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CHAPTER 26

TECHNOLOGICAL CHANGE

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Introduction

During the eighteenth century Europeans embarked on a revolutionary phase of economic growth and social change, the full environmental costs of which we are only just beginning to recognize. Breaking free from an essentially subsistence economy to embrace the market and long-distance trade, they led the world into sustained economic growth. This has allowed the unprecedented phenomenon of long-term population increase in tandem with a rising standard of living; previously one type of gain had always been at the other's expense, as never before had it been possible to expand an economy fast enough to accommodate both.[1] The causes of this shift into sustained (if ultimately unsustainable) economic growth are still debated, but there can be no doubt that the fundamental driver has been technological change. In this chapter, we will explore the nature of those new technologies and reasons why Europeans began to invest (literally and metaphorically) in technical innovation.

At the core of Europe's economic growth was its discovery of new resources and the techniques necessary to exploit them. Medieval Europe's principal resource had been its land. Wealth and power in feudal society rested on the tenure of land, and everyone's livelihood was totally dependent on it.[2] Agriculture and the processing of its produce employed the vast majority of the population: it fed, clothed, and shod them (in woollen, linen, and leather garments) and it provided them with fuel (wood), kinetic energy (fodder for horses and oxen, supplemented by watermills and windmills), and timber, the primary structural material for buildings, ships, tools, and furniture. Largely self-sufficient, farmers rarely bought anything other than metal goods (smelted with wood or charcoal) and locally produced earthenwares. Transport was expensive, and the small trading sector dealt overwhelmingly in luxury items for the rich minority. Medieval Europe's technology was by no means unsophisticated (as witnessed by its cathedrals),

but its gains in land productivity tended to be labour-intensive and more hands (or horses) meant more mouths to be fed from a resource that was subject to diminishing returns. In many parts of Europe, particularly in the south and east, major elements of this organic technology persisted long into the twentieth century, before being overtaken by new methods powered by, or made with or from, fossil fuels.

Yet, since the late fifteenth century (when Europe finally recovered from the serial depredations of plague and bad harvests), its population has grown exponentially while simultaneously enjoying rising levels of material comfort. Although this new trend was scarcely visible before 1750, population increase became (worryingly) evident thereafter and widespread improvements in living standards followed about a century later. Initially, this European achievement was facilitated by technologies that allowed international trade and the conquest and settlement of other continents—ocean-going sailing ships and navigational instruments, guns, horses, and agriculture, not forgetting the leg-irons and chains that disciplined its slave labour. From these new trades emerged the desire for exotic groceries (sugar, tea, coffee, chocolate, tobacco) and new consumer goods (cottons, silks, porcelain, etc.) that could be imitated by Europe's craftsmen.[3] Subsequently, this growing demand provoked the mechanization of industrial and agrarian processes, powered by new, underground sources of energy that were independent of the land surface—coal, and later, oil, gas, and the electricity generated chiefly from fossil fuels—and the manipulation of new chemicals also largely derived from minerals. It created a demand for many new skills (e.g. in engineering or mining) and rendered others obsolete.

Historians are still discussing what, at this juncture, prompted Europeans increasingly to turn to innovation as their preferred means of resolving problems and improving their material conditions. Undoubtedly, the world-view of late medieval Europe was seriously destabilized from several directions. Renewed contact with the ideas and technologies of the ancient Greeks and Romans during the renaissance, the Copernican 'revolution' in astronomy, the 'discovery' of the New World and increasing communication with the Far East, and the challenge to authority posed by the Reformation, all suggested there were alternative, perhaps better, ways of doing things and new knowledge to be obtained through experiment, ingenuity, and bravado. Within Europe, the demands of emerging nation-states for novel types of expertise and the migrations of craftsmen generated by the wars of religion and waves of persecution consequent upon the Reformation, not to mention the stimulus both politics and religion gave to the multiplication of printing presses, all promoted the dissemination and cross-fertilization of ideas.

The Contours of Technical Progress, c. 1300–1800

Technological change was central to the process of European expansion and development of international trade. Without critical improvements in navigational techniques and instrumentation, in ship design and production, and in firearms, the process of European expansion would have been impossible. The origins of many of these improvements remain obscure; undoubtedly some were Asian. For example, the magnetic compass was evidently in use by 1300 but the precise date and place of its invention are unknown. Its adoption promoted the systematic use of instrumentation and *portolans* (nautical charts with detailed indications of winds, tides, depths, etc.). Similarly, the origins of the caravel and the carrack (the first successful oceanic ship designs) are unclear. Both designs represent a remarkably fruitful marriage between Mediterranean and Nordic maritime traditions, which emerged from a continuous phase of empirical tinkering (reinforced by imitation and exchanges of best practices) around 1300.[4] Very rapid progress in shipbuilding techniques and ship design continued throughout the seventeenth and eighteenth centuries, mostly thanks to empirical improvements, although there were attempts, especially in France under Colbert, to introduce a more scientific approach to naval architecture.[5] This trajectory culminated in the late eighteenth-century 'ship of the line' (a warship equipped with up to 100 guns)—an artefact of almost unparalleled sophistication. During the Napoleonic Wars, Britain's Royal Navy undertook the construction and maintenance of these ships in its own dockyards, which pioneered early forms of mass production that employed machine tools and other specialized machinery. These naval dockyards were easily the biggest industrial establishments of the time, far ahead of other large-scale industrial employers, such as mines and breweries.[6]

