a stream of future technical advances. At least for the eighteenth century, the diffusion of knowledge in the form of machines as functioning models set new technical parameters, posed and focused questions, promoted and placed the search for improvements upon more steeply inclined trajectories. If and when unpredicted knowledge in the excitable form of working models emerged within the right spaces and social networks, it represented a challenge and stimulus to local communities of businessmen, technologists and other experts concerned with similar problems and opportunities. They recognised when prospects had changed and when the time had come for developing, interpreting and testing a new design in order to make it routinely functional and commercially viable.

If historians could "call up" long runs of engineering data or view comprehensive collections of textile machinery in museums of industrial archaeology they too might recognise and date the appearance of macro inventions by citing particular techniques or machines that, in short, compass transformed the "technical potential" for the performance of specific actions and manufacturing processes. Statistical information of this kind could underpin a quantified history of technology by locating discontinuities in labour productivity, and it would allow us to grasp and graph the familiar sequence of stages from invention through development to diffusion. For example, Cartwright's crude model of the first power loom constructed in 1784, transformed prospects for automating or mechanising the operations and judgements performed by handloom weavers. If we possessed relevant data we could graph productivity ratios for decades of time after 1784 in the form of square yards of fustian, woollen or cotton cloth, woven per man hour on a power loom improving through time compared to the productivity of a skilled adult male weaver utilising the state-of-the-art handloom, embodying Kay's Shuttle and his son's drop box at work between 1750-84. Unfortunately, available estimates of labour productivity for weaving cloth are entirely limited. Any graphs that could be drawn could be nothing more than a "synopia" – outlines of the kind of pictures economic historians would be pleased to draw if (when?) they possessed productivity data machine by machine for long spans of time. Meanwhile, visualizing such graphs as "virtual realities" simply helps to make notions of a macro invention and their converse, a micro invention more pictorial.

The Validation and Significance of Macro Inventions

Although macro inventions for the eighteenth century cannot be isolated with reference to statistical data, or reconstructed as machines, historians should continue to pay close attention to the definitions of engineers who insist that any macro invention selected as the prototype model either addressed a significant, but hitherto unperceived, problem or, more commonly, can be accepted as a potentially efficient answer to a problem that had eluded solution before the appearance of a particular design (and a designer) as a candidate for the inclusion in a Pantheon of macro inventions and macro inventors. Thus, historians are required to demonstrate not only that the cotton textile machinery associated with the names of John Kay, Louis Paul, James Hargreaves, Richard Arkwright, Samuel Crompton, Edmund Cartwright and Richard Roberts can be represented as macro inventions in some or all of the senses demanded by engineers, but that their initial design and supervised construction can legitimately be imputed to these named inventors. Two assumptions are implicit in that requirement. First that the Shuttle, the First Roller Spinning Machine, the Jenny, the Water Frame, the Mule and the Power Loom were not purloined from other inventors with superior claim to property rights in their design and construction. In other words, that sources can be adduced to validate connexions between the inventions and their inventors. Secondly, that the machines were recognised particularly at the time and since to be more than mere modifications to extant models and techniques for combing, carding, spinning, weaving, finishing etc.

Validation remains problematical in the history of technology and the most dubious sources can often be an inventor's own claims, which may be little more than well composed examples of "self-fashioning". That seems to be the case for Richard Arkwright, but not – I am prepared to argue on the basis of an extensive trawl through an insufficient and imperfect body of primary and secondary sources, of rather equally famous, but for economically less successful inventors who appear in histories of English cotton textiles.

There will be no need for present purposes to go through all the problems of validation surrounding the Flying Shuttle invented by John Kay, James Hargreaves' Spinning Jenny and Samuel Crompton's Mule. Edmund Cartwright's power loom and with the exception of roller spinning, connexions between the these celebrated inventors and their inventions are not in serious dispute. What is less clear (and not measurable) is either the magnitude of gains in productivity imputable to particular machines or the nature and slope of the trajectories for improvements and future development that their prototype working models initiated. For example, Kay's Shuttle (even in the form of the version improved by his son) did not allow for a doubling in labour productivity among handloom weavers, as claimed by some historians of technology. Paul's conception of roller spinning was realized mechanically and pushed slowly forward to the stage of commercial viability by several artisans and by that indefatigable projector Richard Arkwright. Roller spinning powered by water diffused rapidly and jacked up the productivity of labour employed in the production of yarn by a multiplier that was much greater than the seven or eight fold increases achieved by Hargreaves' jenny. Within three decades, most of the innovatory ideas embodied in both machines had been reassembled and recombined and above all supplemented by the moving carriage included as components of the Mule. Thereafter Crompton's Mule provided the model for a century long process of improvement and development, including self-acting devices added by Roberts in 1825. Since validation and significance are probably not serious issues for these spinning and weaving machines the narrative can now move on to consider the biographies of their inventors.

Biographical Narratives and Macro Inventors

Biography, Psychology and Theories of the Individual

Discovery (invention) remains as the single most important but least understood of all the "causes" elaborated in the now voluminous historiography of the first industrial revolution and histories of technological progress. It remains as a final, but perhaps impassable, frontier for modern economic history. My proposition is that an entirely traditional genre, biographical narratives may, after all this time, still have something serious to contribute to the discussion and perhaps to the formulation of theory. Once contextual (necessary) conditions are in place for the probable emergence of new technologies for a well-defined industry, some threshold scale and scope operating in circumscribed locations and evolving over time, then biographical narratives may well be the only discourse left to scholars who wish to reinstate macro inventions and human agency into the story of any British, European, Asian or global industry.

