The Mechanization of English Cotton Textile Production from Kay (1733) to Roberts (1822)

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"English industrial history … can almost be resolved into the history of a single industry" J.A. Schumpeter, *Business Cycles*, Vol.1, New York, 1939, pp 270-71

1. The Great Divergence, the First Industrial Revolution and the Mechanization of Cotton Textile Production

Current debates about the chronology and origins of the 'Great Divergence' in standards of living between Europe and Asia, as well as recent 'Reconfigurations of the First Industrial Revolution' as a seminal episode in global economic history, return us toward histories of science and technology and the mechanization of industry. For that chapter of a reconstructed meta-narrative on differences between Europe and Asia and the specificities of a British Industrial Revolution, there is a large and significant corpus of historical research on several famous machines that transformed possibilities for the production of cotton textiles in the Hanoverian realm, which might conceivably clarify and settle parts of the argument.

By the time of the Great Exhibition of 1851, a predictable sequence improvements to classic inventions from 1733 to 1822 had led to: relocation of the cotton textile industry, 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 its transformation (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 precocious British 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 several historians have dismissed it as a misnamed episode in European economic and technological history. That seems premature because even the macro economic discontinuities 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 famous narrative supposed, or as Deane and Cole's (Kuznetian) attempts at quantification claimed.

This restored interpretation insists that where and when productivity improvements occurred, they tended to be located in just a few sectors of the 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 years 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 Industrial Revolution has been reconfigured as an example of ‘unbalanced growth’.

In many ways that interpretation of the First Industrial Revolution read like a very old story in which textiles in general, and cotton in particular, were taken as precocious and paradigm cases of early mechanization. Of course, 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. Debate continues, but for purposes of this essay, the ‘cliometric painting’ of the Industrial Revolution (together with the unsatisfying attempts of economics to ‘endogonize’ explanations for technological breakthroughs) provides a justification for focusing again on textiles and for re-examining that sequence of famous machines, processes and improvements that emerged between the times of John Kay and Richard Roberts. So many of the pre-conditions posited for modern economic growths 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, within the confines of a single industry, albeit one that accounted for a substantial share of manufacturing activity in Britain.

Writing 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 on the way to communicating some understanding of a major "prime mover" behind British and European industrialization and (to be ambitiously reductionist) offer insights into the origins of the 'Great Divergence' between West and East which emerged rather later in the 18th century and became first discernible and then stark by 1914.

2. Three Familiar Macro Theories of Technical 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. Presumably countless other adaptations also appeared that are now, alas, lost to historians seeking to reconstruct the entire flow of technological knowledge, applied through time. Nevertheless, familiar taxonomies have been imposed on surviving data in order 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, since craftsmen and women had been engaged in making cloth, this uplift in productivity occurred in so short a span of time, the rate of transformation within and across stages of production was rapid, the original locus so geographically contained in one county of one kingdom and its initial applications so concentrated upon one fabric, that the 'British revolution in cotton textiles' continues to recognized as a, if not *the*, seminal episode in the history of technology.

But can we explain that revolution in general and communicable ways? Only this paper will suggest, by way of tightly focused historical research upon the machines and the men who 'conceived', 'assembled' and 'developed' them by an obdurate refusal to be satisfied with any or all of the theories of technological change which posit that the transformation of cotton textile production depended either upon the growth of consumer demand, or inelastic supplies of labour, or on sequences of challenge and response. All three theories are theoretically flawed without firm empirical foundations and are certainly under-specified.

2.1 <u>Demand for Technological Progress</u>

Demand-led explanations for technological progress have 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 in the 18th century, are not social historians 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 his … developed a rather 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 "willing" to spend more on 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 to convert leisure into industrious work in order to find the were-with-all to consume more goods. Devoted as most Anglo-American historians are to English exceptionalism, some are not convinced that the rise of material culture came conveniently on stream shortly after the Restoration or that radical changes in consumer behaviour (even if they could be dated) can be represented as quintessentially English or Protestant or even Dutch. Furthermore, the period selected for the "reordering of culture", 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 sate 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.

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 potentially heuristic to contemplate. The creation widening deepening as well as the protection of the kingdom's domestic and imperial markets for cotton textiles is certainly an early chapter in any narrative of the rise of cotton textile production in England.