Such technical improvements were facilitated by expansion in both mercantile and military navies. During 1500–1780, western Europe's merchant fleet grew from approximately 200,000 tons to over 3 million tons, almost a tenfold increase per inhabitant (see Table 26.1). Considering that throughout the same period most European economies experienced relatively sluggish growth of income per head, this evidence points to shipbuilding as one of the continent's most dynamic industries.[7]

By contrast, very limited progress was attained in land transport during the early modern period. As Fernand Braudel remarked: 'Napoleon moved no faster than Julius Caesar'.[8] During the eighteenth century, the expansion of inland waterways facilitated the bulk transport of low value to volume goods, such as timber, coal, ores, and grain, while road-building programmes (both state and private) and improvements to carriages expedited the circulation of people, posts, and news. The installation of optical

Table 26.1. The West European merchant fleet, 1500–1780

Year	Total fleet (000s tons)	Tonnage per 1000 inhabitants
1500	200–250	3.2–4
1600	600–700	7.7–9
1670	1000–1100	12.8–14.1
1780	3372	30.7

Source: Van Zanden (2001: 82)

telegraph posts, primarily for military purposes, and the intense excitement generated by early ballooning that was consequent upon the Montgolfier brothers' successful experiments in 1783, testify to the demand for greater speed and range. Until, however, the construction of national railway and electric-telegraph networks in the mid-nineteenth century, everyday communications remained slow and expensive and markets overwhelmingly local.[9]

The second critical area of strategic importance for Europe's ascendancy was weaponry. Its adoption of gunpowder was coupled with a rapid development of firearms. The emergence of nation-states and the almost continuous military competition between them produced a strong, steady demand throughout the continent. Although gunpowder had been a Chinese invention, when the Portuguese reached China in the early sixteenth century their guns were greatly superior to those that met them. Since then, the production of artillery, firearms, and gunpowder in Europe experienced sustained productivity growth. Possibly even more important than that were inventions which improved the fighting performance of firearms, such as the flintlock, the paper cartridge, and the bayonet, making it possible to replace pikemen with soldiers carrying guns. According to Parker, the rapid spread of increasingly destructive weaponry, combined with the growing size of armies, produced a European 'military revolution' that was crucial to its expansion. In order to survive, the newly emerging European states had to mobilize and manage armies and navies of unprecedented size and destructive capacity. In this way, the West's recently acquired technological edge in weaponry was coupled with substantive organizational advantages.[10]

The emergence of a distinctive European pattern is also to be found in power generation. While the watermill was known at least from Roman times, its widespread adoption began during the middle ages. Initially, the product of determined attempts by feudal lords to enforce their seigniorial rights (the monopoly of milling was one of the most ancient and widespread),[11] the use of watermills expanded from the primary method for grinding corn to a variety of applications, such as metal manufacturing, 'fulling' woollen cloth, paper making, food and drink production, etc.[12]

Makkai's estimates of the growth of water power in pre-industrial Europe suggest a process of moderate but steady growth in horsepower per head (Table 26.2), but other counting exercises indicate a more rapid increase.[13] His estimate of the power output of watermills around 1800 is probably also too low: according to Reynolds, the average power of eighteenth-century water-wheels was between 5 and 7 HP.[14]

The mechanical energy produced by water and windmills represented only a very small share of the total,[15] which continued to be supplied principally by human and

Table 26.2. Number and power of European water-wheels, 1200–1800

Year	No. of water-wheels	Average power (HP)	HP per head
1200	300,000	2	0.008
1800	750,000	3	0.012

Source: Makkai (1981: 178); see also Malanima (2009: 74).

animal muscle until the mid-eighteenth century. Nonetheless, it is important to acknowledge the increasing availability of inanimate sources of power, for a wide range of production activities, before the classical period of the industrial revolution.

Power from inanimate sources was rapidly becoming indispensable in the mining sector. The seventeenth century saw intensive growth in Europe's extractive industries (coal, iron, tin, and copper), which emphasized the problem of mine drainage. Without effective technical solutions to this problem the exploitation of deep ore deposits would have been impossible. Consequently, while European engineers increasingly focused on the design and improvement of water-powered mining pumps, it was in response to this challenge that the early steam engines were developed in south-western England by Savery and Newcomen *c.*1700. Estimates by Kanefsky and Robey indicate that 48.6 per cent of all the steam engines installed in Britain during the eighteenth century were used for mining purposes (pumping water or hauling ore to the surface).[16]

Traditional accounts of British industrialization have tended to conflate the economic significance of steam-power technology with its early development.[17] For example, Rostow dated Britain's take-off to the years 1783–1802, linking it explicitly with the commercialization of the Watt engine. However, the diffusion of steam power, even in a precocious coal-abundant user such as Britain, was a long and protracted process. Table 26.3 reports Kanefsky's estimates of the use of steam in comparison with wind and water power in manufacturing and mining, at various dates between 1760 and 1907.