For historians of the fine and decorative arts, music, theatre, architecture, science and business (let alone for political and military historians) a recommendation to treat biographical narratives as heuristic needs much less initial persuasion than it does for economists, economic and social historians and for historians of technology. That arises because these four academic tribes deal with group rather than personal behaviour and because their educated predilections are to absorb individuals into a corpus of economic, psychological and sociological theory which has developed for more than a century now in reaction to Victorian and early styles of explanation cast in transcendental terms. They (use) continue to react with antipathy to quasi-biblical texts, such as Samuel Smiles, *Lives of the Engineers*, which resounds with "sagacity, foresight, obsessive curiosity, triumphs against adversity and above all the ascription of divinely ordained genius". His engineers appear to be secular saints, dedicating their lives for little reward to the glories of mechanical progress.

Nobody suggests a return to that kind of moral uplifting lives of the great and good. Although we will observe that our Victorian forebears sensed that an appreciation of creativity required a dense description of an inventor's life and its "meaning". They wrote about technological discovery with society and economy too far in the background. We have now become equally guilty of pretending to offer rounded explanations for the primus mobile of British economic growth in its golden age with particular "inventors" (and "entrepreneurs") off the page and out of the frame. Macro inventions must, by definition, be associated with macro inventors and their patrons.

Even when they resort reluctantly to this essentially literary genre, social scientists derive confidence from deploying theory (mainly from psychology) as well as a sense of security from rhetorically persuasive vocabularies that replicate: evolutionary metaphors from biology; deploy taxonomic distinctions between macro and micro areas of economics and parade notions of "conceptual spaces", derived from post modern geography. Imported vocabularies can be memorable, but it is not clear that these taxonomies have added much to the search for explanations of technological progress. For example, "macro" may be little more than a Schumpetarian term for technology that embodied potential for increasing returns to scale, scope and further technological spinoffs. Spatial metaphors are often arresting, but are they anything more than metaphors? Biology provides an irresistible language for historians (and increasingly for evolutionary economists) inclined (as many are) to emphasise the gradual and adaptable nature of change. There are analogues in technological history to adaptations, mutations and new species. But are they compelling? When man needed to travel faster he did not "evolve" a pair of legs like Linford Christie's, but developed the automobile. When he aspired to fly he did not wait to grow feathers on his arms, but produced knowledge that led towards the construction of aeroplanes.

Experimental psychology offers theories designed to elucidate the cognitive processes of people labelled as creative that are ostensibly based on bodies of hard scientific evidence. Alas, historians of the eighteenth century textile industry will not be able to subject the cognitive process of inventors they select for investigation to tests of any kind. Only rarely will surviving documentation allow them to probe into the psyche of dead individuals in search of evidence about their mental capacities and propensities for engagement with creative, pathological or any other kind of remarkable activity.

Psychologists have also collated substantial quantities of biographical evidence in order to "classify" and conceptualize the personalities of artists, musicians, scientists, politicians, soldiers, inventors and others recognised post hoc as creative. This now voluminous body of psychometric literature depicts exceptional individuals as intrinsically motivated, self-confident, obsessive, undaunted by prospective or actual failure, curious across a range of knowledge, possessed of zeal, perseverance and a visual imagination and manipulative and exploitative of those close to them. Historians in touch with sources usually find some documents which could allow them to expose several of these traits as they appeared in the behaviour and/or the pronouncements of inventors of textile machinery. Alas, the evidence also reveals other equally prominent features of their personalities and even more serious problems continue to undermine the application of psychology to the history of technology. For example, innate traits of character did not find extraordinary expression in Crompton's talents as a violinist, in Cartwright's dreadful poetry, or in Kay's business acumen. Historically, famous personalities might occasionally be "unpacked", but as Howard Gruber has observed, there is no reason to think that: 'creative people are alike in those respects that lead us to label them as creative. What is evident about each one is the uniqueness of his or her achievement.'

Psychometric definitions of personal qualities associated with creativity has failed, moreover, to consider modern analogies that undermine its ambitious statistical attempts to supply general theories that might help us with the problem of invention. For example, athletic abilities are more widely distributed than the precise prowess required to become a star performer at any particular sport. Furthermore, historians find it impossible to discover whether or not the rather elastic characteristics of personality, quantified by psychometrics from evidence derived from samples of historically creative individuals, were not also present in larger groups samples among the population at large – or (what is more to the point) among equally valid samples of people at work at the same time on similar problems within an inventor's own sphere of interest. They will also recall that "myths" usually emerge to surround individuals celebrated as creative. For lives of the great, the evidence for imputed and presumably genetically transmitted traits of personality was usually "discovered" or "made-up" by their Victorian biographers after and not before their creative acts had been celebrated as remarkable.