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

Once British and European consumers appreciated and learned more about qualities and properties of cottons, the pace of substitution for other fabrics accelerated and the demand curve shifted to the right. Demonstration, bandwagon and fashion effects certainly flowed from imports from the East and shifted the volume of cotton consumption up to a level where incentives became strong enough to promote the familiar process of import substitution. Thereafter, domestic production of cloths embodying mixtures of cotton and other yarns attained a scale and level of know-how that created conditions for mechanization. But how far "a shift in tastes, for novelties, fashion goods and luxuries" associated with cottons without (and even with) protection from Indian imports might have carried the production of English cotton textiles is not seriously addressed by historians on the separable and significant roles for the Orient and consumers in 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. Shifts in the supply curve surely mattered far more than shifts in demand for the rise of the cotton textile industry.

2.2 Labour Saving Machinery

Shortages of labour (and updated line yarn) probably warrant longer chapters and greater weight in narratives about the rise of the cotton textile industry. Businessmen had complained for decades about the high levels of wages paid to English, compared to Irish, French and other workforces. Recent, and still incomplete, programmes of research on wage rates paid to builders' labourers and craftsmen (measured in grams of silver per day) were discernibly higher in London than other large cities on the mainland and had since the mid-seventeenth century risen sharply relative to price indices for capital inputs (wood, iron, nonferrous metals and bricks). Higher wages and cheaper energy (coal) seem to have been outstanding features of the British economy, 1675-1775. 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 into industrial and urban labour markets.

2.3 The Challenge and Response Model

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 (859) 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 the 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 "included" 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 the invention of the power loom shows) with increased incentives to utilise cheaper supplies of intermediate outputs. That story comes from an account by Edmund Cartwright's daughter of his chance meeting in 1784 with a group of Manchester manufacturers in an inn at Matlock:

> '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.'

This famous account of a sequence of technological progress ends with Cartwright's loom, but begins and becomes linear with Kay's Shuttle. It has 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 the story 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 dis-equilibrium. 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. At the moment, no assurances can be provided that the Shuttle (which was 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 model. 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 to the Africa trade from India.

Apart from the problem of those long and (as usual) unexplained lags (left open in this very old story) 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, the evidence 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 un-weighted) 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 a widely perceived need to relieve bottlenecks in weaving.

Even sophisticated manipulators of statistical techniques would be hard put to manufacture convincing evidence drawn from admittedly imperfect *data set* (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 any conceivable versions of a challenge and response model. Annual figures for patents and other data 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 Hargreaves’ Spinning Jenny, Arkwright’s Water Frame and Crompton’s Mule.

To construct any kind of “pattern” 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. 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 pattern was repeated following the registration of Edmund Cartwright’s designs for prototype power looms. Within a decade 16 “improvements” to his machine appeared and eight of them were patented. Opportunities for profit presented by the emergence into the public domain of machines that worked in engineering terms seem more likely to prompt a search for further improvements (and/or stimulate the development of differentiated technologies in order to undermine a patentee's monopoly rights) than to promote any discernible reallocation of expenditures on research and development to alleviate bottlenecks up or downstream in the production of cotton textiles.

3. The Geopolitical Context for the Mechanization of Cotton Textile Production

Reconfigurations of the First Industrial Revolution have downplayed its revolutionary and essentially British character. That famous event is now represented as an example of relatively slow unbalanced industrial growth, but still includes a demonstrational role for technological progress in cotton textiles. The Reconfiguration of what used to be a quintessential Anglo or Eurocentric story leads logically, however, to demands that the macro economic background for that early transformation of that industry be sketched into a picture that will place the outstanding achievements of English inventors of textile machinery into its golden triangle. Unless their inventions could just as easily have emerged on a spectrum of European locations (to flag a view entertained by Nick Crafts) then there must have been some features of its economy and culture – that made England a "more probable" 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 pro-industrial regions of India, China and Japan as well. Indeed five features of the island economy (two within and three beyond its shores) can be elaborated to suggest that the location timing for the technological breakthroughs that occurred in England between 1733-85 cannot be represented as merely random.

Firstly, 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 almost the entire range of textiles: woollens, linens, silks, cottons, fustians and an astonishing variety of mixed yarns and cloths.

Secondly, (alas this assertion may never be quantified), 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 the workforces elsewhere on the European mainland. Josiah Tucker certainly 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 for inventions or improvements for differentiated products from the British textile industry between 1688-1851 does not suggest that this particular, but very important, segment of the English skilled workforce can be represented as a "definable resource", separable from the population at large. Names and traceable patentees do not emerge as a clearly "distinctive" 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 my samples of men who claimed to be innovative are small, they represent a rather predicable cross-section of the kingdom's urban population.

