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# The Precocious Mechanization of a Global Industry: English Cotton Textile Production from the Flying Shuttle (1733) to the Self-Acting Mule (1825): A Bibliographical Survey and Critique

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“English industrial history ... can almost be resolved into the history of a single industry”

J.A. Schumpeter, *Business Cycles*, Vol. I, New York, 1939, pp 270-71

JEL Codes: B, J, N, O

## Abstract:

This survey and critique covers recent debates and part of a library of books and articles that have endeavoured to explain a seminal conjuncture in economic, industrial and technological history; namely the precocious mechanization of English cotton textile production.

### **1. Cotton textiles as a global industry**

Following the publication of three famous books by Landes, Frank and Pomeranz (dealing with the meta-question of when, how and why labour productivities and standards of living varied between economies located in the eastern and western parts of Eurasia) the divergence debate remains high on any agenda for economic history that aspires to become comparative and global.

The “when” question normally takes epistemological precedence for historians and their immediate answer has been: sometime in the eighteenth century when

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\* This working paper is the outcome of re-engagement with an ESRC funded project on technical progress in the cotton textile industry from 1733-1825. It owes a great deal to the research and intellectual collaboration I was privileged to enjoy with two first class graduates of the History School of Oxford University (Philip Hunt and Trevor Griffiths). I also extend my thanks to Robert Allen for the conversations we have had about technological innovation over the years.

western Europe began to mechanize its industries more than two centuries ahead of the east. Until recently, research and debate over explanations concerned with why divergence first became discernible and then unmistakable has taken place at rather macro-economic levels and with reference to such extensive geographical spaces as Western Europe and Imperial China. They are focused upon divergent levels and trajectories for GDP per capita or real wages expressed in international dollars, grams of silver subsistence baskets or kilocalories. Many economists and historians now recognize, however, that all macro-economic data that purport to refer to imperial China or Mughal India do not meet either the conceptual or statistical standards required for the construction of an explicanda representing a chronology for divergence.<sup>1</sup>

Thus, although economic historians are challenged by the prospect of writing history on a global scale, they remain uncertain about the approaches, methods, paradigms and evidence for research to employ in order to engage with problems, ostensibly unbounded by the chronologies and frontiers taken as given for orthodox contributions to local, regional and national economic histories of Europe. They do know, however, that over the centuries locations for many manufacturing industries moved from one country to another and that a family of models derived from classical theories of trade by Ricardo and Heckscher-Ohlin have accounted for changing patterns in the concentration of industry around the world in terms of regionally or nationally based comparative advantages derived from factor endowments that changed over time.

Unfortunately the sophisticated econometric tests that continue to fill academic journals in economics and economic history to validate the insights of international economics, offer under-specified explanations cast in terms of quantities of factor endowments exemplified by differentials in the relative prices for just two factors of production (labour and capital) for observed inter-regional, international and inter-continental shifts in the geographical location of most forms of industrial production. In short, Ricardian models deal with chronologies

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<sup>1</sup> O'Brien, 2015, Deng and O'Brien, 2016; Blunt and Fidalgo, 2018

that are too truncated to illuminate forces at work in long-run development and are parsimonious to a degree that provides us with proximate or only partially specified historical accounts for shifts in the location of industries around the global economy. Based upon static equilibrium models, they are the final, and perhaps the least interesting, chapter of almost any global industry selected for historical investigation?<sup>2</sup>

Meanwhile the divergence debate has moved on from the Euro and Sino-centric acrimony that marked its early publications to investigate potentially rigorous ways of qualifying, extending and deepening metanarratives that have served to degrade Eurocentric histories, Weberian explanations, geographical reductionism and cultural exceptionalism. The heuristic way to conduct historical research is to regionalize amorphous geographical entities like the East and the West and to deconstruct un-measurable categories like national outputs into specific industries that became involved in global production and trade over long spans of time. There are several potential examples, but cotton textiles fulfils all the criteria required for it to become a foundational building block for the reconstruction of metanarratives in global economic history. For example, and although the distant origins of that industry are ecological, its protracted and (after 1650) accelerated shift from east to west requires a history that is spatially extensive, spans the centuries and draws upon insights derivable from the natural and several social sciences, as well as history and economics.

Although that history certainly needs to take factor endowments and relative prices seriously, historians will wish to investigate the very long time lags taken by Europeans to exploit the potential (realized for centuries in the east) to manufacture numerous varieties of cloth from a natural and tradeable fibre that embodied obvious advantages, compared to Europe's own indigenous fibres of wool, flax and hemp. For example, the varieties of cloth manufactured from cotton fibres contain properties that make it more suitable for multiple purposes than cloth manufactured from rival fibres. Furthermore, cotton cloth was relatively

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<sup>2</sup> Broadberry and Gupta, 2009 and Vries, 2013 and 2015

amenable to the finishing processes of bleaching, dyeing and printing.<sup>3</sup> Why then did it take Europeans so long to appreciate the value of such a versatile and cheap organic raw material?

To answer that question close attention must be accorded to the complex anthropology of taste formation for novel forms of household consumption. Historical investigations have also been concerned with all the factors promoting the extension, deepening and integration of markets that operated to persuade European consumers to relocate their expenditures away from traditional preferences for textiles made from wool, flax, hemp and mixtures of these organic materials produced from other fibres for millennia in the west.