Finally, and unlike tedious politicians or many canonical figures from literature and the arts, technologists rarely leave diaries or collections of intimate letters. This means that the now diminishing minority of historians inclined to use Freudian categories of analysis cannot draw upon any kind of internal soliloquies to expose anything much about their psyches. My own attempt to probe into Cartwright's personality by deconstructing his considerable body of verse failed, because he wrote in classical idioms of the day which tell us as much about the inner compulsions of eighteenth century poets as their frescoes do about the artists of ancient Egypt. Although psychologists do suggest that creative thoughts often occur to minds that move easily through topographies of images and ideas. There might have been something out of the ordinary in Edmund's genes because three of the four Cartwright boys pursued "callings" that can be portrayed as deviant, eccentric or anything but safe for sons of a

Nottinghamshire landowner and High Sheriff of that county to pursue. Edmund's brother, John, the Radical Major, devoted his long political life to the cause of universal suffrage at politically and unpropitious times in the history of an aristocratic state responding repressively to revolutions in America and France. George went off for years of exploration in the dangerous wastes and climes of Labrador. At the age of forty –one Edmund left the comfort of the Anglican Church to spend the rest of his life engaged in mechanical engineering and science.

Family and Social Networks for the Invention and Development of Machines

Metaphors, Freudian probes and psychological taxonomies are unlikely to add much to Victorian lives of England's famous inventors. Contextualised biography that includes an in depth investigation into those cultural, social and economic "spaces", "inhabited" and "exploited" by Kay, Paul, Hargreaves, Crompton, Cartwright and Roberts, up to and during their years of creative activity seem more enlightening to contemplate. When anthropologists define such "spaces" as "cultures" they refer to social networks and personal frames of reference and awareness within which inventors operated as they passed through their life cycles. Biographers can reconstruct micro cultures to <u>expose</u> contexts for opportunities and obstacles, encouragement and restraint; praise and obloquy; risk and caution playing upon men with the relevant skills and which conditioned their responses to prospects to invest emotion, energy, time and money in the pursuit of new solutions to mechanical problems confronting the English textile and other industries. Cultures cannot account entirely for the sequence of macro inventions and macro inventors that transformed cotton textile production in England, but presented and emplotted within a biographical format, they allow us to configure narratives of <u>how it came to pass</u> that John Kay, Samuel Crompton and others mobilised inner, financial and other social resources required to produce prototype machines of lasting significance for the development of that paradigm global industry.

Historical biography does not, moreover, eschew narrative and chronology because those literary devices can make recondite research readable, coherent, and persuasive. Narratives can be designed to move almost in linear fashion to a "point of closure" – which for the history of technology will be the appearance of a process, artefact or machine recognised as macro. Along the way, the form will allow historians to research into the life of an inventor in order to reveal how a potentially creative personality" interacted with his family and friends, with society, the economy, politics, the dominant ideology of his times and the locations and networks in which he happened to be born and placed. Such an approach might, in Gruber's words, "grasp the individual without disregarding the social nature of every human being". Dr Johnson, who recognised that the biographical form provided a way of reflecting upon the resources and constraints surrounding the activities of remarkable individuals, advised us to "keep an eye out not for trivia but for the significance of the trivial". Biographies of inventors could, if the evidence permits, be emplotted in order to gather, organise and synthesise random detail into a "configured story" which might help us to deepen explanations and to bring back agency into explanations for such significant outcomes as technological progress in the English cotton textile industry.

Although secondary and primary sources make it possible to weave and juxtapose a disappointing range of relevant detail (some more or less verified and some circumstantial and contestable) into a dense but disciplined representation of just six macro inventors, the expectation that their combined story could (together with the structural and political contexts outlined above) add up to a satisfying account for macro invention in the English cotton industry may not as the following narrative clarifies, take us to a conclusive story of how their inventions transformed the English cotton textile industry – but at least it restores agency to the story.

Turning first to social origins: with the possible exception of James Hargreaves, none of these "remarkable" men came from families at the low end of status and income scales. John Kay of Bury was the youngest son of a prosperous yeoman, who inherited £40 from his grandmother. Louis Paul's father, a Huguenot, carried on a business as a druggist in St Paul's Churchyard, worked as a schoolmaster and acted as a tutor to the future Earl of Shaftesbury and his brother. James Hargreaves, born in Blackburn, had but a single sibling (a younger sister). His parents could not be depicted as impoverished and they saw to it that he acquired "skills" as a carpenter and a handloom weaver. Samuel Crompton was born on a family farm near Bolton in 1753. His father died when he was five and his "industrious and proud" mother moved with his two sisters to become caretaker of a mansion called The Hall-in-the-Wood and left her children a small legacy of £100. Edmund Cartwright was born as the third son of the High Sheriff of Nottingham. His father owned land in Yorkshire, Lincolnshire, Lancashire and Huntingdonshire. His sister married a Whig peer and the family had links to the apex of England's social hierarchy.

Almost nothing is know about their intra-familial relationships and childhoods, except that Kay, Paul and Crompton lost fathers at very young ages and Cartwright left home for boarding school at the age of eight. Only Hargreaves was first born. All six inventors "belonged" to the established Anglican religion; although Paul may have attended a Huguenot church. At the age of 38 (but after he invented his Mule) Crompton became choirmaster, organist and treasurer to the Swedenborgian chapel in Bolton. Apart from Samuel Crompton (and including the Reverend Edmund Cartwright) none of our sample appear as particularly religious.

