ReFRESH Spring 20 1995

Recent Findings of Research in Economic & Social History

The role of technological change in Britain's process of industrialisation has long been debated by historians. In this perceptive and wide-ranging discussion Christine MacLeod reviews the present state of understanding of the stimuli to invention in the eighteenth and early nineteenth centuries, and the nature of the response to those stimuli. She argues that in Britain particular opportunities and circumstances directed inventiveness into exceptionally fruitful channels, but that, in order to decide why some societies were more inventive than others, it is necessary to compare more precisely who was inventing what, how and why?

The Springs of Invention and British Industrialisation

Technological change was at the heart of the industrial revolution. A quickening pace of technical innovation, sustained across a broad front, set apart this case of economic growth from all preceding ones. There were, of course, other sources of growth, but only persistent technological change could underwrite the novel phenomenon of population increase, combined over the long term with rising incomes per head. Striking innovations in technique and Organisation invigorated all sectors of Britain's industrialising economy - agriculture, transport, and financial services, as well as manufacturing indus- try, the subject of this essay. How can we explain this acceleration of technological change?

Historians are increasingly asking: what makes certain societies more inventive than others? [3] Since the Middle Ages western Europe had enjoyed an upsurge in inventive activity. Britain, long on the periphery, assumed the technological leadership during the eighteenth and nineteenth centuries in specific, but economically important, industries and processes - primarily cotton textiles, iron, and steam power (with its links to coal) - although inventive activity was not confined to these giants of industrialisation, and many of the industrial revolution's technological roots lay in the three centuries before 1750.

The stimuli to invention

To attempt to explain Britain's new technical prowess we must begin with the goals of invention. For effort was not haphazard; inventors tended to congregate around a number of distinct problems and opportunities for profit. The impetus came from individuals identifying, and responding to, particular technical obstacles or desiderata in specific social and economic circumstances. All inventions are the creatures of a particular society, selected and shaped by its dominant values and priorities.

There are two ways to gauge the stimuli to invention in this period, neither completely reliable. One is to deduce them by associating detectable economic and social changes, usually price movements or new market opportunities, with predominant types of invention. Patent records can be helpful, provided one remembers they are not an accurate reflection of inventive activity as a whole: some industries had a greater propensity to patent than others, and many improvements were never included. The records of the Royal Society of Arts (founded in 1754 to promote invention and its diffusion) and technical literature in general provide a valuable supplement. A more direct, though rarer, indication is the explicit reasons given by inventors in their applications for patents and awards, and in promotional pamphlets.

Efficient energy generation

Energy generation, particularly its cost and reliability, attracted many inventors. Britain's relative shortage of wood and abundance of coal were responsible for its early, though protracted, transition to coal-burning technologies. Debate has raged over the existence of a 'timber farnine' in the sixteenth and seventeenth centuries. The most recent research restores the case for a serious shortfall in supplies of wood fuel and building timber (especially for the expanding royal, and merchant, navies) during the seventeenth century, and again in the second half of the eighteenth century.[41 In both periods charcoal prices climbed steeply; importers of Scandinavian iron and timber responded on a large scale to undercut domestic producers. So did inventors.

Experiments with coal began where the raw material could easily be separated from noxious coal fumes; soap, salt, and sugar boilers were using it by the late sixteenth century; glass makers found they had to cover their melting pots; smelters of non-ferrous metals adopted the reverbatory furnace. Repeated attempts to smelt iron with coal met with little success, however, until about 1709 when Abraham Darby, following the maltsters' practice, decarburised coal to produce coke. But Darby operated in the small, cast iron sector where coke pig iron offered distinct advantages. To produce wrought iron, coke pig iron required more processing; this only became economical as the differential between coke and charcoal prices widened after 1750.

Dr Christine MacLeod is Senior Lecturer in Economic and Social History at the University of Bristol. Her publications include *Inventing the Industrial Revolution : The English Patent System, 1660-1800* (1988).