Meanwhile three familiar "exogeneous" histories behind and beyond the rise of cotton textile production within England can be inducted from the political economy of imperialism. Firstly, there is the rather particular (but in outcome functional) reaction of the British 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 development of a 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 line warps (imported from Ireland). In the reign of William III his ministers formulated policies for the pacification of England’s rebellious Catholic province that included subsidies and encouragement for an Irish linen industry, which they hoped would provide employment for dispossessed peasants and would placate Irish merchants and manufacturers after parliament had passed legislation in 1697 to close English home and imperial markets to Irish made woollen yarns and cloth. Their policies worked and for decades Ireland supplied warps of linen yarn for the rapid development of fustian manufacturing in Lancashire. Eventually inelasticities in imported linen yarn supplies and instabilities in delivery (occasioned by mercantilist 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 could be realised from the manufacture of cloth from warps and wefts of cotton yarns spun entirely within Lancashire.

Thirdly, 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 later on for former Southern colonies on the mainland of Southern America. Meanwhile, French competition on European markets for sugar intensified, following the exploitation of new and fertile plantations on Haiti, and provided the push required to diversity production and exports from the colonies into cotton fibres. In any case any food or industrial crops that could be grown cheaply on tropical soils anywhere in the American colonies (utilising the cheap labour of African slaves) promised profits from investment in plantations, in trade and shipping and from the manufacture of cheaper textiles. In short, as Britain moved into a position of leadership among European powers in exploiting the commercial and economic potential of the growing Atlantic economy, opportunities to integrate cotton textile production across the domestic economy and the empire began to look increasingly profitable and more immune to risk than they did almost anywhere on the mainland of Europe. Although the large Indian and East Asian cotton textile industries still need to be integrated into a global framework to complete the comparison.

4. From Necessary to Necessary and Sufficient Conditions: Macro Inventors and Macro Inventions

Theories of structural preconditions and the political economy of English imperialism help to explain why an embryo or proto-cotton textile industry in England had by 1688 climbed to a “plateau of possibilities” from where breakthroughs in technology might (at least with hindsight) be regarded as more probable than random.

Alas, any elaboration of context (even if all the details about the accumulation of domestic skill and capital, as well as the European, African and East Asian contrasts, could be filled in) can only be represented as necessary, but is a long way from becoming both a necessary and sufficient explanation for technological breakthroughs in the manufacture of cotton textiles. That will remain the case, because macro inventions were 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 will move on to reconnect the lives and the work of England's great textile inventors to the contexts in which they operated.

4.1 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 could be regarded as very much 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 Joel Mokyr relabelled these devices as "macro inventions". That apposite term is 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 prices and little else. Nevertheless the term is a useful reminder that prototype models provided "essential" foundations for a stream of future technical advances. At least for the eighteenth century, the existence and the diffusion of information about machines as functioning models set new technical parameters, posed and focused questions, promoted and placed the search for improvements upon a more steeply inclined trajectory. If and when unpredicted knowledge tangible 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. They recognised that prospects had changed and that 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 we could then recognise and date the appearance of macro inventions by citing particular techniques or machines that, in short, compass transformed “technical possibilities” for the performance of specific actions and processes. Statistical information of this kind could underpin a quantified history of technology by locating discontinuities 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 which appeared 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 long spans of time in the form of square yards of fustian, woollen or cotton cloth, woven per hour by a skilled adult male weaver utilising the state-of-the-art handloom, embodying Kay’s Shuttle and his son’s drop box. Unfortunately, available estimates of labour productivity for weaving cloth are entirely limited. Any graphs that could be drawn would be nothing more than a “synopia” – outlines of the kind of pictures economic historians would be pleased to draw if (when?) they possesses 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.

4.2. The Validation and Significance of Macro Inventions

Although macro inventions for the eighteenth century cannot be isolated with reference to statistical data, historians must continue to pay close attention to the definitions of engineers who will insist that any design selected as the prototype model either addressed a significant, but hitherto unperceived, problem or, more commonly, can be accepted as a new and 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 machines associated with 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 or mechanics 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, hopefully, since to be more than mere modifications of or improvements 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 Arkwright, but not for Cartwright, who assets his ‘right to say not only were the first machines for combing wool my invention, but I invented the very art of combing by machinery’. That is certainly true because the mechanical process for combing fibres, jumps from a handicraft technique using hot wax and combs, to a complex machine which emerged almost overnight. Cartwright never made that kind of large claim for his automated power loom. Indeed and ex-post a “possible path for the development” of his Doncaster loom could be traced in engineering terms along a sequence of machines from the Dutch swivel loom for the weaving of ribbons which appeared in Germany and the Netherlands in the sixteenth century, through Kay’s Shuttle to Vaucanson’s version of a Dutch design, in operation at Gartside’s factory in Manchester in 1765. Although there is no evidence that Cartwright ever studied any of these machines – on the contrary he denied having witnessed any weaving machinery in operation before he conceived and organised the construction of his Mark I version of the Doncaster look in 1784-85, assembled in his words, ‘from his first principles’.