Only Hargreaves has been described as illiterate, but he received training as a carpenter and a weaver and possessed sufficient knowledge to set up a business partnership in Nottingham. Paul's aristocratic guardians saw to it that he received the education of a gentleman and he was recognised as such by both his social "inferiors" and "superiors". He moved easily among Samuel Johnson's circle of highly educated friends. His partner and "mechanic" John Wyatt, who went to the same grammar school (Lichfield) as Johnson, allowed and entrusted negotiations over patents to Paul who managed to convince middle class and aristocratic patrons to back his ideas and enterprises in both spinning and carding. Crompton apparently received a schooling that included mathematics. John Kay possessed sufficient education to compose well written letters and to negotiate with government officials from the aristocratic apex of both British and French society. Edmund Cartwright benefited from six years of instruction at the Free Grammar School of Queen Elizabeth, Wakefield, where he studied Latin, Greek, Hebrew and Logic before going up to University College, Oxford at the age of fourteen. He remained there for fifteen years, matriculating in 1760 and taking up a fellowship at Magdalen in 1762. It is difficult to imagine that Cartwright acquired knowledge at Oxford that might have been of direct relevance to his later career as a mechanical engineer. He wrote poetry which contains several references to Newton. His Latitudinarian approach to life exhibits optimistic beliefs in improvement and the application of reason to the solution of problems in all spheres of life. Cartwright and Paul came, however, into the textile industry; from beyond its normal economic, social and cultural borders. Their presence among a group of "insiders" such as Kay, Hargreaves and Crompton suggests regional societies on the move, open and attractive to talents from metropolitan and rural locations as well as for the higher reaches of society.

Compared to later periods and to creative activities in the arts, politics, even business, almost no evidence survives (in the form of diaries, post hoc reflexions, letters and observations by others present at the time) that might provide insights into how the Flying Shuttle, the very first Roller Spinner, the Jenny, the Mule and the Power Loom came to be initially conceived and assembled into functional models. For the making and development of John Kay's loom there is literally no evidence at all. Louis Paul may have derived the basic idea of spinning by means of rollers from Huguenot craftsmen engaged in the silk industry in Spitalfields? He may (again an educated conjecture) have developed some sort of model design in his own workshop used for the manufacture of crepe, a high quality fabric used by his business for the lining of coffins, before he consulted and entered into partnership with John Wyatt at Birmingham. Rolling was, moreover, already a common process for the manufacture of metals and paper.

Around the Jenny there is, the possibly apocryphal, tale that James Hargreaves conceived of the notion of multiple spindles by observing a Saxony spinning wheel that had fallen on its side. But the notion and ambition for a machine that could help spinners to produce more than a single strand of yarn at any one time had existed for centuries and had been tried in China. In England "designs" to increase the productivity of spinners had been patented by Harris in 1678, Thwaites in 1723 and, by Taylor in 1755 and according to one historian, solved but not patented by Thomas Earnshaw in 1753. Forced to flee from Blackburn after attacks on early but functional models of the Jenny (and on his person), James Hargreaves continued with its development between 1764-67 in Nottingham in partnership with a local joiner, one Thomas James.

In a letter to Sir Joseph Banks, Samuel Crompton claimed that he had assembled and developed the Mule over a period of six years. Apparently he had tried and failed to adapt Hargreaves' Jenny to spin warps and the Mule (as its name suggests) combined into a single machine basic concepts embodied in the Jenny and the Water Frame. Crompton also told

Banks that as a working weaver he had embarked on his long, arduous and self-financed period of research and development in order to produce a machine capable of spinning yarns (warps and wefts) of qualities far higher than anything that could be spun on the Jenny and the Water Frame. Like John Kay, Crompton apparently worked alone. Along with all our group of inventors he also worked in conditions of secrecy and anxiety, not simply because his knowledge could be exploited by others, but because labour saving machinery invited violence from those whose livelihoodscame under threat, particularly in Lancashire. That county was by no means a haven for the development of new knowledge. Hargreaves and Arkwright moved to Nottingham to take their ambitions forward. Lancashire factories containing Water Frames and Power Looms were burned down. Kay and Hargreaves suffered from violence and the consciences of Crompton and Cartwright clearly became troubled by the potential effects of the machines on local employment.

More evidence concerned with "process of invention and preliminary development" survives for Edmund Cartwright than for any other inventor of textile machinery. Some letters, observations and recollections related to the eight years Cartwright passed conceiving, assembling and attempting to carry the mechanisation of weaving and wool combing to a routinely functional and commercially viable stage of operation have survived. This detail tells why an Anglican parson, of gentry status, and with no prior knowledge of textile or any other kind of machinery, spent eight years and a great deal of his family's money on the design of two machines of enduring significance for the development of the textile industry. First of all the impetus to move on from the arts (poetry, theology and religion) towards mechanics and science at an advanced age of 41 came from the chance meeting with Manchester manufacturers in the inn at Matlock narrated in Margaret Strickland's memoir.

Cartwright constructed his prototype loom from basic principles: "as in plain weaving according to the conception I then had of the business, there could only be three movements which were to follow each other in succession and there would be little difficulty in reproducing and repeating them". This statement is congruent with Cartwright's classical education, admiration for Newton and a commonplace belief (by then commonplace among the educated elites) that all simple manual operations could be mechanised. Cartwright set out to transform a "mental construction" into a "working model". As he testified, 'Full of these ideas, I immediately employed a smith and a carpenter to carry them into effect', a procedure recommended by Malachay Postlewayt's *Universal Dictionary of Trade and Commerce* published three decades earlier. "When they have designed any new invention in their mind, which they cannot execute … they should apply to some practical mechanic, or consult some skilful mathematician, who may have been more particularly turned himself to mechanical inventions."