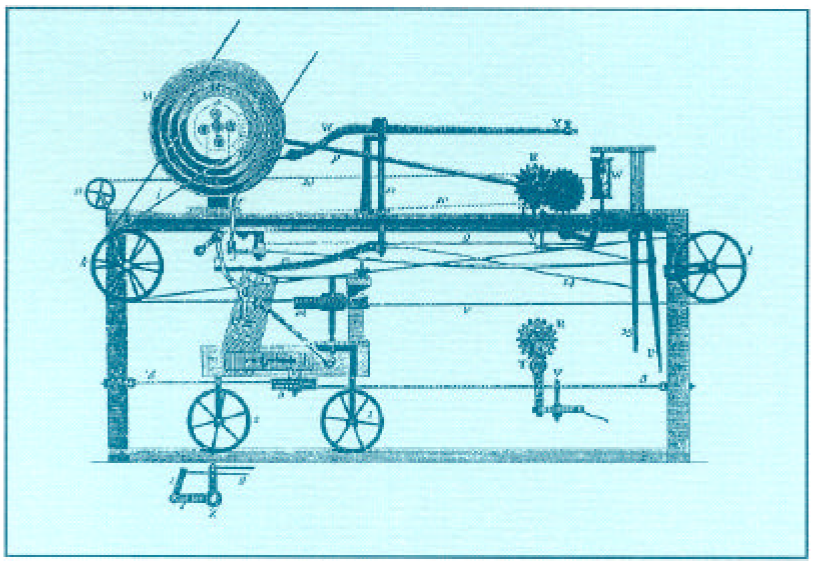

Figure 1. Samuel Crompton's Mule Source: A.Rees, *The Cyclopaedia*

Moreover, there were unavoidable delays in training sufficient work- men in the new techn iques.[2] Henry Cort's puddling and rolling process, patented in 1783-4, which allowed both the complete replacement of charcoal in wrought iron production and massive economies of scale, caused dramatic cuts in prices and consequent rapid expansion.

Saving time and capital

Despite its relative cheapness, economies in the use of coal remained an important target for invention - Neilson's hot-blast (patented 1828), for example, in the iron industry, Watt's separate condenser (patented 1769) for steam engines. Efficient energy production offered one means of reducing running costs - a concern that arose in many guises, reflecting the high proportion of industrial capital tied up in stocks of raw material, work in progress, and unsold inventories, rather than in fixed assets (such as factories and machinery).

Speeding up industrial processes therefore offering major savings of capital. A prime example was the substitution, in the late eighteenth century, of chlorine bleach for the protracted exposure of cloths to sunlight. Not only was the time cut from months to hours, but the bleacher could operate all year (not just during the summer) and land costs were minimised. Similarly, temperature -regulating equipment allowed brewers to extend their operations into the summer months, defying the heat that had previously ruined their beer.

Greater reliability of machinery and regularity of products also promised savings through quicker turn-around of materials. Inventors addressed the problems of fluctuating wind speeds and water supplies that threatened to stop mills and interrupt production. Steam engines offered independence from such delays and greater flexibility of location, but were less mechanically dependable than wind- or water-mills: in 1797 Edmund Cartwright professed to cure their tendency without great care and attention to be frequently out of order'.

Increased regularity of intermediate products would cut the amount of stock a manufacturer needed to hold. It was hard to maintain uniformity among hand workers, operating unsupervised in their own homes. Mechanisation offered a remedy: Wyatt and Paul in 1738 claimed their spinning machine would produce 'any degree of size or twist' to order. For inventors of machine tools, such as Henry Maudsley and his galaxy of ingenious pupils, the attainment of new standards of accuracy and standardisation, as well as speed, was paramount, to the benefit of machine makers and their manufacturing customers.

Saving labour

Saving labour, by contrast, was a rarely conceptualised goal for eighteenth-century inventors. Between 1660 and 1750 three times as many patents boasted that their invention would create employment as claimed, conversely, that it would save labour. Thereafter the tide began to turn, and in the 1790s, when canal construction and the French wars were siphoning labour away, forty seven patentees professed to save it (chiefly in the textile, metal and leather trades) - more than in all the rest of the century together, though still representing only seven per cent of patents issued in that decade. A further fourteen per cent patented without comment inventions which appear to increase labour productivity. Much ambivalence remained about the value to society as a whole of labour-saving inventions that threatened to bring unemployment and mounting poor rates. And many manufacturers remained wary of sinking their capital in fixed assets, so long as cheap labour was available - as the slow diffusion of the power loom and the persistence of 'sweated' outworking throughout the nineteenth century attest.