As an Anglican clergyman he may have been more hesitation than, say, Richard Arkwright or the ever plausible Monsieur Louis Paul, when it came to committing the sin of lying for material gain or scientific reputation. As the scion of a gentry family of high social status, Cartwright had no obvious need to “refashion an identity” at the age of 41. Furthermore, there is nothing in the testimony of contemporaries, or in his recorded statements, to suggest a character given to deceitful or beastly claims – quite the contrary.

At his own expense Cartwright completed the legal formalities and paid the not inconsiderable fees required to register eight patents to mark the several stages in the development of the power loom and the wool comber between 1785 and 1792.

Parliament, after considering evidence brought before a Select Committee in 1807, granted him a fourteen year extension on his patents for combing wool. Furthermore, he and his brothers won three court cases against Toplis and other pirates of that machine. From a Tory and laissez-faire government, Cartwright also obtained a rare and very generous award of £10,000 (something like £500,000 in today's prices) for his work on automating the loom. Nobody at the time, or since, has claimed property rights or primacy for designing the very first comber or automated loom. On the contrary, an impressive list of mechanical engineers (many patentees in their own right) either paid retrospective tribute to Cartwright's pioneering designs or signed the petition requesting Parliament in 1808-09 to make recompense and reward for the investment of time and his family's money) in the early development of the automated or powered loom.

Neither of these machines emerged from Cartwright's "research and development" workshop as routine functional or even as profitable knowledge for cautious businessmen to invest in. Textile machinery of the early industrial revolution period seems to have been subject to a great incidence of design faults, to unforeseen difficulties with materials and probably depreciated much more rapidly than machinery performing similar functions in later periods. Cartwright's own attempt to exploit the commercial potential embodied in his machines ended in failure and virtual bankruptcy.

Nevertheless, other more experienced and worldly-wise businessmen invested without much delay in both the comber and loom. For example, three patents for the mechanised combing of coarser wools appeared between 1789-90 and according to testimony laid before Parliament just two years later, the machinery was coming into widespread use and appeared to be threatening the livelihood of skilled handicraftsmen in the West Riding, the Midlands, Durham, the West

Country and East Anglia. Just four years after he registered the last of his patents for an automated weaving loom, Cartwright entered into contract to install 400 looms in a factory owned by two nonconformist businessmen, the Grimshaw brothers of Gorton. Alas, and after only 24 looms had been installed, their mill burned down and the Manchester Mercury observed ‘there is reasons to suspect that same was maliciously set on fire’. A year later war broke out with Revolutionary France. By 1806 improved versions of the automated loom were apparently profitably and widely employed in and around Manchester. By then it was recognised among technologists and businessmen, with the *expertise* to appreciate such matters, that Cartwright’s machines had placed the search for improvements to mechanised designs for the weaving of yarns and the combing of fibres upon an altogether more promising trajectory.

Unfortunately, and this final assertion cannot be clinched with references to engineering data, but supported only from the imperfect and unverifiable suggestions cited in Baines, we can conjecture that for specified and simple kinds of weaving and combing in operation, Cartwright’s machines might well have raised the physical productivity of labour employed in these activities by factors of around 4 and 6 respectively.

Cartwright happens to be the inventor I know most about because I have trawled through nearly all secondary and primary sources I could find about this truly remarkable man. For the other famous eighteenth century inventors of textile machinery (except for Louis Paul and John Wyatt, whose surviving papers in the Birmingham Reference Library have also been consulted), primary sources are extremely meagre and we can only read secondary sources in order to discover who else might qualify to be represented in the history of textile technology as a “macro inventor”.

For purposes of this survey I do not propose to analyse the claims of John Kay, James Hargreaves and Samuel Crompton in detail. I am, however, prepared to argue that Arkwright's commercially successful Water Frame is very probably based upon a highly original "conception" of spinning by rollers and a conception which almost certainly emerged as a "notion" of Louis Paul and which had been "developed" intermittently over an interval of more than three decades by a line of gifted mechanics and artisans, including John Wyatt (who worked with Paul), John Kay (the Warrington clock maker), Peter Atherton (also of Warrington), Corniah Wood (a Nottingham joiner) and Thomas Highs of Leigh in Lancashire. Their experiments with roller spinning were improved, adapted and "brought to commercial viability", "exploited", "purloined", "pirated" (take your pick) by Sir Richard Arkwright. Arkwright would not, on the evidence now assembled by historians of technology and his biographer, qualify for burial in a cemetery reserved for "inventors".