It shows that, as late as 1830, steam power was yet to become the predominant source of power.[18] The early phases of industrialization were accommodated by the expansion and 'stretching' of the traditional mixture of water, wind, animal, and human power.[19]

Although still in its early stages, another technological trend that characterized the early modern European economy was the increasing use of machinery for productive processes. From self-regulating cathedral clocks to Gutenberg's printing press and William Lee's stocking knitting-frame, these sophisticated mechanisms were indicative of the highly developed mechanical skills and ingenuity available in renaissance Europe wherever new degrees of precision or levels of output were sought. It was only, however, once such mechanisms were harnessed to inanimate sources of power in the late eighteenth century that their capacity to expand and cheapen production began

Table 26.3. Sources of inanimate power in use (HP) in Britain (mainly mining and manufacturing)

Year	Steam	(%)	Water	(%)	Wind	(%)
1760	5000	5.88	70 000	82.35	10 000	11.76
1800	35 000	20.59	120 000	70.59	15 000	8.82
1830	160 000	47.06	160 000	47.06	20 000	5.88
1870	2 060 000	89.57	230 000	10.00	10 000	0.43
1907	9 659 000	98.14	178 000	1.81	5000	0.05

Source: Kanefsky (1979: 338).

to be fully realized. With access to rapidly growing markets in Africa and America as well as at home, Britain's cotton textile industry pioneered numerous attempts to mechanize production.[20] Devices invented to increase the productivity of domestic ('proto-industrial') spinners and weavers, such as Hargreaves's spinning jenny and Kay's flying shuttle, were quickly surpassed by the factory-based machines driven by water or steam: Arkwright's water-frame, Crompton's spinning mule, Cartwright's power loom, and Peel's cylindrical cotton-printing machinery. These prototypes showed the way to a generation of entrepreneurs, who hurried not only to install them but also to improve and diversify them, to extend their use to other fibres, and, in some cases, to manufacture them.

The machine-making industry became a major source of innovation, both increasing its own productivity by the development of powered machine-tools and helping to disseminate mechanization throughout the industrial sector and, later, agriculture. By the early nineteenth century, its customers included the paper and printing industries, which were meeting the burgeoning demand for everything from stationery and tracing paper to newspapers, books, and pamphlets by installing water- and steam-powered machinery and presses. Machine-makers recruited many skilled workers from the horological and instrument-making trades, where accurate methods of cutting and shaping metals (and grinding glass) were highly prized. In their turn, these trades, hitherto dependent on a small, luxury market for scientific instruments and watches, found new opportunities to diversify their products and expand: transport projects and maritime trade required numerous surveying and navigational instruments; the fiscal state invested heavily in measuring equipment; manufacturers experimented with thermometers or pyrometers; and middle-class households increasingly expected to own clocks, microscopes, barometers, globes, and (soon) pianos. Vital to industrialization, the instrument trades remained, however, workshop-based and unmechanized. The introduction of the dividing engine in the late eighteenth century, the greater division of labour, and the steady accretion of skills gradually increased their productivity but expansion came chiefly through the entry of new firms.[21]

While metal-working and glass-making skills were indigenous to early modern Europe, the import of Asian luxuries, such as Indian silks and fine cottons or Chinese porcelain triggered the search for techniques to replicate them and capture the market. One strategy was to discover and copy the secrets of Asian manufacturers. Intensive experiments with different clays and kilns, for example, led in 1710 to the establishment of Europe's first hard porcelain manufacture at Meissen in Saxony. Together with a few rival factories across the continent it largely ousted China in supplying this exotic luxury to the wealthy. Another strategy was to develop new ceramic bases and glazes in imitation of porcelain but, by employing cheaper materials and more efficient methods of production, to manufacture a distinctly European product for a middle-class market. One of its most successful exponents was Josiah Wedgwood, the Staffordshire potter whose high-quality stoneware incorporated fashionable neo-classical designs. It was produced with an extensive division of labour that minimized the need for skilled workers, and was marketed through innovative techniques, including a West End showroom, newspaper advertisements, and celebrity endorsements. Where Wedgwood led, many others followed. Matthew Boulton, prominent in the Birmingham 'toy' trades, simultaneously reorganized the production and marketing of small metalwares. Birmingham workshops thrived by experimenting with new finishes, such as silver plating, 'ormolu' and lacquered ('japanned') papier mâché.[22]

The Organization of Innovation

The economic and military rivalry between the newly emerging European nation-states of the early modern period led gradually to the creation of a number of new institutions whose ultimate goal was the improvement of national innovative performance.[23] This point has been aptly summarized by Rosenberg and Birdzell:[24] 'In the West, the individual centres of competing political power had a great deal to gain from introducing technical changes that promised commercial or industrial advantage and hence greater government revenues, and much to lose from allowing others to introduce them first.'

In this respect, the institutional reform that has received most attention from historians is undoubtedly the creation of patent systems. The roots of this institution are to be found in the proprietary and exclusionary attitudes towards technological knowledge and skills that had emerged within the medieval guild system.[25] Early modern technology was, fundamentally, a matter of 'expert' knowledge and skills.[26] Consequently, the diffusion of technology was tightly linked with the migration of skilled workers.[27] Furthermore, there seems to have existed a widespread awareness among governments and other authorities of the key role of this migration in the process of technology transfer, because, from the late middle ages, a growing number of laws tried to restrict the emigration of skilled craftsmen. At the same time, governments introduced measures aimed at attracting or suborning skilled workers from other countries. One of the commonest policies was that of awarding special patents or 'privileges' to the importers of new technologies, which conceded them incentives such as the exclusive right (for a limited amount of time) to the use of the specific body of knowledge and skills they brought with them.[28]

In 1474 the Venetian government enacted a statute that codified such previously *ad hoc* practices. This contained, in an embryonic form, several features of modern patent laws. In particular, Venetian grants depended on the applicant's ability to fulfil certain criteria, rather than being subject to the discretion of the authorities: the invention should offer something of recognized 'usefulness' for the state and it should not already have been made or be known within the boundaries of the Republic. Thus, the two fundamental criteria for awarding the grant were established as *utility* and *novelty* (which remain in modern patent systems). The Venetian model of protection and exclusive privileges spread rapidly to other states, such as the Netherlands, England, and France (where they coexisted with more direct means of rewarding inventors) . This is hardly surprising, since the objective of import substitution represented a key component of

the mercantilist model of political economy. Privileges of invention, by encouraging the immigration of foreign craftsmen and skilled workers were, in fact, a particularly effective measure for achieving this goal.[29]