The principal productivity-raising inventions of the eighteenth century textiles trades originated in the domestic (cottage) industry. Kay's flying shuttle, Hargreave's spinning jenny, Crompton's mule, even Arkwright's water frame were first designed to raise the productivity of decentralised workers.[I] Since the demand for cotton yarn was outstripping supply, it seems probable that to expand output by re-equipping workers was a higher priority than to reduce labour's cost. Crompton, a handloom weaver, invented the mule to secure his own supply of yarn - yarn of good, even quality. However, once the mechanised factory was introduced, its requirements started to shape inventor's designs. Organisational innovations became a powerful impetus to complementary technological change; in combination they strongly boosted productivity.

In the tradition of charitable make-work schemes, several patentees ernphasised their invention's capacity to utilise female and child labour. To early factory owners, often in remote areas and faced with adult males' reluctance to enter factory employment, such machines were a godsend. Nor, with a growing dependency ratio and thou- sands of women made redundant by mechanised spinning, was it necessarily a cynical justification. Male workers, however, increasingly perceived such machinery as a threat to their livelihood and resisted it, while employers often saw it as a means of subduing militant skilled workers. A threatened spinners' strike notoriously provoked

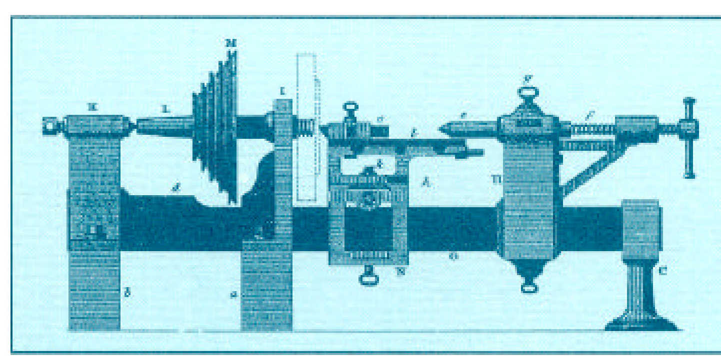

Figure 2. Maudslay's Lathe Source: A. Rees, *The Cyclopaedia*

Lancashire employers to commission Richard Roberts to automate the mule in 1825; it was far from a solitary instance. Factory legislation subsequently prompted employers to seek ways of speeding up their machinery and extracting more effort from their workforce to compensate for restricted hours.

New products

Inventive activity was directed as much to new products as to productivity-raising techniques; indeed, the former often entailed the latter. Exposure to goods from the Far East stimulated changes in taste, prompting imitation. Cotton textiles offer a prime example. Again, while many entrepreneurs prospected for clays to produce porcelain, Josiah Wedgwood developed earthenware of equal elegance. The r-is- ing disposable incomes enjoyable by the 'middling sort' encouraged manufacturers to tempt them with novelties and to compete in quali- ty and design with Asian and Continental craftsmen. Approximately one-third of late eighteenth-century patents covered items of personal and domestic consumption: everything from new designs of buckles and buttons to wigs and false teeth; from washing machines and water-closets to pianos and fire alarms.

The dynamics of invention

The scope of inventive activity during the industrial revolution defies summary. But certain points merit emphasis. First, new techniques did not sweep the board, and older ones were improved. For example, despite the availability of rotative steam engines, the demand for wind- and water-mills also increased and pressure on suitable sites mounted, prompting inventors to make them more powerful, efficient, and reliable. Secondly, improvements in one technology or process directed inventors' efforts to weaknesses in complementary spheres. For example, the development of deep-mining techniques emphasised the need for improved drainage and transportation: Newcomen's atmospheric engine, invented about 1712, was one among many responses to the former; canal construction and wagon ways (the forerunner of railways), to the latter.

Thirdly, innovation progressed by mainly small steps, forgotten blind alleys, and an army of anonymous inventors, who pushed forward technologies from their original awkward conceptions, though mechanism, available in a range of sizes, shapes and prices. Some imaginative leapswere greater than others, but no successful invention was ever the work if a single individual.