After some decades of historical research and controversy (which arose because their Victorian biographers often made tendentious claims) other candidates, including John Kay, James Hargreaves and Samuel Crompton, seem to possess rather well validated claims to be represented by historians of textile technology as inventors of prototype machines that placed the prospects for increasing the productivity of labour employed in the manufacture of natural fibres into yarns and cloth onto an altogether more steeply inclined trajectory for development, improvement and, further up the road, towards commercial viability.

Baines has argued, however, that Louis Paul (the most eccentric and unlikely of eighteenth century inventors after Cartwright) stole the idea of roller spinning from Kohn Wyatt, the humble and exploited craftsman of Victorian mythology. Wyatt's own papers lend no support to Baines, whose assertions are based on statements by the craftsman's son published in 1818. Without protest Wyatt allowed Paul to register two patents for spinning machines embodying the rollers and other newly mechanised operations in 1738 (patent 562) and 1758 (patent 724). Again, Wyatt never contested his partners' patent for carding of 1748 (patent 636). In his letter to the Earl of Shaftesbury Paul wrote, 'I exerted myself with such success that notwithstanding the various impediments necessarily in the way of a person who has spent his time in every way remote from the arts of trade, I nevertheless completed a machine of great value in the most extensive manufacture in the kingdom'. Dyer's famous poem, the Fleece, published in 1757, describes and refers to 'A most curious machine invented by *Mr Paul*. It is at present contrived to spin cotton but it may be made to spin fine carded wool'.

John Wyatt deserves to be celebrated as a highly skilled mechanic whose own innovations included a file cutting machine and a compound lever weighing machine. He acted as superintendent of the first mill set up in Birmingham in 1740 to develop and exploit roller spinning using power from two asses. That enterprise closed in 1743. Three other mills set up subsequently in London, Northampton and Leominster also failed to become profitable. The technical and commercial promise of Paul's machines were (as Richard Arkwright later acknowledged) understood by that famous exemplar of common sense, Samuel Johnson. Johnson knew Paul well and was at school with Wyatt. He actively promoted the invention and assembled a distinguished group of backers to develop its potential, including Edward Cave (Editor of the Gentlemen's Magazine), Thomas Warren (a Birmingham printer), Dr Robert James (the discoverer of a fever powder), James Johnson (a cotton manufacturer of Spitalfields), Samuel Touchett (a famous projector) and several other investors from Lancashire, as well as the uneasy partnership of Wyatt and Paul. It is a measure of Johnson's esteem for Paul that he attempted to obtain from Parliament "such right as shall be thought due to the inventor". As late as the outbreak of war in 1756 and after three serious attempts to exploit it commercially, the machine had failed to cross the threshold between an operational model and viable and profitable investment. In 1762 Wyatt gave up and went off to work with Matthew Boulton, who observed that better management could have carried the project through to a profitable outcome.

For more than two decades, Louis Paul with John Wyatt, had endeavoured to bring the seminal idea of roller spinning to fruition. Paul also took out two patents for carding in 1748 and another for a revamped version of the original roller spinning machine embodying numerous improvements a decade later. Wyatt wrote in an undated document: 'Thoughts originally Mr Paul's. 1^{st} the joining of the Roles. 2^{nd} Them passing through cylinders. 3^{rd} The calculation of the wheels by which means the Bobbin draws further than the cylinders I presume was picked up before I knew him'. There then followed a list of ten contributions by Wyatt towards the machine's development. And when Wyatt was being pressed to put himself forward for the Society of Arts Premium for this innovation of Spinning he declined and instead submitted a design for a friction removing device for wheeled carriages.' Thus the case for Paul as *the inventor* of roller spinning made by Robert Cole in 1859 (based on letters, documents and plants in Paul's papers at the time of his death in 1759) looks convincing. In my view Paul can be designated as *the* inventor and or related devices concerned with carding. Alas, historians can never be certain because Cole's sources were destroyed by fire in 1879.

There is no need to go through the possible problems of validation surrounding the Flying Shuttle invented by John Kay, James Hargreaves' Spinning Jenny and Samuel Crompton's Mule. Connexions between the three inventors and their inventions are not in serious dispute. What is less clear, and not measurable, is the precise magnitude of gains in productivity imputable to particular machines and the nature and slope of the trajectories for improvements and future development that these three 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. Hargreaves' Jenny and Paul's conception of roller spinning (pushed slowly forward to the stage of commercial viability by several mechanics and by that indefatigable projector Richard Arkwright, diffused rapidly and jacked up the productivity of labour employed in the production of yarn by an extraordinary multiplier.