Cartwright's registered his first model by patent dated 4 April 1785. It was, by his own account, "a most rude piece of machinery." The warp, strengthened by flax yarns normally used to weave sail cloth, was placed perpendicularly; the reed fell with the weight at least half a hundred weight, and the springs which threw the shuttle were strong enough to have thrown a Congreve rocket. It required the strength of two powerful men to work the machine at a slow rate and for just a short time. Only after the inventor "condescended to see how other people wove" was he astonished when "he compared their easy modes of operation with mine and availing myself of what I then saw, I made a loom in its general principle nearly as they are now made. But it was not until 1787 that I completed my invention when I took out my last weaving patent August 1st of that year."

Further development of the crude model of 1785 into an operational prototype, patented in August 1787 as an 'Improved Machine for Weaving' took place in the rapidly growing cotton metropolis of Manchester. From his closer observation of how contemporary techniques, including Flying Shuttles, worked in practice, Cartwright realised that the process of weaving yarn into cloth included far more than the three simple operations and that he needed to employ skills and seek advice that was not available to him in Doncaster. Early in 1786 Cartwright visited Manchester 'to engage some <u>superior</u> workmen of that place to assist him in constructing a better model' and also to try and attract entrepreneurial and financial support for his project.

Manchester craftsmen apparently lacked conviction to continue development unsupervised because in May 1786 Cartwright complained that 'I found my machine not even begun upon; indeed the workmen who had undertaken it, despaired of ever making it answer for the purpose it was intended for, and therefore, I suppose, were not willing to consume their time upon a fruitless pursuit'. Evidently he stayed around and motivated his men to push the experiment forward to a point 'that the whole system of it is now fully adjusted, and so much as both to mine and the workmen's conviction that we cannot entertain the shadow of doubt respecting its success'. By the end of June in an affidavit sworn in Doncaster, Cartwright laid claim to an improved loom patented in 1786.

Cartwright also used his time in Manchester to acquire relevant knowledge and had 'taken some pains to make [himself] acquainted with the manufactures of this place which has contributed much to the perfection of what I have been aiming at'. His day-to-day assessment of work on the loom fluctuated, however, from optimism to pessimism. On the 8th May 1786, his friend George Crabbe, expected the inventor would soon be in a position to maintain him "handsomely as a poet". Meanwhile Crabbe's putative benefactor had written to

Wray (another clerical friend) complaining of 'delay upon delay' which did 'not arise from any unforeseen difficulty. The apparatus for stopping when the thread breaks, either in warp or woof is completed and performs its business with the greatest accuracy and facility'. Before the end of the month Cartwright is untypically afflicted with self doubt about his mechanical talent, 'for though chance might help you at first, it must be a chance indeed that could carry you on so without skill'. You only mean', suggests Crabbe, 'to conclude that you know mechanics practically without having a mathematical foundation to build upon; nor had Archimedes himself that I know of'.

Cartwright's loss of confidence proved to be temporary, because a second patent for a Mark II 'New Invented Weaving Machine' appeared on 30th October 1786. This innovation, regarded by its inventor as 'exceedingly simple and exceedingly cheap as not to cost (after the model is made to work) above five or six pounds', failed to secure financial and entrepreneurial backing in Manchester. Cartwright then embarked on a costly business venture, designed to exploit is commercial potential by setting up a factory near his home in Doncaster.

Destined to come under the hammer less than eight years later the 'manufactory' located on the river Cheswold, contained machinery for spinning as well as twenty looms, ten to weave muslin, eight for cotton, one for sailcloth and one for coloured checks. Sometime in 1788 Cartwright purchased a 42 inch cylinder Newcomen engine to replace the power initially provided by a bull and a water wheel. He also hired the most skilful workmen be could procure and provided scope for 'every description of mechanical experiment'. He proceeded as recommended in an endeavour now labelled as "collective invention" because as Bacon bserved, 'in the mechanical arts the talents of many combine to produce a single result'. Over the years 1787-88 the enthusiastic inventor continued to make alterations to his automated loom and took out two further patents for an 'Improved Machine for Weaving', the first on

14th August 1787 and a second for 'certain additional improvements' exactly three months later. According to Walter's memoir of 1862, 'Shortly after he had brought his loom to perfection, a manufacturer, who had called upon him to see it work, after expressing his admiration at the ingenuity displayed in it, remarked, that wonder as was Dr Cartwright's skill, there was one thing that would effectively baffle him, and that was the weaving of patterns in checks, or, in other words, the combining in the same web a pattern or fancy figure with the crossing colours which constitute the check. The doctor made no reply to this at the time; but some weeks afterwards, on receiving a second visit from the same person, he showed him a piece of muslin, of the description mentioned, beautifully executed by machinery, which so astonished the man, that he roundly declared his conviction that something more than human agency must have been called in the occasion'.