The inventive response

It is perhaps hard to remember now that this creative response, let alone its success, was neither automatic nor guaranteed. Societies may tolerate, or adapt to, difficulties without recourse to technological change. A timber shortage might be eased by planting more trees [as advocated in *Sylva (I* 664), John Evelyn's great work for the Royal Society], or by importing wood, or by using it less wastefully. A labour shortage might be met by drawing in new sections of the population (perhaps more women and younger children), or by extracting more effort from existing workers. Tried and tested ways might be preferred in the face of uncertainty. The sudden demise of Chinese technological creativity in the fourteenth century seems to provide an example of this.[3] What made Europeans, particularly Britons, at this time both willing and able to invent and to assume the risks of innovation?

Technology and science

A much debated causal factor is the advance in experimental science associated with the 'scientific revolution' of the seventeenth century; the chronology offers a neat fit. However, we should beware of native equation of technology with 'applied science': the notion that scientists discover new knowledge, technologists put it to use. Technological disciplines develop their own body of theory and expertise, derived from controlled experiments, observation, and experience, and are distinguished from those termed 'sciences' only by their overriding concern with technical design. Initially technologists may succeed with only a superficial understanding of fundamental principles, but long-term progress depends on discovering why something works - or fails to work. Jenner's invention of vaccination and Watt's of the separate condenser succeeded largely in ignorance of immunology and thermodynamics respectively, but each set the agenda for future research - which would, in turn, inform future improvements in practice.

An anachronistic distinction between 'scientist' and 'technologist' compounds the difficulty of comprehending their relationship. For instance, Josiah Wedgwood and Joseph Priestley both pursued chemical investigations, exchanging information and ideas; that one was also seeking to improve his products, the other not, is irrelevant to the status of science in technological change. More significant in this particular context is the growth of new opportunities for contact between creative people of disparate backgrounds, such as the Lunar Society of Birmingham to which both men belonged.

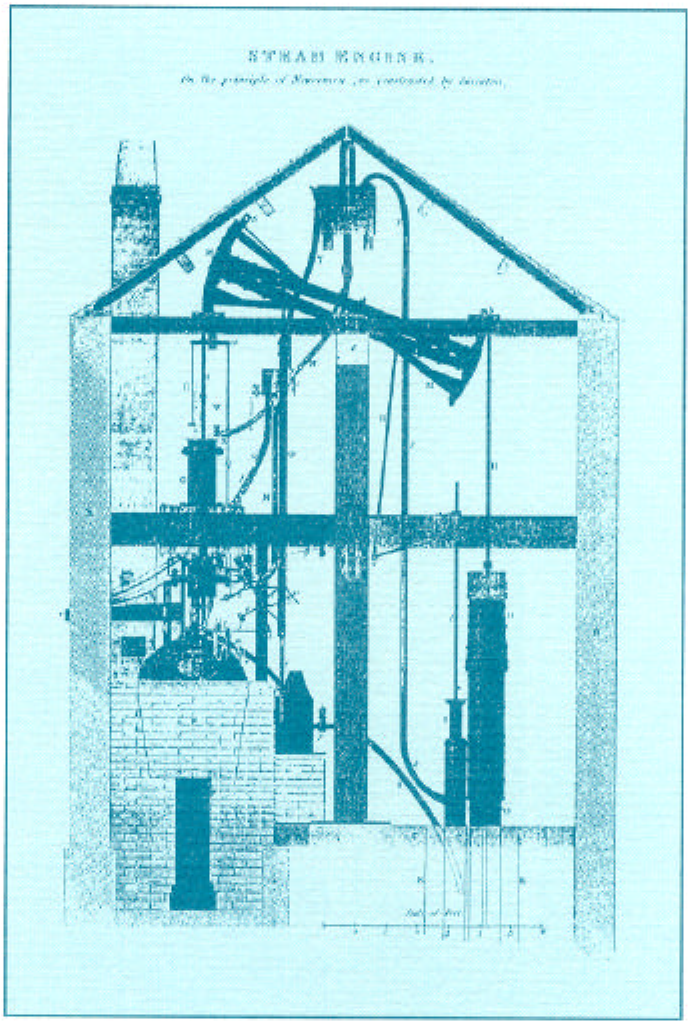

Figure 3 Newcomen's atmospheric engine   Source: A.Rees, *The Cyclopaedia*

Most historians now derecate the role of science in the British industrial revolution, limiting its impact to an indirect promotion of experimentation and recise measurement. Yet even this requires qualification. The novelty lay in a more rigorously quantitative approach that would provide practitioners with generalisable principles. Thus John Smeaton's exacting research, in the rnid eighteenth century, which was intended to improve his own water-wheel designs, informed much subsequent water-mill construction.