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 in the Mule. Thereafter Crompton's Mule provided the basic model for a century long process of improvement and development, including self-acting devices added by Roberts in 1825. Validation and significance are probably not serious issues for these spinning machines and the narrative can now moved on to consider the biographies of their inventors.

5. Biographical Narratives and Macro Inventors

5.1 Biography, Psychology and Theories of the Individual

Technological discovery remains as the single most important but least understood of the many "causes" elaborated in the rich historiography of the first industrial revolution and the history of technological progress. It is the final, but perhaps un-crossable, frontier for modern economics. My essay concludes by attempting to persuade 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. Indeed, once contextual (or necessary) conditions are in place for the probable emergence of new technologies (used within a well-defined industry, operating in a circumscribed location and emerging over particular spans of time), biographical narratives may well be the only discourse left to historians who wish to reinstate macro inventions and human agency into the story of British, European and Global industrialization.

For historians of fine and decorative arts, music, theatre, architecture, science and business (let alone for political and military historians) a recommendation to treat biographical narratives as serious, need much less initial persuasion than it does for economists, economic and social historians and for historians of technology. That arises because all these 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. We 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 histories of technology 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.

Nevertheless, and even for this essentially literary genre, social scientists find solace in theories (mainly from psychology) as well as comfort from rhetorically persuasive vocabularies that replicate: evolutionary metaphors from biology; taxonomic distinctions between macro and micro areas of economics and notions of “conceptual spaces”, derived from post modern geography. Imported vocabularies can be memorable, but it is not clear that re-labelling has added much to the search for explanations of technological progress. For example, “macro” may be little more than a Schumpetarian term for technology that had wide ramifications and enduring economic significance. Spatial metaphors are often arresting, but are they anything more than metaphors? Biology provides an irresistible language for historians (and increasingly for economists) inclined (as many of these tribes are) to emphasise the gradual, evolutionary 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 aeroplanes.

Experimental psychology offers theories designed to elucidate the cognitive processes of people labelled as creative that are, in theory, based on a body of empirical evidence. Alas, historians o the eighteenth century textile industry will not be able to subject the cognitive process of inventors they select for investigation to scientific tests of any kind. Only rarely and superficially 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, however, collated substantial quantities of biographical evidence in order to “classify” and conceptualize the personalities of artists, musicians, scientists, politicians, soldiers, inventors and others recognised 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, manipulative and exploitative of those close to them etc. Historians in touch with sources, could adduce 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 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 and presumably constant 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 statistically based and ambitious attempts to supply theories and general explanations that might help with the problem of innovation. 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 note the rather elastic and general characteristics of personality, quantified by psychometrics from evidence derived from large groups of historically creative individuals, were not also present in more extended samples among the population at large – or (what is more to the point) among samples of people at work at the same time on similar problems within an inventor's own sphere of interest. They 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 discoveries and creative acts had been accepted as remarkable.

Finally, and unlike politicians or 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 the 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 worried about 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 safety of the Anglican Church to spend the rest of his life engaged in mechanical engineering and science.

5.2 Family, Social and Cultural Contexts

Metaphors, Freudian probes and psychological taxonomies are unlikely to provide much illumination for the study of England's macro inventors during the Industrial Revolution. 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 and personal frames of reference and awareness within which inventors operated as they passed through their life cycles. For historians such "cultures" can sometimes be reconstructed in order to *expose* contexts for: encouragement and restraint; praise and obloquy; risk and caution playing upon men with the relevant skills and which conditioned their responses to opportunities to invest emotion, energy, time and money in the pursuit of new solutions to mechanical problems confronting the English textile industry. 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 the format of biographies, they might allow historians to construct configured narratives of *how it came to pass* that John Kay, Edmund Cartwright and others mobilised inner, financial and other resources required to produce prototype machines of lasting significance for the development of that paradigm industry.

Such biographies could not, moreover, eschew narrative and chronology because those literary devices can make recondite research readable, coherent, and persuasive. Narratives can be designed to more 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 selected and recognised as macro. Along the way, the form will allow historians to contextualize 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 first recognised that the biographical form provided a way of reflecting upon the resources and constraints surrounding the activities of individuals, advised historians 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 for such significant outcomes as technological progress in the English cotton textile industry.

Although it seems possible to weave and juxtapose a considerable volume of relevant detail (some more or less verified and some circumstantial and contestable) into an inclusive biographical narrative for these six macro inventors, the expectation that their combined story could add up to a satisfying account for macro invention in the English cotton industry may not, alas, be realisable. Our research is incomplete, but meanwhile we are ready to hazard just a few premature and not entirely secure speculations simply to carry the conversation forward.