Once the multiple properties of cotton textiles had matured in the perceptions of European merchants trading with the east as desirable, they became widely marketable varieties of cloth, with clear potential for growth. Historical investigations then moved on to enquire why England (particularly Lancashire) took the lead in mechanizing the discrete processes of preparing, spinning, weaving and finishing cotton cloth – sold initially on the realm’s heavily protected home but open imperial markets, and in rather short compass to Europe, the Americas, Africa and eventually to Asia, from where cotton fibres and textiles originally emanated?<sup>4</sup>

That question will also be concerned to comprehend early attempts to market cotton cloth imported from the east and to elaborate upon Western experiments with the manufacturing of proto-cottons (fustians) in Italy and South Germany. Why this early phase of the introduction of cotton textiles into consumption across Europe failed to diffuse more widely and why early attempts at spinning, weaving and finishing in several regions of Italy and Germany never matured to reach a plateau of possibilities from where mechanization became, first possible and then probable, is not clear. Perhaps the prospect was destroyed by the ravages of the

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<sup>3</sup> Lemire, 1991 and Riello, 2010 and 2013

<sup>4</sup> Wadsworth and Mann, 1931, Walton, 1989 and Riello, 2013

Thirty Years War? That problem for further research will, however, be bypassed in favour of a concentration upon the rich historiography concerned with the question of why England mechanized its cotton textile industry before established and rival centres of production on the mainland of Europe and coastal regions of Asia.<sup>5</sup>

Too many English histories begin with the import of Indian cottons into London in the late seventeenth century and end with a mechanized English industry dominating world markets for cotton yarns and cloth by, say the 1820s. As economic history they are chronologically fore-shortened and constrained within the theoretical-cum-statistical parameters of international trade theory to a point of myopia. Cotton textiles had attained the status of a global industry in the east and on the mainland of Europe before it was taken forward to become the world's first fully mechanized industry. Since this famous English contribution to the global history of technological progress cannot be plausibly represented as a random walk, historians have elaborated upon several other reasons (necessary but not sufficient) which lead us through a more complex story behind the mechanization of the operations involved in the preparation, spinning, weaving and finishing of cloth manufactured from cotton fibres that emerged in Northern Britain, before other potential locations already engaged in manufacturing cottons on the mainland of Europe and also in several regions of south and east Asia.<sup>6</sup>

## **2. Macro-economic theories of technical change**

For that purpose it has been heuristic to adopt standard distinctions in economic theories of technological change and separate evidence for an intensification in the demand for new technologies from the supply side forces that enabled and induced entrepreneurs to invest in, or to actively patronize endeavours to search for,

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<sup>5</sup> Vide, the series of unpublished papers by Styles 2017 and 2018.

<sup>6</sup> O'Brien, 1991, 1996 and Basalla, 1998

develop and diffuse machinery and new forms of organization for the production of cotton textiles.<sup>7</sup>

For demand (or to be concrete) for British consumers to have played anything approximating to a primary role in the transformation of English cotton textile production between the times of Kay and Roberts, the nature and status of domestic consumption as a major determinant that can be represented (in some significant degree) as autonomous from changes in either the market prices for cotton goods or family incomes, needs to be specified. Historians who have pursued impressive research for some decades now on the rise of material culture or the particularities of an English consumer revolution may not have accorded sufficient weight to the fact that the extension and deepening of the domestic market for cotton textiles (that was indeed important for the early development of a new industry evolving towards a factory system of water and steam-powered mechanized production) depended upon a rise in family incomes and/or declines in the prices of cottons compared to the prices of woollen, silk and linen textiles.<sup>8</sup> Changes in taste, together with its manipulation by merchants, shopkeepers and others responsible for sales certainly helped markets for the new fabric to expand to a level from where inducements to mechanize production became stronger. Yet comparable inducements might well, however, have been present for all firms and locations where cotton textiles were being produced both in Europe and Asia. Narratives that emphasize a quasi- autonomous role for English and other consumers of cotton textiles are implicitly comparable and may not be attaching sufficient degrees of significance to changes in relative prices and family incomes in the United Kingdom compared with other parts of an expanding international market for cotton textiles.<sup>9</sup>

Unless historians can demarcate and validate a peculiar English propensity to reallocate expenditures towards cotton textiles prior to the mechanization of

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<sup>7</sup> Crafts, 1977.

<sup>8</sup> Brewer and Porter, 1993 and Trentman, 2016.

<sup>9</sup> Berg, 1980, 1985, 2002, 2005.

production, then the wave of recent and scholarly research devoted to: exposing “meanings” embodied in cotton textiles, to the power of fashion, to the imitation of imported oriental luxuries and other elements labelled as cultures of consumption can only be represented as complementary variables within a narrative long dominated by the analysis of technological innovation. While the particularities of domestic demand certainly *sustained* and influenced the composition of an accelerated growth of English cotton textile output, particularly in its formative stages, the origins of its status as Britain’s leading textile and an outstanding industry in world trade continues, nevertheless, to reside basically where traditional historiography placed it, namely, with mechanization which drastically reduced costs of production in England before centres for its manufacture in other parts of the global world economy.<sup>10</sup>

Global histories of technology now suggest that advances gradually occurred over very long periods of time as the product of an accumulation of useful and reliable knowledge that emanated from every culture and all parts of the world. Nevertheless, that history also shows that innovations appeared in specific locations at particular times.<sup>11</sup> Famous breakthroughs in the form of machines and processes for the preparation, spinning, weaving and finishing of cotton cloth emerged in England over the century after John Kay patented the Flying Shuttle in 1733. Alas (and despite a library of research into the history of English technology) their emergence remains easier to describe than to explain.

One general theory continues to make sense to economists. They are strongly inclined to predict that any sustained flow of innovations that saved labour is likely to persist in countries and regions with relatively high levels of real wages. That plausible and familiar prediction derived from the theories of induced innovation (extended by Habakkuk who linked rates of technological progress to choices of capital intensive techniques) provides the essential foundations for

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<sup>10</sup> Lemire, 1991, Berg, 2002, Guest, 1823, Baines, 1835-36, Daniels, 1920, Mantoux, 1925, Chapman, 1972, Kerridge, 1985, Rose, 1996, Harley, 1998 and Stobart, 2004.

<sup>11</sup> McIntosh, 2017?