Similar eulogies appeared in the Doncaster Press, of July 1787. By that time the looms were perceived by that newspaper's editor to be, 'upon such an improved construction as to weave any kind of cloth either fine or coarse, with more exactness than can be done by the hand; at the same time it was supposed a child of six or seven years old would be able to do as much work in one day as can be done by the old method in a week'. The factory must have been working to capacity in the summer of 1787 when the Crabbes visited their friend in Doncaster, because when Mrs Crabbe 'entered the vast building filled with engines thundering with restless power, assisted yet under the apparent management by the labour of children, the sight of the little creatures condemned to such a mode of life in their days of natural innocence quite overcame her feelings and she burst into tears'. In the fall of that year the venture continued to progress and Cartwright's patron, the Bishop of Durham, wrote to congratulate him. 'We were exceedingly glad to find that you have so happily succeeded in all your machinery and no less happy to hear that it will provide so very lucrative for the ingenious mechanic. Mrs Thurlow ... has determined to put herself into a dress made out of the pieces of muslin that you were so good as to present her and which for its novelty, and being the first fruits of your labours and art she prizes beyond the richest production of the East'.

In the spring and summer of 1788 Edmund advised his brother John on plans to establish a factory, Revolution Mill (so named to commemorate the glorious events of 1688) to spin and weave wool at East Retford, Nottinghamshire. Apparently the Radical Major had secured 'very extensive gentry support for his industrial venture' which, by the year of the French revolution, employed some 600 people. Major John took technical advice from Matthew Boulton and James Watt about the size, type and installation of one of their engines to power the spinning and weaving machinery. Over its short existence Revolution Mill concentrated, however, upon spinning worsted yarn and for that purpose used another and equally famous invention by his brother - a machine for combing wool.

Not one of this group of famous inventors seems to have been a member of England's famous eighteenth century scientific societies. Cartwright applied for Secretaryship of the Society for the Encouragement of Arts, but after his career as a textile engineer had failed. Several of his friends and supporters, active in the Manchester Literary and Philosophical Society, lobbied parliament in order to secure recompense from the public purse for his investment as an innovator in the development of the Power Loom. Cartwright's brothers and their friends who backed his ventures into the mechanisation of textile production at Doncaster and East Retford in Nottinghamshire surely included people versed in natural philosophy and au fait with developments in mechanical and chemical knowledge and with commercial intelligence.

Louis Paul, as a ward of the Shaftesbury family and an intimate of Samuel Johnson and his circle, seems to have been well "positioned" in both London and Birmingham to tap into networks of potentially useful contacts. John Kay travelled to several regions of England (north and south) in order to promote the development and diffusion of the Flying Shuttle. He corresponded with the Earls of Albemarle and Bedford (the British Ambassador in Paris) and with the Society for the Encouragement of Arts in London. With his family Kay resided for many years in France in order to sell himself and his machines to the French government. There is no reason to suppose that Kay was anything other than well informed about European knowledge that could be applied to the mechanical arts and exploited for pensions, awards and private profit. James Hargreaves knew Richard Arkwright and as a young and promising maker of textile machinery had attracted the patronage of Peel. Only Samuel Crompton could be represented as solitary and possibly not in close contact with the scientific and commercial currents of his times. Even then he had been well schooled and his deep interests in music and textile design suggests a cultivated man of independent spirit rather than someone outside mainstream English culture.

All these inventors comprehended and could tap into the ranges of mechanical and other knowledge required to realise their innovatory conceptions for new mechanical ways of: preparing natural fibres for spinning, for carding and combing fibres into yarns and for weaving those yarns into cloth. Kay, Hargreaves and Crompton could spin and weave and understood the process of carding. Kay trained his three sons to assist him with his mechanical engineering business. Paul formed an uneasy partnership with John Wyatt, a skilled and well educated mechanic from Birmingham. Cartwright made the first and entirely crude model of his loom with whatever help he could find in the rural parish of Goadby Marwood. Thereafter he recruited the artisanal skills he mobilized in Doncaster, Nottingham and Manchester.

Although total annual flows of investment required through many years to bring an initially design to the stage of a routinely functional machine was substantial, not one among this group of inventors lacked access to the funds required to design and assemble a working model. Proudly (and in the view of Samuel Smiles) foolishly independent, Crompton refused all offers of patronage, partnership and external financial support required to exploit the economic potential of the Mule. He preferred to go it alone and as a result lived the "comfortable" life of an artisan. He (and his family) experienced that deep sense of injustice which comes to inventors who witness the fortunes made by businessmen who possess that rather commonplace "entrepreneurial"acumen required to realise the commercial potential of creative ideas.

Hargreaves initially accepted patronage from Peel to develop machinery for carding, but for some reason he severed that potentially profitable connexion. After local Luddites had attacked his home and Jenny, he left Blackburn for Nottingham where he entered into partnership with Thirley and James, local craftsmen to develop, manufacture and sell spinning machines. By then his knowledge had entered the public domain and his patent of 1770 could not be enforced and, like Crompton, James Hargreaves reaped little more than a modest competence from his seminal ideas. Louis Paul emerges from the hostile portrait contained in letters in John Wyatt's papers, an energetic and plausible projector with mechancical conceptions of his own. He managed to convince aristocratic and middle class investors to fund no less than four factories established to develop and exploit the potential of concepts for the mechanisation of spinning by rollers and carding. For more than two decades up to the year of his death in 1759, Paul persisted and allocated the money he "acquired" through two lucrative marriages, loans from Wyatt and backing from his impressive network of metropolitan and midland patrons in an ultimately futile endeavour to advance his designs for roller spinning and carding towards commercial viability. Paul never experienced poverty. Indeed, he boasted to the Earl of Shaftesbury about the fortune (£20,000) he had acquired from licensing his machinery. That looks like a false claim but it seems ironic that the technical ideas and designs that Paul and Wyatt and their distinguished patrons took a long way, were within little more than a decade after Paul's death, exploited for enormous profits and a knighthood by that celebrated "entrepreneur", Richard Arkwright.