Turning first to social origins: with the possible exception of James Hargreaves (for whom biographical evidence is meagre) none of these “remarkable” men came from families at the low end of eighteenth century 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 appeared 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 five 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 joined and subsequently became choirmaster, organist and treasurer to the Swedenborgian chapel in Bolton. Apart from Samuel Crompton (inventors including the Reverend Edmund Cartwright) none of our sample appear as particularly devout or religious men.

Only Hargreaves among the group is described as illiterate, but he has received training as a carpenter and a weaver and possessed sufficient knowledge to set up a business partnership in Nottingham. No direct evidence survives about Paul’s upbringing, but his aristocratic guardians probably saw to it that he received the education of a gentleman and he was recognised as such by both his social “inferiors” and “superiors”. For example, Paul 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. Paul managed to convince educated, middle classes and aristocratic patrons to back his ideas and enterprises in both spinning and carding. Crompton apparently received a good schooling that included mathematics. John Kay possessed sufficient education to compose well written letters and to negotiate with government officials from the aristocratic reaches 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 cast of mind appears as Latitudinarian, 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, as outsiders into the textile industry; from way 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 from the higher reaches of English 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 other present at the time) that might provide historians with insights into *how* the Flying Shuttle, the very first Roller Spinner, the Jenny, the Mule and the Power Loom were initially conceived and assembled into functional models. For the making and development of John Kay's Shuttle there is literally no evidence at all. Louis Paul (and this is nothing more than conjecture) 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 guess) 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.

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 exited for centuries and had appeared 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 his 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 the basic ideas 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 (although we cannot be certain for either case) Crompton apparently worked alone without assistance from other craftsmen. Along with all our group of inventors he also worked in conditions of secrecy and anxiety, not simply because his knowledge could be stolen and exploited by others, but because labour saving machinery invited violence from those whose livelihoods and employment came under threat, particularly in Lancashire. This is why Hargreaves and Arkwright moved to Nottingham to develop their ideas. 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 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 us something about 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 already narrated above.

According to his own testimony Cartwright constructed his very first model of the 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 belief (widespread across English society) that all simple manual operations could be mechanised. Cartwright set out to transform a "mental construction" into a "working model". As he said, '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 in 1757:

> '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 very first model registered by patent dated 4 April 1785 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 only a short time. Only after Edmund Cartwright '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 *superior* 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.

They apparently lack 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 Cartwright stayed around and motivated them 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'. At the same time his day-to-day assessment of work on the look fluctuated from optimism to pessimism.

Thus on the 8th May 1786, his friend the poet 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 entirely 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 his own 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" 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'. As Francis Bacon had observed, 'in the mechanical arts the talents of many combine to produce a single result’. Over the years 178i7-88 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 patter or fancy figure with the crossing colours which constitute the check. The doctor made not 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, published in 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’. Obviously 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 his 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 the plans to establish a factory, Revolution Mill, so named to commemorate the glorious evens 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 Edmund Cartwright, a machine for combing wool.

After a brief apprenticeship in developing an automated loom, Edmund matured into a confident polymath. He introduced (unpatented) improvements to his own spinning machines, continued his experiments with the steam engine (patents appeared in 1797 and 1801) and over a two year period 1789-90 turned his imagination to the mechanization of combing wool. That process (preparatory to spinning) was labour intensive and costly. Eighteenth century wool combers constituted well organised combinations of ‘skilled’ men who had for centuries vigorously defended their handicraft against employers’ attempts at labour dilution and resisted all threats to mechanization. We know much less about the development of Cartwright's wool combing machine than we do about his loom. Between 1789 and 1792 he registered four patents for a machine which mechanized wool combing in one great leap forward from a traditional handicraft; where experienced men sprinkled oil on washed slivers of wool and then disentangled, straightened and sorted fibres into comparable lengths ready for spinning – with the aid of two heated combs. For centuries their skill had consisted in the careful alignment of fibres (long for worsted yarns and short for woollens) and the avoidance of breakages and waste. Cartwright's final version of the machine (known as Big Ben because the motion of the lasher arms resembled the movements of a famous contemporary prize fighter of that name) appeared in 1792 and reproduced all the actions of hand combing and incorporated basic ideas used by all subsequent improvements to combing machines.