The evolution of privileges of invention in England is of particular interest.[30] Here, they were tarred by association with the crown's licences of monopoly, which by interfering with established trades triggered a series of protests that culminated in the Statute of Monopolies of 1624. Yet Parliament made an explicit exemption in the Act to allow the crown to continue granting patents for new inventions.[31] The Statute also introduced a fixed term of fourteen years (corresponding to twice the normal term of an apprenticeship). The exclusive focus on the protection of inventions has led legal historians to consider the Statute of Monopolies as the first modern patent law. Following this cue, Nobel laureate Douglass North argued that its enactment, by creating an appropriate set of property rights over inventions, constituted the indispensable precondition behind the acceleration of technical progress that defined the industrial revolution.[32]

In fact, the relationship between patents and innovation during the early modern period was not straightforward. If we limit ourselves to the British case, it is surely true, as suggested by Dutton and Sullivan,[33] that some of the investments in the development of new technologies (including the large 'research and development' projects of the water-frame, spinning jenny, power loom, and steam engine) envisaged their commercial exploitation within the coverage of patent protection. However, before the mid-nineteenth century most inventive activity was undertaken outside the purview of the patent system, as becomes evident through a systematic comparison of patent records with industrial histories and other sources. First mover advantages and secrecy, in many fields, were effective tools for appropriating economic returns from inventive activities. This evidence of widespread technical change outside the patent system suggests that views such as North's, which have ascribed to the patent system a critical role in triggering industrialization, are probably wide of the mark. Moreover, the relationship between patents and innovation is confounded by the sometimes negative impact of patents on the *subsequent* improvement of any given invention, as witnessed by Watt's prolonged patent for the separate condenser (1769), which for two decades frustrated the further refinement of steam power, in particular the development of Hornblower's compound engine.[34]

If the development of patent systems is traditionally regarded as an institutional change that promoted innovation, the resilience of guild systems after 1500 is frequently seen as an institutional obstacle to the development of new technologies.[35] This view has been recently challenged by several scholars, including Epstein who argues that, in a world of largely tacit technological knowledge, some features of the guild system, such as apprenticeship regulations, were an effective means of transmitting and consolidating technical skills.[36] Epstein contends that the overall contribution of the guild system to technological progress in early modern Europe was positive. In fact, the traditionally negative judgement of craft guilds is based on a number of documented instances of guild opposition to the introduction of specific inventions. Epstein invites us to be extremely careful in drawing generalizations from these cases. These episodes, rather than demonstrating an outright hostility to innovation *per se*, show the guilds' opposition to *a specific form of technological progress* (typically the use of capital-intensive and labour-saving devices). By contrast, skill-enhancing and capital-saving inventions were often promptly adopted and developed by the guilds. In fact, guild regulations and practices, by emphasizing the 'collective ownership' of skills and technical know-how, actively promoted the sharing of technical knowledge, with favourable effects on the rate of innovation.[37] Since guild inventions typically took the form of incremental improvements and refinements to current processes and products, they tend to be much less visible in the historical records. Epstein's revisionist view has been refined by Belfanti, who argues that patents and guild prerogatives ought to be seen as two instruments of technology policy that were consciously used in tandem by mercantilist states. The guild system offered a way of preserving, protecting, and gradually enhancing the repertoire of skills and technical know-how in existing trades, whereas patents were a means for importing new manufactures and technologies from abroad. In most cases, in order to receive a patent or privilege, the inventor was required to reveal the secrets of his invention to some authority or directly to a guild or his indigenous apprentices. In this way, a newly imported technology could be absorbed into the guild system.[38]

Awareness of the critical role of technology for economic and military competitiveness led to the implementation of a number of other measures intended to stimulate inventions or encourage technology transfer. The awarding of prizes for specific technical attainments (which amounts to a form of technological procurement) is a case in point. For example, during the eighteenth century Britain, Spain, and France instituted prizes for inventions that would allow a correct determination of the longitude at sea. In other cases, innovative projects and ideas were frequently discussed and implemented within the purview of the large 'military-industrial' complexes of Ancien Régime states as, for example, block-making machinery at the Portsmouth dockyards, or the pioneering attempt to introduce interchangeable-parts manufacturing into the production of muskets in France following the humiliating defeat the Seven Years War. Nor should we forget the concomitantly intense industrial espionage, which again reveals the deep concern of these governments with the prevention of technological lacunae that could irreparably damage the power of the state.[39]

Another critical institutional novelty in the area of knowledge production that has attracted historians' attention is the emergence of 'open science'. The term 'open science' refers to the set of norms that, since the scientific revolution of the seventeenth century, governs the procedures of scientific inquiry, which is perserved as a collective undertaking based on the progressive accumulation of research findings. Accordingly, they require the timely publication of new research findings, which permits other practitioners both to rigorously check the validity of results and to build on them in new inquiries. In this system, the chief incentive is represented by the rewards attached to the enhancement of the scientist's reputation when his/her claims of priority in a new discovery are acknowledged by the relevant peer community. Paul David has traced the origins of open science norms to the aristocratic patronage system of arts and science of the renaissance courts,[40] which arose, he

suggests, from two motives. The first was utilitarian, a reflection of the growing appreciation that scientific modes of inquiry could offer solutions to technical problems. Men of science were frequently called on by their aristocratic patrons to provide expertise and advice on military matters, building projects, transport systems, etc. The second motive was ornamental, since their achievements (if not susceptible of immediate application) could enhance the prestige of their patrons, in much the same way as those of artists and men of letters. Reputational contests (for example, solving mathematical challenges), the establishment of priority claims, and the publication of research findings (enhanced by the growing circulation of printed books) gave to the men of science of the renaissance the opportunity of signalling their talents, and to their aristocratic patrons the possibility of performing some screening of this not so transparent market on the basis of reputation. Again, it is interesting to note that the emergence of an effective institutional arrangement in the field of knowledge production is related to Europe's political fragmentation, which provided the environment for competitive displays in the fields of arts and sciences between royal and aristocratic patrons.