Robert Allen's rigorously argued and heuristic thesis that relatively high wages (together with cheap fuel) are core chapters for any narrative in global economic history designed to explain why Britain became the locus for a First Industrial Revolution.<sup>12</sup>

As befits a seminal book by a top-class economic historian, his arguments and the data mobilized to support them have come under close and sustained scrutiny since their publication in 2009.<sup>13</sup> Nothing convincing has appeared to dislodge or qualify the importance that Allen also attached to coal. On the contrary it has been reinforced by the publication of statistics from the Cambridge school which have consolidated Tony Wrigley's earlier assessments for the significance of Britain's access to elastic supplies of cheap mineral fuel which sustained accelerated rates of urbanization, structural change and (via agglomeration effects embodying as refined divisions of labour) the formation of skills and the accumulation of human capital over the eighteenth century.<sup>14</sup>

Allen's related thesis that differentials in real product wages can be represented as a highly significant macro-economic incentive behind the precious mechanization of British industry has, however, come under sustained conceptual and empirical challenges that are heuristic to consider.<sup>15</sup>

Given the paucity of reliable data on nominal wage rates or earnings at their disposal as evidence to validate this theory economic historians have been compelled to rely upon primary sources that refer to nominal daily wage rates paid to skilled and unskilled male workers employed in the urban construction industries of Eurasian cities calibrated into statistics purporting to represent real wages received by workers in employed in the towns, regions and industries of Britain, mainland Europe, India, China, the Ottoman Empire and elsewhere in

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<sup>12</sup> Habakkuk, 1962 and Allen, 2009.

<sup>13</sup> Humphries, 2013.

<sup>14</sup> Balderston, 2010, Malanima, 2016 and Wrigley, 2016.

<sup>15</sup> Allen, 2009 and 2015, Bengtsson and Drike, 2005, Grignolati et al, 2011, Styles, 2017 and 2018.

the world economy.<sup>16</sup> Unfortunately for reasons elaborated in tedious detail and published elsewhere, the statistical sources available to construct nominal wage rates for China and India are simply not fit for purposes of conducting comparisons with Britain. There are too many salient contrasts in the family and institutional frameworks surrounding the employment of labour across Eurasia to quantify Eurocentred views that the abundance of cheap labour constitutes a sufficient explanation for the lack of technological innovation displayed by Oriental economies in early modern times.<sup>17</sup>

*Mutatis mutandis* it has turned out to be inordinately difficult to find and calibrate the statistical evidence required to place relatively high and/or rapidly rising real product wage rates centre of a parsimonious and theoretically plausible explanation for the precocious mechanization of textile production in north western England compared to other regions with concentrations of labour engaged with the production of textiles within the kingdom, let alone the mainland of Europe, China and South Asia.<sup>18</sup>

Allen initiated the research programme which has recovered an impressive amount and range of statistics for daily wage rates paid to skilled and unskilled labour employed in a sample cities in early modern Europe and he designed innovative methods to convert this data in ways that have facilitated acceptable and heuristic comparisons of real wage levels across space and over time.<sup>19</sup>

Hard won and carefully calibrated evidence has allowed historians to observe that (adjusted for purchasing power parities) the ‘real’ wages of wage dependent male workers employed in English towns had risen since 1500 to levels that by the mid-eighteenth century were discernibly higher than the real wages earned by their counterparts employed in larger towns throughout western Europe (with the exception of the Netherlands). On this statistical basis (supplemented by

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<sup>16</sup> Deng and O’Brien, 2016.

<sup>17</sup> Muldrew, 2012 and Styles, 2017 and 2018.

<sup>18</sup> Allen, 2001, 2015, 2019 and Styles, 2017.

<sup>19</sup> Kelly et al, 2015, Du Plessis, 2016 and Styles, 2016.

complementary impressions that suggests that the English workforce included higher proportions of skilled and productive labour than the workforces of mainland economies), a plausible thesis could be constructed to support a macro view that England's high wage economy provided either a necessary and sufficient or, at least, a strong and general incentive for the precocious and sequential mechanization of the several operations involved in the manufacture of textiles made from the range of organic fibres beginning for explicable reasons with yarn and cloth manufactured from cotton fibres imported from the Americas.<sup>20</sup>

That parsimonious but under-specified explanation has, however, been exposed to be conceptually ambiguous and to rest upon weak statistical foundations. For example, debates on the validity of the primary sources utilized to track and compare average levels of real wages across Europe have continued, and are centred around a key question: did differentials emerge before or after 1750?<sup>21</sup>

Furthermore, the statistical samples utilized to compare the average levels and trends of real wages of British urban workers with their counterparts on the mainland before the period of mechanization embodies considerable degrees of variance by regions, by age, by gender and by industry and by occupation.<sup>22</sup> Thus, and although Britain may well continue to be represented as Europe's high wage economy, and the paradigm case for a premodern 'Little Divergence' that early divergence in wage levels (if established) provides no warrant for the assumption that relatively high or rapidly rising real wages could be applied *a priori* to the rather large share of England's workforce employed in proto-industrial textile production. On the contrary, and for plausible reasons, the secondary literature suggests the opposite may well have been happening.<sup>23</sup> Shifts of textile production from regions of higher, to regions of lower waged labour has long been well documented.<sup>24</sup> Furthermore, Parliamentary regulations promoted divisions of

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<sup>20</sup> Kelly et al, 2016

<sup>21</sup> Malanima, 2013

<sup>22</sup> Hunt, 1986

<sup>23</sup> Humphries, 2013, 2015 and 2016

<sup>24</sup> Clarkson, 1985

labour coupled to patterns of internal trade in yarns and unfinished cloth emerged between England and the poorer 'kingdoms' of Ireland and Scotland.<sup>25</sup>

Balances of trade in textiles between the realm and its competitors on the mainland suggest that England's textile industry operated at the cheaper end of the commodity chains for linens and silks.<sup>26</sup> There is only one conclusive test for the hypothesis that relatively high wages can be placed at the core of narratives designed to explain the precocious mechanization of England's cotton textile industry. That test requires reliable data for the levels and trends in nominal rates of remuneration for a range of carefully specified and transparently comparable tasks involved in the transformation (i.e the preparation, spinning, weaving and finishing of cotton fibres (of similar counts, weights, qualities and other characteristics) into final outputs for comparable varieties of cotton fabrics. These fabrics should, ideally, be manufactured over a period when relatively high or rising costs for labour were clearly eroding the returns of capitalists engaged in the coordination of production. *Ceteris paribus* this situation would have created significant and relatively clear incentives for mechanization.<sup>27</sup>