After eight years of intensive creative activity across a wide range of mechanical engineering, on 15th May 1792 at the age of 49, Cartwright patented the last of his "great contrivances", the Cordelier or Rope Making Machine, a patent which also included specifications for further improvements to the loom. Unfortunately his acclaimed technological breakthroughs yielded no monetary returns. On the contrary, and as his elder brother informed a Committee of the House of Commons, Edmund 'in pursing mechanical inventions has consumed the best years of his life and exhausted the whole of his private fortune'. John Cartwright did not exaggerate: Edmund had apparently invested some £30-40,000 of his own, his family's and his creditors' money in the workforce and plant at Doncaster in order to demonstrate the technical feasibility and commercial viability of powered looms, mechanised wool combing and rope making. That represented a huge sum for a family and its network of connexions to risk upon infant industrial ventures. At current prices £30,000 is equivalent to £1.5 million. At the time it was sufficient to have sustained more than 1500 working class families in modest comfort for one year. At the end of the eighteenth century research and development in textile engineering was neither cheap nor riskless to support. All too frequently inventors and their backers lost money.

Fortunately for the long term growth of the British textile industry, Edmund Cartwright was both motivated and placed to mobilise sufficient finance to keep himself, his immediate family and his factory going for approximately 9 years, while he persisted, almost without regard to risk and cost, with plans to develop an automated power loom and machines to comb wool and twist rope. Funds for research and development on that scale had not become available to his equally famous contemporaries in textile engineering (Kay, Paul, Arkwright, Hargreaves and Crompton). Cartwright could finance his vision and abstract conceptions because as the scion of a gentry family he had inherited property from his father and (as feminist historians will rightly observe) from his wife's relations. Over the generations, the Cartwrights, Whittakers and Ellekers had accumulated land, houses and other assets. Edmund's share, inherited in the 1780's provided collateral against which he could borrow and which he realised to satisfy his creditors when he eventually, and in everything but law, went bankrupt in 1794. Edmund also exploited the financial advantages which flowed from his birth into a close knit and well connected family. The involvement of his brothers in his ventures is clear. They took care of Edmund's children at low points in his fortunes. When winding up his estate in 1794, he assigned his patents over to them. John and Charles then took over the legal and financial responsibilities involved in trying to protect his property rights through negotiation with "pirates" and, where necessary, in the courts. Six years later they launched and funded a successful campaign to persuade Parliament to pass a Bill extending Edmund's patent for the woolcombing machines for a further 14 years.

The Cartwrights and their friends consistently nurtured the middle-aged genius in their midst, while he pursued his second calling and continued to offer emotional and material support when his Doncaster enterprises collapsed shortly after the outbreak of the war with Revolutionary France in 1793. To achieve what he did, Edmund Cartwright had to be born into a family high up in the income scale. Through "prior accumulation" the Cartwrights commanded money, drew upon their connexions for Anglican benefices and other favours and could successfully mobilize the forces of law and politics to ensure that Edmund obtained the social recognition, and at least some fraction of the return that his inventions merited. The entire Cartwright clan, brothers, children, wives and descendants, lost serious amounts of the accumulated family fortune from Edmund's forays into mechanical engineering. His generation of Cartwrights certainly took risks.

None of our other inventors, Kay, Hargreaves or Paul Crompton lived or died in penury as Victorian legends so often suggested. Kay, Hargreaves and Crompton probably accumulated a little more wealth than they might otherwise have acquired without innovatory forays into mechanical engineering. Without exception (including the unworldly Cartwright and the solitary Crompton) these men wanted to become rich. Although Kay (and possibly Paul) seems to have pursued money much more avidly than Crompton, who did not even attempt to take out a patent to protect his clear property rights to the Mule. As Smiles observed, Crompton was 'not a man to improve an opportunity or take time by the forelock … he seems,' opined the author of *Self Help*, 'to be wanting in shrewdness and worldly wisdom usually prominent in the South Lancashire character.' Yet Crompton certainly sought returns for his innovatory knowledge and through exactly the same channels as all the others.

Patents and Prizes

In the eighteenth century British and Irish inventors of useful and reliable knowledge could hope to make money in several ways. For example, they could register a patent and acquire legal (monopoly) rights to manufacture their machines or devices which could then be sold, licensed or utilised solely in factories under their ownership and/or control for up to fourteen years. Unfortunately for them (and as Kay, Hargreaves, Arkwright and Cartwright discovered) their property rights to machines and designs could all be too easily purloined, copied and used long before their patents ran out. In any case even fourteen years often turned out to be too short a time to develop the full technological potential of a machine and renewal beyond that time required the consent of Parliament.