The spectrum of feasibility is always extended by an increased understanding of natural phenomena ('science'). The **pace** of discovery quickened from the seventeenth century, as the community of investigators and the resources available to them expanded. Consequently, the inventor's intellectual resources also broadened. The discovery of electricity enlarged the scope of those aiming to send messages over a distance, but designing an electric telegraph System required far more than knowledge of the transmitting potential of an electric current. Sinfflarly, Berthollet's discovery of the bleaching powers of chlorine gas suggested a powerful new technique, **provided that safe,** effective ways could be devised to employ that poisonous substance. Neither the design skills nor the high degree of craftsmanship and experience required to make new insights practicable should be underrated.[2] Perhaps it is these, rather than to the scientific knowledge which was more readily communicated throughout western Europe, that we should look to explain Britain's technical lead.

Networks of information

AJI channels of information were running more freely by the eighteenth century. Expanding transport networks, regular newspapers and postal services, complemented by a high level of literacy (especially in towns), speeded up and widened the flow of information through the country at large. Britain was the second most urbanised nation in Europe by 1750: nearly twenty per cent of its population lived in towns of over 10,000 inhabitants. Urbanisation was especial- ly conducive to innovation: concentrated populations circulate information more quickly, and townspeople appear to he more open to novelty. Proximity stimulated competition among manufacturers and facilitated the exchange of ideas by stealth or consent. Patentees were overwhelmingly urban - regularly over half from London alone before 1800. Furthermore, the burgeoning popularity of scientific and technical publications, instruction, and informal societies throughout the country diffused information to a wider audience. Also, by both boosting confidence in the feasibility of technical progress, and helping inventors to identify critical problems, this may have stimulated the search for technical solutions.

Patents

Increasing knowledge facilitated inventive activity, but could not alone motivate it. Altruistic inventors exist but are rare. What did inventors hope to gain from their efforts?

The concept of protecting and promoting inventions by patents of monopoly spread from fifteenth-century Italy throughout western Europe. It has been argued that patents provided a major new impetus to technological change, by capturing for inventors the material rewards of their ingenuity. However, although England's patent System was better than nothing, it was far from ideal. Patents were expensive to obtain and hard to enforce but the system's very existence enjoined its use, partly by inspiring a defensive anxiety that an inventor who failed to patent might be preempted by an industrial spy, partly by bestowing kudos on a product (an implied but specious royal guarantee of quality).

To the multiplying band of professional inventors, such as Edmund Cartwright and Henry Bessemer, dependent on selling or licensing their inventions, patents provided the sole available protection - an imperfect, but perhaps necessary, encouragement that often disappointed in practice. Crompton, watching his unpatented spinning mule being exploited by others, had no recourse whatever, not even the threat of prosecution.

Workplace invention

Josiah Wedgwood, after one troublesome experience, repudiated patents. He could afford to: as a manufacturer, he was well placed to implement his inventions directly; through consistent technical ingenuity alone he could expect to outdistance his rivals.

Inventive activity occurred overwhelmingly in the workplace. From the untrammelled imagination of an outsider, such as Watt, Cartwright or Bessemer, often came the conceptual leap in a new direction, but to the established manufacturer principally belonged the steady incremental steps that ameliorated extant products and processes. Through years of practising their trade and honing their skills, working men and women discovered how best to manipulate their tools and materials; they adjusted their methods and adapted their instruments in the light of experience. Herein, most evidently, lay the advantage of Britain’s early shift to coal-using technologies, where complex techniques took time to acquire and to finesse.[2]

Only a tiny fraction of this economically vital ingenuity ever appeared in the patent records. The biggest rewards for invention at this period lay in regular business activity. Watt was unusual in profitably licensing others to use his own invention rather than using or manufacturing it himself (before 1769). Arkwright, more typically, made his fortune in his factories, employing his novel machinery to produce cloth competitively and in unprecedented quantity; he licensed few others; the cancellation of his patents scarcely mattered. The prospect of raising one's own productivity (or a reward for raising one's employer's) was probably always the greatest incentive to invent.