Needless to say, no such refined data has been (or predictably will be) published.<sup>28</sup> Most of the workers engaged over centuries in handicraft and domestic production of textiles were remunerated at piece rates of pay for which few and geographically scattered records survive. That evidence is heavily concentrated on the earnings received by women assisted by children engaged in spinning flax and wool fibres into numerous and evolving varieties of yarn. Allen critics are prepared to calibrate and use these statistics as proxies to refer levels and trends in the earnings of spinners of cotton fibres. Insufficient attention has been paid to the labour markets from which evidence for the earnings or wage rates of handicraft spinners has emerged. The primary sources rarely refer to cotton fibres or to

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<sup>25</sup> O'Brien, 1998 and Griffiths, 2008

<sup>26</sup> Davis, 1979

<sup>27</sup> Kelly et al, 2012 and Styles, 2017, 2018

<sup>28</sup> Muldrew, 2012

Lancashire, the location of the labour market where spinning machinery first appeared.<sup>29</sup>

As they stand, these statistics do, however, reveal that ‘average’ earnings for spinning wool and flax (and only by extension) cotton fibres, witnessed cycles of upswings between the 1680s and 1750s. Pending further and future research on the timing, degree and duration of these upswings from traditionally stable and low levels remains under debate as does the extent to which the differentials between male and female nominal wage rates narrowed over time.<sup>30</sup>

Throughout Europe endeavours by ‘firms’ to expand the proto-industrial production of textiles was marked by two strategies for the maximization of profits. The first and least difficult was to tap into and employ accessible supplies of cheaper labour (women, children, paupers, convicts and others with limited opportunity costs) or to extend the geographical perimeters for employment to include locations that contained elastic supplies of such labour able and willing to accept lower wages per units of output. The second was to seek to recruit a workforce capable to producing yarns of higher quality and value at wage rates per unit of output that did not erode some acceptable share of the profits obtainable from differentiating and upgrading the finished product into more highly priced fabrics.<sup>31</sup>

Applied to Lancashire, the high and rising wage theory for the invention, improvement and diffusion of jennies, water frames and mules for the production of cotton yarn implicitly assumes that textile ‘firms’ located in relatively low wage counties of north western England had more or less exhausted both options.<sup>32</sup> Thereafter, and for several decades before Hargreaves constructed a prototype spinning jenny, a widely recognized problem (namely an inelastic supply of cheap female labour, who could spin yarns of the required quality from cotton fibres

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<sup>29</sup> Humphries, 2016, Styles, 2017 and Allen, 2019

<sup>30</sup> Humphries, 2016 and Allen, 2016, 2019

<sup>31</sup> Jenkins, 1994 and Styles, 2017

<sup>32</sup> Styles 2017

(warps as well and wefts) and imparted a momentum to the search for mechanical solutions that became more significant and ultimately more successful than was the case for other regions of concentrated textile production located elsewhere in the kingdom or on the mainland of Europe.

Serious scholarly debates to test this theory with reference to proxy indicators for levels and movements for the unit costs of spinning varieties of yarn have apparently floundered in face of inferences drawn from the disappointing amount, quality range and potential relevance of statistical evidence available for north western counties of England and for Normandy.<sup>33</sup> Other relevant and reliable data statistics related to proto-industrial textile regions within the realm or the mainland and of Europe have not appeared in print.<sup>34</sup> In the absence of data to validate or to invalidate it, the high wage inducement theory to explain the precocious mechanization of cotton textile production in the northwest of England retains its status as an hypothesis that continues to be potentially heuristic to investigate and debate.

Meanwhile an alternative hypothesis looks more promising to embrace. This equally untested hypothesis suggests that the strongest impetus behind an intensified search for mechanical solutions to problems associated with spinning cotton fibres within that proto-industrial region of England could be attributed to the presence of an elastic supply of otherwise under-employed poorly paid female labour with sufficient skills to produce low quality cotton wefts but not warps. This Lancastrian workforce utilized traditional handicraft methods which provided them with almost no opportunities to increase output per hour while they continued to work with spinning wheels.<sup>35</sup>

Complaints about the low productivity and quality of Lancastrian spinners are common among the contemporary quotations cited by the rich and long-

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<sup>33</sup> Gagnolati et al, 2011, Horn, 2012 and Styles, 2018

<sup>34</sup> Cipolla, 1971 and Kreidte et al, 1981

<sup>35</sup> Walton, 1989 and Griffiths, 1992

established body of published literature of the origins of the cotton industry.<sup>36</sup> That literature surveyed in the unpublished working papers cited above and in classical books and articles on proto-industrialization published by a previous generation of economic historians, exposes features of Europe's pre-modern manufacturing industry that are familiar.<sup>37</sup> In textiles competitive firms while engaged in a perpetual search for cheaper and exploitable labour confronted markets that were expanding for more diverse and finer varieties of cloth and bottlenecks that became more common in spinning than weaving. Since these problems had remained common and constant across the manufacturing regions for European textiles, it is no surprise to find evidence for their presence among the industrial workforce of northwest England.<sup>38</sup> Allen's presumption that extraordinarily high unit costs for spinning cotton fibres in that region would have promoted a commensurately intense search for mechanical solutions is plausible, but seems impossible to prove and is partial.<sup>39</sup> The local propensity to engage with and fund a process of search would also depend on confidence and expectations that could become operational, commercially viable and profitable for those involved. Post hoc all the problems associated with spinning cotton fibres into the varieties of yarns required for the manufacture of a variety of fabrics were solved. To reduce that outcome to the solution of an unquantifiable symptom of a long standing and widespread problem could be too parsimonious for historians to support.<sup>40</sup>

To sum up: insights derived from theories of "induced technical change" are not irrelevant to the question of why England mechanized the manufacture of cottons ahead of its rivals, but given the paucity and low quality of the statistical evidence available for other proto industrial textile regions of Europe, India, China and Japan they remain contestable and incomplete.