The Sources of Technological Change

The sources of technological change and its impact on the economic development of Europe are highly contentious issues. Despite the growing prestige of the 'experimental philosophy' in early modern Europe, historians of science and technology have generally concluded that scientific discoveries had a very limited impact on technological progress at this time. Indeed, the causal connection probably ran in the opposite direction, with technological developments more often setting the natural philosophers' research agenda. The invention of the steam engine, for example, stimulated the development of modern thermodynamics. Long after the seventeenth-century scientific revolution, technologies were still improved largely through trial-and-error procedures and accumulated rules of thumb.[41] In an important challenge to this view, Musson and Robinson argued in 1969 that, in Britain at least since the early eighteenth century, the connections between science and technology were not tenuous but rapidly became stronger and more direct. They pointed to the interests of leading entrepreneurs, such as Matthew Boulton and Josiah Wedgwood, in scientific enquiries; highlighted the emergence of scientific societies, open to individuals from different walks of life, for the discussion of scientific findings and experiments; and specified a number of inventions in the engineering and chemical industries to which the contribution of a scientific insight or perspective on a practical problem was crucial. Their case has been recently elaborated by Joel Mokyr, who introduces the concept of 'industrial enlightenment' to connect the scientific revolution of the seventeenth century with the industrial revolution of the late eighteenth.[42]

In a nutshell, Mokyr's 'industrial enlightenment' is a cultural revolution with profound implications for the procedures for discovering technical improvements. He contends that the Baconian ideal of employing natural philosophy ('science') for the solution of technical problems became progressively articulated through three interrelated changes. First, there was a drastic reduction in the costs of accessing extant bodies of knowledge (thanks to the expanding publication of scientific and technical works, including more systematic descriptions and representations of the functioning of artefacts); secondly, a systematic effort to account for the functioning of artefacts using existing scientific theories and, when necessary, as in the case of the steam engine, trying to develop new explanatory theories; thirdly, a concerted attempt to create a 'public sphere' for the fruitful interaction between scientific researchers and practitioners confronted with technical problems. Taken together, these developments supposedly amounted to a knowledge revolution which dramatically increased the productivity of inventive activities. Since Mokyr recognizes that the *direct* contribution of science to technology may have been very circumscribed, he suggests the concept of 'useful knowledge' to define the knowledge base underlying all the techniques mastered by a society. 'Useful knowledge' is a much broader set than scientific knowledge, containing not only systematic knowledge about natural phenomena but also other types of practical knowledge about the properties of the natural world that may potentially have a bearing on the design of artefacts. The main achievement of the 'industrial enlightenment' was to establish the conditions for a self-sustaining process of accumulation of 'useful knowledge'. Accordingly, Mokyr emphasizes more the adoption of a scientific method and attitude as the key to improvements in technology than the direct contribution of scientific knowledge.

One of most telling examples of this approach is John Smeaton's research on water wheels. In 1759, through a systematic series of experiments, which measured changes in efficiency in response to variations in the design of a scale model, Smeaton showed that Antoine Parent's theory of water-wheel efficiency was inaccurate and established the superiority of overshot wheels. He used this method, again in the early 1770s, to improve significantly the fuel efficiency and operation of the Newcomen engine. As Cardwell remarks,[43] Smeaton's method of *parameter-variation* represents a cornerstone of modern engineering design. Its power lies in permitting the identification of sound design principles, even in the absence of an accurate scientific understanding of the functioning of an artefact.

Although Mokyr's approach undoubtedly helps to illuminate the role of science as a source of technical advances, we would raise three concerns. The first is methodological. There may be evidence, especially in the British case, of many forms of exchange and communications between the 'world of science' and the 'world of technology'. However, *by itself* this type of evidence provides no proof of the existence of significant causal linkages. For example, James Watt had frequent discussions and exchanges on the properties of steam with Joseph Black, then professor of the University of Glasgow (where Watt was working as a maker of scientific instruments), who was conducting research on the nature of heat. Yet, a careful reading of the evidence indicates that these exchanges probably did not play a critical role in Watt's invention of the separate condenser. This implies that the assessment of the exact contribution of science to technology in this phase needs to be done case by case, by means of detailed reconstructions of inventive processes.

Secondly, Mokyr's concept of 'industrial enlightenment' implies a rather drastic change (a 'knowledge revolution') taking place during the eighteenth century. However, as our survey has shown, since at least the late middle ages a more general 'culture of improvement' permeated Europeans' attitude towards technology. Hence, both the seventeenth-century scientific revolution and the adoption of more systematic approaches to inventive activity should be seen as *ramifications of earlier changes in the general cultural outlook of European societies*. In this perspective, the ascendancy since the renaissance of beliefs advocating the subordination of nature to man and celebrating humanity's increasing ability to manipulate natural forces were the product of the peculiar European attitude towards technical improvements of which Mokyr's 'industrial enlightenment' was itself symptomatic.[44] Thirdly, Mokyr's concept of 'industrial enlightenment' threatens to underestimate the role that the mechanical arts, rules of thumb, and other forms of empirical and tacit knowledge not susceptible of being fully articulated and codified, continued to play in the generation of innovations well into the nineteenth century.