Not one of this group of famous inventors seems to have been a member of any of the well known eighteenth century scientific societies. Cartwright applied for Secretaryship of the Society for the Encouragement of Arts, but that occurred 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 an award 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 must have 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 information. 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 fits into any kind of representation of English inventors of textile machinery as solitary and possibly not deeply in touch with the scientific, commercial and progressive currents of the 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 could tap into and comprehend 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 also understood the process of carding completely. 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 may have 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 mechanical, engineering and artisanal skills he required 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 live the “comfortable” live of an artisan. He (and his family) experienced that deep sense of injustice which comes to inventors who witness the fortunes made by mere businessmen who possess the rather commonplace acumen required to realise the commercial potential of creative people’s ideas.

Hargreaves initially accepted the 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 and entrepreneurs, 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, as a plausible projector. He certainly managed to convince aristocratic and middle class investors to fund no less than four factories established to develop and exploit the potential of his ideas 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 failed endeavour to advance his designs for roller spinning and carding towards commercial viability. Apparently Paul never experienced poverty. Indeed, he boasted to the Earl of Shaftesbury about the £20,000 he had acquired from licensing his machinery. That looks like a false claim and 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 another famous "con man" and "entrepreneur" (again taken as an adjective), Richard Arkwright.

After eight years of intensive creative activity, on 15th May 1792 at the age of 49, Cartwright patented the last of his "great mechanical 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 the Cordelier. That represented a huge sum for a family and its network of connexions to risk upon an infant industrial venture. 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 risk-less 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 the persisted, almost without regard to risk and cost, while he pursued plans to develop and automated power loom and machines to comb wool and twist rope. Funds for research and development on that scale had not been made 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 enjoyed and 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. 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 wool combing machines for a further 14 years.

His brothers and his sisters not only suffered financially from investments undertaken to support his ventures, they took care of Edmund's children at low points in his fortunes which he touchingly recognised in a letter to his sister, written in November 1799. 'From the astonishing depression of poverty, it is impossible to conjecture the loss that will be sustained by the sale of the Doncaster property. You may, however, religiously rely on my doing you the most ample justice the moment it is in my power … Should I be so fortunate as to succeed in obtaining the Secretary-ship of the Society of Arts, I shall be relieved from my embarrassed situation. But my sisters callin for what is allowed for Ann Catherine's (his youngest daughter) the whole of my income is £55 (roughly double the annual expenditure of an agricultural labourer) out of which I have to find board, washing and lodging for Eliza (another unmarried daughter). Should John follow my sister's example respecting Frances (then in the care of her uncle) my income would be £30 less. The salary of the Secretary-ship is £150. After I have paid the income tax by that addition I shall have no better income than I had before, till Mary withdrew from me and Ann Catherine's allowance was given up. The only advantage over what I had last year will be the house rent free and coals and candles'.

This letter can be read as the testimony of a ruined man, in danger of dropping out of his social class, incapable of maintaining his own children in modest comfort and dependent on the charity of his family. Fortunately the Cartwrights and their friends had consistently nurtured the middle-aged genius in their midst, while he pursued his second calling and continued to offer emotional 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 social scale. Through "prior accumulation" the Cartwrights commanded money, drew upon their connexions for Anglican benefices and other favours and could successfully mobile the forces of law and politics to ensure that Edmund obtained he social recognition, and at least some fraction of the return that his inventions undoubtedly 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 Crompton (and certainly not Paul) 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 (and including the unworldly Cartwright and the solitary Crompton) these five 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 pursued returns for his innovatory knowledge and through exactly the same channels as all the others.

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 latter (and *prima facie* successful) attempts by the Cartwright brothers to protect Edumnd's patents for wool combing 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. For example, Crompton's spinner 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, Cormpton (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. Alas, amounts they contributed were 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 acclaimed 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 textile industry and the look less generous than the pension 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.

6. Conclusions: Discovery and Agency for Necessary and Sufficient Conditions

Not one of the six macro 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) is 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 macro 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, his foray into dense description cannot be labelled as economics, sociology or even prosopography. In the end a tiny group of men (who I have selected to place within a restored Victorian pantheon of great inventors) reappear 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. 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 mark 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 …. capitalism before the First Industrial Revolution.

Our 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 embraced both God and a Newtonian cosmology. They grew up and operated in a European culture increasingly reordered by science which extolled a manipulative attitude toward the natural world 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. On examination, their biographies 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) the 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 macro inventors? Are there no human agents as well as contexts and necessary conditions for technological progress? Once again these men, the “cultures” they inhabited and the cosmologies that surrounded them begin to seem at least “necessary” for the precocious success of the English cotton textile industry. When I examine their lives and endeavours, I am convinced that the “sooner or later” counterfactual implicit in theories of technological change begins to look more and more like intellectual sophistry.