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<sup>36</sup> Guest, 1923, Baines, 1835/6, and Ure, 1970

<sup>37</sup> O'Brien, 2005, Kreidte et al, 1981

<sup>38</sup> O'Brien, 2005, Kreidte et al, 1981

<sup>39</sup> Humphries, 2013 and Allen 2015, 2019

<sup>40</sup> Daniels, 1920, Chapman, 1972, Kerridge, 1985, Clarkson, 1985, Mokyr, 2009

Another popular, but more vacuous theory is the endlessly repeated challenge and response model which posits that John Kay's invention of the flying shuttle in 1733 initiated a sequence of challenges and positive responses to each process in a chain of production from the preparation and spinning of fibres through to the weaving, dyeing and printing of finished cloth.<sup>41</sup> The notion of a connexion, whereby the successful mechanization of any single process in a sequence of production running from raw material inputs to final outputs will create shortages, incentives and opportunities up and down stream, cannot alas be validated or invalidated. It just about merits a mention in histories of cotton or similar industries where separable processes could be taken over by machines sequentially. The problem with the model is that it fits almost every situation and never explains variations in lags between challenge and response. Furthermore, the machine that is supposed to have initiated some kind of take off into self-sustained technological progress (Kay's Shuttle) exercised an entirely limited impact upon overall demand for cotton yarn and diffused too slowly to be systematically linked to the appearance of machinery for carding, roving and spinning that came on stream decades after it became commercially viable.

Statistical tests on patents and other records for invention available expose no evidence of clustering for cotton textiles that would signify that research and development became concentrated upon remedying shortages or responding to price signals created by imbalances in flows of intermediate and final outputs. As and when clustering appears in patent and comparable data available for textile industries, it concentrates around improvements to the appearance of *prototype* operational models for the preparation of fibres for spinning and weaving, as well as finishing processes.<sup>42</sup> Furthermore, and although the latter added considerable value to cloth, for inexplicable reasons the dyeing and printing of cloth are often missing from historical narratives based upon traditional challenge and response models.<sup>43</sup>

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<sup>41</sup> Wood, 1911/12, O'Brien, 1996, Griffiths et al, 1992, Kelly, 2015

<sup>42</sup> Griffiths et al, 1998 and Styles, 2015

<sup>43</sup> Turnbull, 1951, Cardwell, 1994, Riello and Pasarasathi, 2009 and Riello, 2010



### **3. Inter-continental and inter-regional contexts for mechanization**

Since prospects for deploying testable theories to explore the reasons behind the lead taken by England in mechanizing cotton textile production are not that promising, perhaps the only ways to construct a more comprehensive and plausible historical narrative is to place the island kingdom's geopolitical and commercial advantages alongside the natural and accumulated human endowments available for its emerging industrialization by, say, the turn of the eighteenth century. That narrative might persuade us that England's advantages seem post hoc to have evolved into a set of relatively favourable contexts that help to explain its lead for the mechanization of a new industry which was closely linked at every stage of its development to trade overseas.

By the Treaty of Utrecht, concluded in 1713, the kingdom had attained the status of Europe's leading commercial and imperial power with a hegemonic standing navy required to maintain external security with internal stability, which supported England's policy of aggressive mercantilism pursued decade after decade in order to increase its share of gains from trade, shipping and commercial services at the expense of European rivals. Part of those gains included well protected access to its own colonial markets, coupled with aggressive policies to secure entry to foreign markets for all kinds of domestic, industrial and other exports.<sup>44</sup>

In addition, the policies and institutions embodied in English mercantilism provided an efficient framework of protection for the regular import of three commodities that appear to have been central for the development of domestic production: namely, finished cloth from India and China carried into London (by the East India Company), linen yarn from "colonial" Ireland and bales of longer staple cotton fibres cultivated, cleaned and ginned on slave plantations in the West Indies and the Southern states of America and Brazil. All three imports increased over time and became key inputs promoting and supporting a transition to a

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<sup>44</sup> O'Brien, 2014

sustained growth of a factory-based mechanized cotton textile industry located mainly in Lancashire but also in the Lowlands of Scotland.

Their significance as inputs produced by cheap and exploited labour overseas for an expanding industry based in England, has long been clear. For example, for some five decades before they were gradually excluded by tariffs and bans from legal access to the Isles, finished and unfinished cheap Indian (and Chinese) cotton cloth created, expanded and integrated a domestic market for a cloth that had long been known as an alien and exotic but marginal textile, compared to indigenous woollen and linen cloth and luxurious silks purchased by the kingdom's consumers. Prices were critical, but it also took time and investment by merchants to alter elasticities of substitution (i.e. to shift purchases) in the direction of a novel textile.<sup>45</sup>

Elaborations upon this familiar process of import substitution probably covers most of the demand side of narratives constructed to show how the rapid rise of an English cotton textile industry evolved and matured.<sup>46</sup> Another chapter (set in an historical context of internal colonization) would be the political economy of a state enforced inter-regional division of labour between a long established proto industry for the manufacture of fustian (a cloth made of linen warps from the Celtic fringes and cotton wefts from Lancashire) within the United Kingdom. Prior to its transformation into a factory based mechanized industry, the manufacture of textiles in Lancashire used imported linen yarns, spun by cheap and subsidized rural labour living in Ireland (and on a far smaller scale from Scotland). These Celtic yarns were the warps for a cloth manufactured from two organic fibres: flax and cotton. When the kingdom's domestic supplies of cheap linen yarns became less elastic, incentives intensified to exploit the potential of cotton fibres imported from imperial plantations, utilizing slave labour and abundant land in the Caribbean, Virginia, Georgia, the Carolinas, Brazil and elsewhere in the Americas to produce a commercially viable substitute for fustian cloth, which could be woven

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<sup>45</sup> Riello, 2013

<sup>46</sup> O'Brien et al, 1996 and 1998, Griffiths et al, 1992

from wefts and warps spun entirely from imported cotton fibres.<sup>47</sup> Fortuitously as it turned out, cotton fibres also embodied tensile and other properties relatively favourable for the spinning, weaving and, above all, the dyeing and finishing of cloth for a widening range of varieties and uses.