Another stream of literature attempts to account for inventive activities by linking them to the economic endowments of different locations. In this approach, inventions are conceptualized as creative responses either to shortages or relative abundances of specific production factors.[45] A recent example is Robert Allen's exposition of Britain's rise to technological leadership during the eighteenth century.[46] Allen argues that Britain's success in developing steam engines and mechanizing textile production and other industries reflected its peculiar wage and price structure (in particular, its high wage economy, created by success in long-distance trade). With coal abundant, the search for technical solutions to problems of power-supply (especially for mines drainage) was, from a very early date, focused on the employment of steam. While there were other attempts to develop steam engines in Europe, such as the steam-powered vehicle for transporting artillery developed by Cugnot in France around 1770, it was only in the British context that a substantial capital investment in the development of a successful steam engine was likely to generate large economic returns. Likewise, the mechanization of cotton spinning. In this case, Britain's relatively high wages (especially in comparison with India, then the leading producer) spurred inventive efforts towards contriving labour-saving machines, such as the spinning jenny and the water-frame. Similarly, it may be argued that Abraham Darby's invention of smelting iron with coke was motivated by the increasing price of charcoal relative to coal. Allen's insistence on the embedding of inventive activities in very specific economic contexts opens an interesting and still largely unexplored research agenda on the border between economic history and the traditional history of technology.[47]

However, the adoption of a new technology involves much more than the direct assessment of the costs and benefits of different pieces of equipment as assumed in the profitability calculations, based on current factor prices, carried out by Allen. In most cases a wider range of factors, such as the availability of skills to operate the new technology, expectations concerning future technological developments, and the overall compatibility of the new technology with complimentary pieces of equipment and other contingent production activities, will affect the choice-of-technique context, making the individual adoption of a new technology the outcome of a complex decision-making process. Hence it remains to be seen whether Allen's economic approach to the study of eighteenth-century technological breakthroughs can be fully integrated into accounts that also recognize the influence of these other factors in the explanation of timing, rate, and direction of inventive activities.[48]

While Allen's analysis highlights the critical role of the economic context in which inventive activities took place, it also tends to minimize the role of scientific insights as *autonomous sources* of invention (partially excepting the appreciation of atmospheric pressure as fundamental to the Newcomen engine). Inventions such as the Newcomen engine (which allegedly required almost ten years of experiments) or Arkwright's water-frame were essentially imaginative new combinations of extant components, such as a rocking beam, a boiler, and a piston cylinder-apparatus in the former, or a new arrangement of spindles, rollers, and flyers in the latter. The real novelty was the unprecedented amount of resources invested in bringing these ideas into practice (and it was to capture the profits of such investments that pressure was mounting for the introduction of more effective patent systems).[49] Previously, most technologies developed through the long-term accumulation of incremental improvements arising through processes of *learning by doing* and *learning by using*.[50] Of course, this form of technical improvements continued to complement the deliberate search for innovations.

Interestingly enough, both Mokyr's and Allen's accounts recognize that essential to the great eighteenth-century breakthroughs in power technologies, textile machinery, and metallurgy was the existence of a pool of sophisticated mechanical skills that transformed designs into practical contrivances. In our view, the precise identification of the factors accounting for the development and consolidation of this strong base of mechanical skills throughout Europe during the Ancien Régime period is indeed one of the most pressing research issues for historians of technology.

Conclusions

Recent research in economic history has been characterized by a renewed debate on western Europe's economic performance during the eighteenth century. The traditional view held that, on the eve of the industrial revolution, it had already 'forged ahead' of the rest of the world, attaining a sizeable lead in its material standards of living. By contrast, the revisionists' account denies any significant differences between western Europe and other advanced locations (especially China) before the eighteenth century, contending instead that the 'great divergence' was the product of subsequent industrialization.[51]

Whatever the outcome of this debate on relative living standards, the historical record suggests that in Europe, since the late middle ages, a number of specific technological trends were already emerging. It is unlikely that these trends (in weapons and transport systems, in power usage, in the mechanization of some production processes) were strong enough to exert a major impact on economic performance before the mid-nineteenth century. Nonetheless, they were critical because of their transformative nature, which put Europe on a steeper path of technological progress, enabling its manufacturers to seize the opportunities presented by expanding markets and trade.

Our survey also points to the emergence of a number of specific institutional arrangements governing the generation and exploitation of technical opportunities. By virtue of this peculiar 'organization of invention', by the eighteenth century technological changes and their application in the economy assumed increasingly the character of a regular and steady flow. Remarkably, most of these institutional changes had a very clear mercantilist imprint, and ultimately were an outcome of Europe's geo-political environment of fierce competition between independent nation-states .[52] These considerations show that accounts of the rise of western Europe which give exclusive emphasis to minimal state intervention, the definition and security of property rights, and the unfettered operation of markets, etc. run the risk of delivering a 'Whig history' which is not warranted, at least in the history of technology.[53] The Ancien Régime state played a significant role in promoting the generation of new technologies, through its pursuit of military supremacy and the wealth to underpin it, but, above all, we would agree with Habakkuk[54] that, 'It is probable that the most important of the conditions which made Europe the cradle of economic advance originated very far back in its history'. Industrialization constituted a change of gear, not a change of direction.