By the late eighteenth century, especially in London, Birmingham, and the northern textile regions, 'engineers' and 'machine makers' started to specialise in supplying the expanding manufacturing sector with equipment. Competing on performance as well as price, they became conduits for innovation, disseminating the improvements embodied in their products. Moreover, they advanced the standard of machine tools, which often proved crucial to the feasibility of an invention reliant on accurate metalworking skills: Watt's steam-engine cylinders, for example, were dependent on Wilkinson's cannon-boring machinery.

The social context

Ingenuity was inspired by a competitive market environment, where inventors and innovating entrepreneurs could expect to reap the gains of their efforts, but the broader social context should not be overlooked. The British state offered a positive, if hesitant, approval of innovation, preserving patents for invention despite massive opposition to monopolies in general, and increasingly withdrawing support from workers whose livelihoods were menaced by technological change.[I] Manufacturers, their enterprise threatened by neither an arbitrary state nor a particularly corrupt legal system, could reasonably expect to profit by innovation. An ethos of religious toleration and a general openness to new ideas, evinced by the ferment, especially in London, of pamphlets, lectures, and demonstrations of scientific phenomena, marked out Britain as a society where inventors might expect a hearing - even approbation.[3] Inventors were attracted from Europe and America.

Historically, British advances drew heavily on Continental expertise. Elizabeth I's government had promoted the introduction of new techniques and products through immigration - German miners and metal workers, French and Italian glass makers, Dutch and Flemish cloth makers. A century later, Huguenot refugees from France boosted the standards of many trades. Britons spied out Continental techniques, John Lombe in 1716, for example, notoriously stealing Italian machinery designs for his Derby silk factory. Britain's reputation for technological 'borrowing' and adaptation persisted into the nineteenth century - for example, from France came paper-making machinery, new methods of making soda and bleach, jacquard's loom, and the era's most exciting invention, the hot-air balloon.

Conclusion

In a largely commercialised economy with rapidly widening markets both at home and overseas and increasingly unfettered competition, the returns to innovation were growing. A slight reduction in costs, an eye-catching variation in design, could secure an edge over the pack of competitors snapping at the manufacturer's heels. The mater- ial gains from technological changes provoked scientific enquiry, setting up a 'virtuous circle' of knowledge creation, and perhaps made entrepreneurs more receptive to innovation.

Britain’s industrial revolution was an important phase in a wide-ranging, long-term phenomenon whose complexity is hard to encapsulate and even harder to explain. Inventiveness was widespread, but as constraints, resources and tastes varied across Europe, so did technological strength and preferences. In Britain particular opportunities and constraints on expansion had directed inventors into exceptionally fruitful channels. A relative mobile, tolerant, and flexible society facilitated this eclecticism, as did a reservoir of appropriate skills, partly imported, partly built up among artisans, the domestic industries and the coal-using technologies.

My opening remark has equal force when turned on its head: industrialisation, with its long and spreading roots, lay at the heart of accelerating technological change. We are just beginning to appreciate the need to delve more deeply into its antecedents and to focus more closely upon specific types of invention and the circumstances of their generation. Broad comparisons between different countries have served to eliminate the grosser explanations for Europe's and Britain's advance;[3] now we should compare more precisely who was inventing what, how, and why.

Further Reading

[1] **Maxine Berg,** *The Age of Manufactures, 1700-1820: Industry, Innovation and Work in Britain* (2nd ed., 1994).

[2] **J. R. Harris,** *Essays in Industry and Technology in the Eighteenth Century: England and France* (1992).

[3] **Joel Mokyr,** *The Lever of Riches: Technological Creativity and Economic Progress* (1990).

[4] **Brinley Thomas**, *The Industrial Revolution and the Atlantic Economy* (1993).