To sum up: a matrix of possibilities and opportunities for the development of a mechanized cotton textile industry emerged and evolved from prior and sustained commitments by the kingdom's state to naval defence for the realm, coupled with mercantilism overseas, to internal colonization and economic regulation of its Celtic fringe, as well as joint ventures with private enterprise for the protection of commercial expansion into the Caribbean, Americas, Africa, India and China. Maritime and imperial opportunities for economic expansion overseas had also been available to the rest of Europe over the centuries. Nevertheless, the English state seized and sustained advantages for the Island's domestic commerce and industry (particularly as it turned out) for the long term development of a mechanized cotton industry. In retrospect its geopolitical policies seem to have matured from the times of the Commonwealth onwards into a more effective form of mercantilism than anything provided by the states of England's industrial and commercial rivals on the mainland.<sup>48</sup> English mercantilism which included significant participation in colonization and the Atlantic slave trade) must be included in a matrix of necessary conditions for the development of a new textile industry that fortuitously embodied what emerged as a potential for mechanization.<sup>49</sup>

#### **4. England's agents and cultures for invention and innovation**

Further elaboration on the context of preconditions for the emergence and evolution of a fully mechanized cotton textile industry is not necessary and will not, moreover, complete the narrative. It does not account for the emergence and

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<sup>47</sup> Griffiths et al, 2008 and Thales, 2016

<sup>48</sup> O'Brien, 2014 Rose, 1996

<sup>49</sup> Rose, 1996, Inikori, 2002

timing of water and steam-powered machines and chemical processes that, over the course of a century, completely transformed the costs of producing cotton yarns and cloth. Mechanization points us back towards agency and to a remarkable group of mechanical engineers, who conceived, experimented and invented prototype machines as well as generations of skilled artisans agglomerating in towns who improved and maintained the machinery that raised the productivity of labour employed in the preparation, spinning, weaving and finishing (dyeing and printing) of this imported natural fibre into varieties of cotton cloth.

In print there is a rich vein of traditional historiography particularly for the English cotton industry, dealing with inventors that traverses a spectrum from heroic hagiography to analyses based upon predilections (inherent in modern social science) to derogate the role of individuals in this core sphere of innovation by abandoning notions of invention or breakthroughs. This literature emphasizes processes of continuity and taxonomies for development, improvement and incremental change which are more congenial to model than the unpredictable achievements of small and somewhat random groups of creative individuals. These parsimonious models do not find favour among historians who have studied the English cotton industry over the long run. They continue to represent its precocious mechanization as a stepwise evolution that looks neither inevitable linear nor continuous.<sup>50</sup>

That view can be located in a densely and deeply researched tradition that represents the history of this industry as a process that proceeded between the times of Kay and Roberts as a sequence of progressive advances marked by the emergence into the public domain of prototype machines that provided foundations for modifications, improvements and learning by use before they became commercially viable.<sup>51</sup> Inventors recognized, but modestly rewarded, by their contemporaries have long been celebrated by Victorian biographers and previous generations of historians for initiating transitions from mechanically

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<sup>50</sup> Ure, 1970, Chapman, 1972, Kerridge, 1985, Jenkins, 1994, Rose, 1996 and MacLeod, 2007

<sup>51</sup> Griffiths et al, 1992, O'Brien, 1996 and 2005

operational to commercially viable shuttles, jennies, carders, rollers, mules, looms, other machinery and chemical processes that took more than a century to mature into a mechanized cotton textile industry powered by steam.

Kay, Wyatt, Paul, Hargreaves, Arkwright, Crompton and Roberts whose status as inventors of prototype operational machines has been more or less transparently established by historians with the credentials required to distinguish a macro-invention from a micro-development or improvement are a small sample of Englishmen residing in one of several advanced proto industrial regions close to the waterways of Eurasia.<sup>52</sup> This sample of six inventors is, however, simply too small to be aggregated into a database for a prosopography of inventors. Furthermore, the group emanated from a range of such different family, occupational and educational backgrounds that to represent them as a distinctive sub-group of England's complex social structure seems anachronistic.

For that purpose not much help is, moreover, on offer from psychology. Although that discipline has calibrated substantial volumes of biographical evidence in ways designed to conceptualize the personalities of artists, scientists, politicians, soldiers, inventors and others recognized post hoc as "creative". This body of psychometric literature depicts creative people as "intrinsically self-motivated; possessed of confidence, zeal, perseverance and a visual imagination as well as manipulative and exploitative behaviour towards those close to them". Some limited evidence is out there in primary sources that could be applied in an ad hoc ad hominen way to all six of our sample. Alas, such innate traits of character would not find extraordinary expression in Crompton's talents as a violinist; Cartwright's tedious and idiomatic poetry or Kay's, Hargreaves and Roberts' acumen as businessmen. The rather amorphous range of adjectives reified into concepts for psychometrics could well, moreover, have been present in larger samples of men engaged with the production of textiles whose endeavours simply failed for reasons that are almost never investigated. In any case the same vocabulary emerges far too often in most biographies of creative people. There is,

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<sup>52</sup> Stobart, 2004

moreover, no evidence or reason to suppose that these six remarkable mechanical engineers were alike in those respects that led to their particular achievements as inventors of prototype machinery for cotton textiles.<sup>53</sup>