Notes

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1. See G. Clark, *A Farewell to Alms: A Brief Economic History of the World* (Princeton, 2007) for a discussion of the general significance of the Malthusian model for human history before 1800.
2. E. A. Wrigley, *Continuity, Chance and Change: The Character of the Industrial Revolution in England* (Cambridge, 1988).
3. Maxine Berg, 'In Pursuit of Luxury: Global History and British Consumer Goods in the Eighteenth Century', *Past and Present*, 182 (2004), 85–182.
4. Carlo M. Cipolla, *Guns and Sails in the Early Phase of European Expansion, 1500–1700* (London, 1965); F. C. Lane, 'The Economic Meaning of the Invention of the Compass', *American Historical Review*, 68 (1963), 605–17; Fernand Braudel, *The Structures of Everyday Life* (London, 1981), 403.
5. G. B. Naish, 'Ships and Shipbuilding', in C. Singer, A. J. Holmyard, A. R. Hall, and T. I. Williams (eds.), *A History of Technology*, iii (Oxford, 1957), 471–99; J. Goodman and K. Honeyman, *Gainful Pursuits: The Making of Industrial Europe, 1600–1914* (London, 1988), 157; C. Fox, *The Arts of Industry in the Age of Enlightenment* (New Haven and London, 2009), 48–69; David McGee, 'From Craftsmanship to Draftsmanship: Naval Architecture and Three Traditions of Early Modern Design', *Technology and Culture*, 40 (1999), 209–36, has noted that, before 1800, the direct impact of science on improvements in ship design was very limited. L. D. Ferreiro, *Ships and Science: The Birth of Naval Architecture in the Scientific Revolution, 1600–1800* (Cambridge, Mass., 2006), argues for a more positive role for science in the development of naval architecture.
6. Fox, *The Arts of Industry*, 116–30; J. Coad, *The Portsmouth Block Mills: Bentham, Brunel, and the Start of the Royal Navy's Industrial Revolution* (Swindon, 2005); J. Brewer, *The Sinews of Power: War, Money and the English State, 1688–1783* (London, 1989), 36; D. C. Coleman, 'Naval Dockyards under the Later Stuarts', *Economic History Review*, 6 (1953), 134–55.

7. J. L. Van Zanden, 'Early Modern Economic Growth: A Survey of the European Economy, 1500–1800', in M. Prak (ed.), *Early Modern Capitalism: Economic and Social Change in Europe, 1400–1800* (London, 2001), 80–6.
8. *Structures of Everyday Life*, 424.
9. S. P. Ville, *Transport and the Development of the European Economy, 1750–1918* (New York, 1990); D. R. Headrick, *When Information Came of Age: Technologies of Knowledge in the Age of Reason and Revolution, 1700–1850* (Oxford, 2000), ch. 6.
10. Geoffrey Parker, *The Military Revolution: Military Innovation and the Rise of the West 1500–1800* (Cambridge, 1988); P. T. Hoffman, 'Prices, the Military Revolution and Western Europe's Comparative Advantage in Violence', *Economic History Review* 64 (2011), 39–59. For a more cautious assessment of the role of western military advantage in European expansion in the period 1500–1800, see P. J. Marshall, 'Western Arms in Maritime Asia in the Early Phases of Expansion', *Modern Asian Studies,* 13 (1980), 13–28.
11. E. M. Carus-Wilson, 'An Industrial Revolution of the Thirteenth Century', *Economic History Review,* 11 (1941), 39–60, also argued that the rapid spread of fulling mills in England during the 13th cent. was linked with attempts by landlords to establish new, profitable seigniorial monopolies.
12. T. S. Reynolds, *Stronger than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore, Md., 1983), 69–96.
13. L. Makkai, 'Productivité et exploitation des sources d'énergie (xii^{e}–xviii^{e} siècles)', in S. Mariotti (ed.), *Produttivitá e tecnologie nei Secoli xvii e xviii* (Florence, 1981), but see Reynolds, *Stronger than a Hundred Men*, 123–5. The population of Europe (including Russia) in 1800 is generally estimated to have been around 187 million.
14. Reynolds, *Stronger than a Hundred Men*, 174. For Britain *c.*1800, J. W. Kanefsky, 'The Diffusion of Power Technology in British Industry, 1760–1870' (University of Exeter, Ph.D. thesis, 1979), 220, estimates the average power for watermills as 10 HP.
15. P. Malanima, *Pre-Modern European Economy* (Leiden, 2009), 84–6.
16. J. W. Kanefsy and J. Robey, 'Steam Engines, in Eighteenth Century Britain: A Quantitative Assessment', *Technology and Culture,* 21 (1980), 181.
17. Esp. W. W. Rostow, *The Stages of Economic Growth: A Non-Communist Manifesto* (Cambridge, 1960); *How it All Began: Origins of the Modern Economy* (London, 1975); and somewhat more cautiously D. S. Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge, 1969).
18. Kanefsky, 'Diffusion of Power Technology'. G. M. Von Tunzelmann, *Steam Power and British Industrialisation to 1860* (Oxford, 1978), ch. 6, and N. F. R. Crafts, 'Steam as a General Purpose Technology: A Growth Accounting Perspective', *Economic Journal,* 114 (2004), 338–51, provide independent assessments of the contribution of steam power technology to productivity growth in Britain, concurring that it became significant only after 1840.
19. E. A. Wrigley, *Energy and the English Industrial Revolution* (Cambridge, 2010), 36–46, 91–101. In an important article, R. B. Gordon, 'Cost and Use of Water Power during Industrialization in New England and Great Britiain: A Geological Interpretation', *Economic History Review,* 36 (1983), 240–59, shows that as late as 1840, even in the most developed industrial areas, only a limited fraction of the potentially usable water-power sites had been exploited. This contradicts the idea that steam power was a necessary response to an energy crisis in the 18th-cent. economy.
20. R. Friedel, *A Culture of Improvement: Technology and the Western Millennium* (Cambridge, Mass., 2007), 102–28, 218; J. Inikori, *Africans and the Industrial Revolution* (Cambridge, 2002).
21. N. Rosenberg, *Perspectives on Technology* (Cambridge, 1976), chs. 1, 8; C. MacLeod, 'Strategies for Innovation: The Diffusion of New Technology in Nineteenth-Century British Industry', *Economic History Review,* 45 (1992), 285–307; A. D. Morrison-Low, *Making Scientific Instruments in the Industrial Revolution* (Aldershot, 2007), 249–96.