John Kay's relentless pursuit of pirates through Chancery turned out to be ultimately futile and very expensive as indeed did the later (and *prima facie* successful) attempts by the Cartwright brothers to protect Edumnd's patents for woolcombing against the unscrupulous Toplis and other businessmen. In a competitive industry like textiles, secrets embodied in relatively simple and cheap machinery seem to have been impossible to retain and an inventor's patent rights extremely problematical to enforce. Crompton's spinners soon left his employ to set up rival enterprises using his Mules, assemble by other craftsmen. With the examples of Hargreaves and Arkwright as a warning, Crompton (despite Smiles) may have been shrewd enough not to have wasted money on a patent or the energy and legal fees required for its problematical enforcement by the courts. In the event he preferred to reply on the largesse of voluntary subscriptions of local businessmen whose profits and prosperity depended on the diffusion of the Mule. Sadly the amounts they contributed look derisory – £680 in 1780 and a further sum of £872 in 1802. Hargreaves had asked for £7,000 from manufacturers in Manchester using his Jenny in return for a promise to forego the legal rights as registered in his albeit contestable patent of 1770. He probably received less than half that amount. John Kay, or rather his son Robert, did manage to obtain money for their improved Shuttle from the Society for the Encouragement of Arts in London. But the premia awarded by this celebrated metropolitan Society under stringent competitive conditions were pathetic. £50 seems to have been the standard amount and the Society refused to grant anything to Crompton or to Hargreaves.

Government and Parliament seem to have been far more generous and responsive to campaigns to reward Cartwright and Crompton for their seminal contributions to the progress of the country's leading industry. After well orchestrated lobbying by distinguished businessmen and members of Parliament representing textile regions in the north and midlands, select committees of the House examined a wide range of witnesses with relevant scientific and technical expertise, Parliament agreed in 1811 with its Committee's recommendations to award £10,000 to Edmund Cartwright and a year later awarded £5,000 to Samuel Crompton. These sums (roughly £500,000 and £250,00 in today's prices) are hardly in keeping with their contributions to the then discernable progress of the English cotton textile industry and seem less generous than the pensions and the patents of monopoly the supposedly "unprogressive" government of Louis XV awarded for the services and machinery of John Kay in 1747. Alas, the supremely confident and avaricious Kay lost his pension prior to the outbreak of the Seven Years War. Undaunted, he attempted to persuade the Earl of Albemarle and his majesty's Ambassador in Paris to persuade the British government to pardon his illegal emigration to France and to grant him a pension to return and resume his career as an inventor in England. Apparently the negotiation came to nothing because John Kay (who clearly held an entirely modern view of the value of his skills and creative abilities) died in Burgundy in 1780-81.

Conclusions: Discovery and Agency for Necessary and Sufficient Conditions

Not one of England's celebrated inventors discussed in this essay lacked confidence in his abilities to solve the problems involved in the mechanisation of the several processes carried on by handicraft methods for the manufacture and finishing of cotton, woollen and linen cloth. Biographical detail about the major technologists of this (or indeed most other periods) remains extremely thin. Of course, along with most other residents of any highly commercialised market economy, they utilised their talents in order to become rich. That propensity was probably commonplace throughout Europe already by the sixteenth century and in East Asia long before that. What strikes us about this particular group of English inventors is their obsession with finding technical solutions to problems of production across a wide range of mechanical processes, their curiosity (all six were multiple inventors) and their persistence in the face of adversity and disappointment.

Alas, my foray into dense description cannot be labelled as economics or sociology and could not be accepted as prosopography what the biographical method offers is an approach that reconstructs social and cultural contexts around individuals rather than the other way round which has become the hegeomic and possibly a repressive tradition in social science. Thus a tiny group of men (who I have selected to place within a Victorian pantheon of great inventors) are restored as indispensable and significant human agents behind major technological breakthroughs during the First Industrial Revolution. They are not easily amalgamated into a logically bounded narrative that could move on from a context of necessary conditions to the intellectual highground of a plausible and validated explanation for the precocious mechanization of the English cotton textile industry. With due respect to all who labour in this unfertile vineyard of history they cannot be incorporated into modern theories of technological progress (or theories of the firm) that might be utilized to account for accelerations in total factor productivities that demarcate the pre-modern from modern economic growth and separate two centuries of economic development as experienced by Europe (and European offshoots overseas) from West, South, East Asia and other regions of the world that had also passed through several centuries of commercial capitalism before the first industrial revolution.

My English pantheon contains men who are placed there because they happened to reside in one of the most advanced of a range of successful market economies located along coastal regions of the Eurasian landmass. They are (again in some sense) exemplars of a peculiar Anglican version of Protestantism that had retained God along with Newtonian cosmology. They grew up and operated in a European culture undergoing accelerated reordering by science which extolled a manipulative attitude toward the natural world that was already present in Medieval Christendom, but which came on stream in the Renaissance and entered into the perceptions and motivated the patronage of educated elites and endeavours of craftsmen since the time of Copernicus (1453). On examination, the biographical detail that we can recover does reveal an intensified form of that "frenzy for improvement" that European visitors to the British Isles remarked upon throughout the eighteenth century.

In technology (as in the arts and sciences) halls of fame are not full of dispensable men and women. Are we no longer entitled to resort to the heroic vocabularies of the Greeks and Victorians and to simply celebrate the achievements of England's great inventors? Are there no human agents as well as contexts of necessary conditions for technological progress? On examination these men, the "cultures" they inhabited and the evolving cosmologies derived from science that surrounded them still seem significant for the precocious success of the English cotton textile industry. When I looked into their lives I became convinced that "sooner or later counterfactual" predictions that such inventions would have emerged begins to look more and more like intellectual sophistry bolstered by mathematical language and theory. Economic history exists to remind its parent disciplines of technological progress without human agents are severely under-specified. The meta question for global economic history must be: are comparable groups of innovators conceivable in India, China or Japan during these same decades?