Thus the cultural, social and economic spaces inhabited and exploited by Kay, Wyatt, Paul, Hargreaves, Crompton, Cartwright and Roberts during their years of creative endeavour continue to seem more enlightening for historians to investigate and contemplate than probes into the creative features of their personalities, let alone the neurology of their brain cells.<sup>54</sup> The “spaces” that anthropologists (and latterly historians) have in mind are the social networks and personal frames of reference that represent the visualized opportunities, the encouragement of families and friends as well as a range of material and other incentives that in all probability conditioned the aspirations of a far larger group of potential inventors than the six “successful cases” under review here and who clearly invested emotion, energy, time and money in pursuit of new solutions to the mechanical problems confronting the English cotton textile production. No parsimonious theory that offers a cliometric test for the problem could conceivably account for the sequence of macro inventions and macro inventors that transformed cotton textiles into a paradigm industry for mechanization.<sup>55</sup> A biographical format might, however, allow historians to recover and reconfigure a neglected chapter for narratives that could reveal how men as different as Samuel Crompton and Edmund Cartwright mobilized the financial resources as well as their social networks and local supplies of accessible skills in order to produce prototype machines of lasting significance for the mechanization of this early example of a global industry.<sup>56</sup>

Secondary and primary sources have made it possible to include a disappointing range of relevant detail into a dense description of six inventors into this working paper which, together with the economic, political and geopolitical contexts

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<sup>53</sup> Guest, 1823, Baines, 1835/6, Boden, 1994, Ure, 1970,

<sup>54</sup> Tallis, 2016

<sup>55</sup> Meisenzahl and Mokyr, 2012

<sup>56</sup> French, 1970, O'Brien, 1997 and Allen, 2016

summarized above might add up to a comprehensive and satisfying account for the mechanization of the English cotton textile industry. Biographical narratives are not conclusive but at least they restore agency to the story. Although historical biography is, however, infamous for a tendency to wallow in extraneous detail, that can be resisted by offering generalizations that apply to a group of just six successful and famous inventors and by concentrating whenever sources allow on their social backgrounds and actual processes of constructing prototype machines.

For example, with the exception of Hargreaves none of these men came from the lowest ends of England's income and status scales.<sup>57</sup> Nothing is known about their childhoods except that Kay, Paul and Crompton lost fathers when they were young and Cartwright was despatched to boarding school at the age of eight.<sup>58</sup> Again, only Hargreaves has been depicted as illiterate. The rest look well-educated by the standards of the day. Arkwright, Cartwright and Paul entered the textile industry from social positions, occupations and locations beyond its economic borders.

Almost no evidence survives into just how the Flying Shuttle, Roller Spinning, the Jenny entered and matured in the minds of their inventors. Rolling was a common process for the manufacture of paper and metals before Paul, Wyatt and Arkwright applied it to textiles.<sup>59</sup> Designs to increase the productivity of spinners to more than single strands or spindles of yarn had already been patented in 1678, 1723, 1755 and 1753 and had disappeared centuries before in China.<sup>60</sup> Cartwright said that he had conceived of his prototype loom from basic principles: "as in plain weaving according to the conception I then had of the business there could only be three movements which were to follow each other in succession and there could be little difficulty in reproducing them". This statement comes from a clergyman – well-read in natural philosophy, interested in automata with an admiration for Newton expressed in poetry and a belief becoming common among educated elites of Western Europe that manual operations could be analysed and mechanized as

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<sup>57</sup> Aspin, 1968

<sup>58</sup> Midgley, 1927, Hunter, 1951-53

<sup>59</sup> Hills, 1979

<sup>60</sup> Elvin, 1973, Griffiths, 1992 and 1998

expressions of a rational world created by God on national principles that could be investigated and manipulated by men. <sup>61</sup>

To take a “conception” forward in engineering terms to the point stage where an operational machine emerged, inventors or projectors including Cartwright, Paul, Hargreaves and Arkwright entered into periods of close collaboration with artisans. As weavers, Kay and Crompton already possessed some of the skills required to construct prototypes for the shuttle and the mule. Other inventors needed help in Cartwright’s words, to transform a “mental construction” into a “working model”. As he put it, “full of these ideas I immediately employed a smith and a carpenter to carry them into effect”. <sup>62</sup> This step had been recommended by Malachy Postlewayt’s *Universal Dictionary of Trade and Commerce*, published some three decades earlier. “When they have designed in their mind any new invention, 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”.<sup>63</sup> This sensible advice, as the biographical sources for all six inventors as well as legal histories of disputes over patents reveal, was by no means easy to follow. The search for artisans with relevant skills was often protracted. While acrimony over payments, property rights and precedents for ideas and their realization as machines or techniques characterized partnerships and collaboration between inventors and skilled mechanics that they located in Birmingham, Nottingham and Manchester. <sup>64</sup>

Although John Kay migrated to France to secure greater returns in the form of royal prizes for his mechanical ideas, the patronage, encouragement and finance required to stimulate and enable all sorts of Britons to participate in the conjoined and often protracted processes of invention, development and improvements

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<sup>61</sup> O’Brien, 1997 and 2005

<sup>62</sup> Strickland, 1971

<sup>63</sup> Postlewayt, 1751

<sup>64</sup> Fitton, 1958 and 1989, O’Brien, 1997, Bottomley, 2014



required to carry operational machines to the final stage of commercial viability were apparently surmounted in cotton textiles before other industries.<sup>65</sup>

Hargreaves attracted support from the Peels; Paul from the Shaftesburys, two lucrative marriages and some affluent friends of Samuel Johnson; Cartwright from a network of clerical connexions and a circle of literary friends but above all from the fortunes of his landed and aristocratic family.<sup>66</sup> Crompton seems to have been kept by his mother, who worked as a caretaker of a grand house for six years while he laboured on constructing the mule – a hybrid machine that combined mechanisms from the jenny with roller spinning.<sup>67</sup> The ever plausible and entrepreneurial Arkwright experienced almost no difficulties in finding partners to help him to exploit the talents of skilled artisans and in securing patents to protect the rights of his creditors to profits from investments in water-powered carding and roller spinning machines.<sup>68</sup>

Eventually (after Roberts had constructed an automated mule and loom) machinery and processes were in place) to transform the production and finishing of cotton textiles into the first automated steam powered mechanized industry.<sup>69</sup> Its inception can be traced back to the mid seventeenth century. Its evolution was far from linear and along the way had encountered serious opposition from interests vested in established textile industries and violence from working men and women engaged in handicraft forms of production.<sup>70</sup> None of the inventors of prototype machines that initiated the “Schumpeterian” trajectory for technological innovation leading to full scale mechanization and the replacement of India and China on global markets for cotton textiles made fortunes from their contributions to the development of this famous industry, apart from Sir Richard Arkwright. Yet none died as some Victorian myths suggest in penury.

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<sup>65</sup> Challoner, 1965-66, Meisenzahl and Mokyr, 2012, Wood, 1911, Midgley, 1927

<sup>66</sup> Midgley, 1927, Bates, 1996, O'Brien, 1997, Strickland, 1971

<sup>67</sup> Rose, 1927, French, 1970

<sup>68</sup> Unwin, et al, 1924

<sup>69</sup> Hills, 2002

<sup>70</sup> Nuvolari, 2002

During the early stages of the mechanization of cotton textiles patents and the Cartwright's lost a fortune by investing in the genius born into an enlightened family provided limited protection. While donations to Hargreaves and Crompton from businessmen who profited from their inventions were derisory and parliament's generous reward of £10,000 to a gentleman, Edmund Cartwright, was predictable for an age of equipoise.<sup>71</sup>

## **5. Conclusions: discovery and agency in a narrative of necessary and sufficient conditions**

Not one of England's celebrated inventors discussed in this essay lacked with a belief in the possibilities or the confidence in his abilities to solve the problems involved in the mechanization of the several processes conducted by handicraft methods for the manufacture and finishing of cotton cloth. Illuminating biographical evidence for the process of invention for this (or indeed for other periods) remains extremely thin. Along with most other residents of any commercialized market economy, inventors utilized their talents in order to make money. That propensity was probably commonplace throughout Europe already by the sixteenth century and in East Asia long before that.<sup>72</sup> What invariably strikes biographers of this elite group of English inventors is their obsession with finding technical solutions to problems of production across a wide range of mechanical processes, their curiosity (all six were multiple inventors); their persistence in the face of adversity and disappointment and their capacity to mobilize the skilled mechanics and artisans to carry an invention to commercial viability.<sup>73</sup>

Alas, dense description cannot be labelled as economics or sociology and six names could not be accepted as prosopography. What biography offers is an approach that reconstructs social and cultural contexts around individuals rather than the other

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<sup>71</sup> MacLeod, 1988 and Nuvolari and MacLeod, 2010

<sup>72</sup> R. Bin Wong, 1997

<sup>73</sup> Ure, 1970, Guest, 1923 and MacLeod, 2007

way round, which has now become a hegemonic and possibly regressive tradition in social science. To undermine that tendency a tiny group of men have been selected and placed in a Victorian pantheon of great inventors and restored as indispensable and significant human agents behind major technological breakthroughs during the First Industrial Revolution. They are not easily amalgamated into a logically bounded narrative that could move on from a context of necessary conditions to the intellectual high ground of a plausible and validated explanation for the precocious mechanization of the English cotton textile industry. With due respect to all who labour in this unfertile vineyard of history, they cannot be incorporated into modern theories of technological progress (or theories of firms investing in research and development) that have been utilized to account for accelerations in total factor productivities, to demarcate the pre-modern from modern economic growth and to separate two centuries of economic development as experienced by Europe (and European offshoots overseas) from West, South, East Asia and other regions of the world that had also passed through several centuries of commercial capitalism before the First Industrial Revolution.

This English pantheon contains men who find places there because they happened to reside in one of the most advanced of a range of successful market economies located along coastal regions of the Eurasian landmass. They are (again in some sense) exemplars of a peculiar Anglican version of Protestantism that had retained God within a Newtonian cosmology. They grew up and operated within culture for the educated elites of Western Europe permeated by science which extolled a manipulative attitude toward the natural world that was already present in Medieval Christendom, but which came on stream in the Renaissance and entered into the perceptions and motivated the patronage of educated elites and promoted the endeavours of craftsmen since the times of Copernicus (1453).<sup>74</sup> On examination, the biographical detail that we can recover does reveal an intensified form of that “frenzy for improvement” that a stream of European visitors to the British Isles remarked upon throughout the eighteenth century.<sup>75</sup>

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<sup>74</sup> Wootton, 2015, Jones, 2009, Mokyr, 2002 and 2017, O’Brien, 2005 and 2013

<sup>75</sup> Riello and O’Brien, 2009

In technology (as in the arts and sciences) halls of fame are not full of dispensable men and women. Are we no longer entitled to resort to the heroic vocabularies of the Greeks and Victorians, and to celebrate the achievements of England's great inventors? <sup>76</sup> Are there no human agents as well as contexts of necessary conditions for technological progress? On examination these men, the "cultures" they inhabited and the evolving cosmographies derived from science that surrounded them remain significant for the precocious success of an English cotton textile industry. The "sooner or later counterfactual" predictions that such inventions would have emerged anyway, begins to look more and more like intellectual sophistry bolstered by the rhetorical power of mathematical language and theory. Economic history exists to remind its parent disciplines that theories of technological progress without human agents are under-specified. But a Eurocentred and meta question for global economic history remains: what range of necessary and sufficient conditions combined with a cosmographical belief system that might have made comparable groups of innovators equally conceivable in India, China or Japan during these same decades?<sup>77</sup>

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<sup>76</sup> MacLeod, 2007

<sup>77</sup> Pomeranz, 2000, O'Brien 2005 and 2013

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