22. J. Gleeson, *The Arcanum* (London, 1998); M. Schonfeld, 'Was there a Western Inventor of Porcelain?', *Technology and Culture,* 39 (1998), 716–27; Friedel, *Culture of Improvement*, 243–8; Berg, 'In Pursuit of Luxury'.
23. One of the first scholars to note the positive role of European political fragmentation on economic performance and technical progress was Edward Gibbon: 'Europe is now divided into twelve powerful, though unequal kingdoms, three respectable commonwealths, and a variety of smaller though independent states.... *In peace, the progress of knowledge and industry is accelerated by the emulation of so many active rivals*: in war, the European forces are exercised by temperate and undecisive contests.' *Decline and Fall of the Roman Empire,* ch. 38 (emphasis added).
24. N. Rosenberg and L. E. Birdzell, *How the West Grew Rich: The Economic Transformation of the Industrial World* (New York, 1986), 137.
25. P. O. Long, 'Invention, Authorship, "Intellectual Property" and the Origins of Patents: Notes towards a Conceptual History', *Technology amd Culture,* 32 (1991), 846–84.
26. A particularly revealing example of the 'tacit' nature of technological knowledge is the case of the water-powered silk throwing mill developed in northern Italy. The famous treatise *Nuovo Teatro di Macchine e Edificii* by Vittorio Zonca published in 1607, with subsequent edtions. in 1621 and 1656, contained a quite detailed description and a drawing of the apparatus. Yet the successful transfer of this invention to England *c.*1710 was possible only after nearly two years of industrial espionage by John Lombe. See C. M. Cipolla, *Before the Industrial Revolution: European Society and Economy, 1000–1700* (London, 1976), 174.
27. In many cases, migrations of skilled craftsmen resulted from the forced migrations of religious minorities, which proved to be one of the main drivers of the spread of technological know-how across early modern Europe, as with the emigration ofHuguenots from France in the late 17th cent.: see W. C. Scoville, 'Spread of Techniques: Minority Migrations and the Diffusion of Technology', *Journal of Economic History,* 11 (1951), 347–60; 'The Huguenots and the Diffusion of Technology', *Journal of Political Economy,* 60 (1952), 294–311, 392–411. For the emergence of Geneva and London as leading centres of clock-making, one of the most technically sophisticated industries of the time, see C. M. Cipolla, *Clocks and Culture, 1300–1700* (London, 1967).
28. Cipolla, *Before the Industrial Revolution*, 174–81; Long, 'Invention, Authorship'; C. M. Belfanti, 'Between Mercantilism and Market: Privileges for Invention in Early Modern Europe', *Journal of Institutional Economics*, 2 (2006), 319–38.
29. C. May and S. K. Sell, *Intellectual Property Rights: A Critical History* (Boulder, Colo., 2006), 59, 63; L. Hilaire-Pérez, *L'Invention technique au siècle des lumières* (Paris, 2000); Belfanti, 'Between Mercantilism and Market', 326.
30. For the influence of the Venetian model on the first concessions of monopoly privileges as a reward to inventors during the reign of Elizabeth I, see J. Phillips, 'The English Patent as a Reward for Invention: The Importation of an Idea', *Journal of Legal History,* 3 (1982), 71–9.
31. C. MacLeod, *Inventing the Industrial Revolution: The English Patent System, 1660–1800* (Cambridge, 1988), ch. 1.
32. D. C. North, *Structure and Change in Economic History* (New York, 1981), 164–6.
33. H. I. Dutton, *The Patent System and Inventive Activity during the Industrial Revolution* (Manchester, 1984); R. J. Sullivan, '"England's Age of Invention": The Acceleration of

Patents and of Patentable Invention during the Industrial Revolution', *Explorations in Economic History*, 26 (1989), 424–52.

34. MacLeod, *Inventing the Industrial Revolution*, ch. 6; C. MacLeod and A. Nuvolari, 'Patents and Industrialization: An Historical Overview of the British Case, 1624–1907' (UK Intellectual Property Office, 2010), http://www.ipo.gov.uk//pro-ipreseach/ipresearch-policy-economic.htm. On the case of the Hornblower engine, see H. S. Torrens, 'New Light on the Hornblower and Winwood Compound Steam Engine', *Journal of the Trevithick Society*, 9 (1982), 21–41.
35. J. Mokyr, *The Lever of Riches* (Oxford, 1990), 191, 258–60.
36. S. R. Epstein, 'Craft Guilds, Apprenticeship, and Technological Change in Preindustrial Europe', *Journal of Economic History*, 58 (1998), 684–713.
37. Liliane Hilaire-Pérez has termed the knowledge-sharing practices of the guild system 'open technique' institutions. For a detailed case study, see her 'Inventing in a World of Guilds: The Case of Silk Fabrics in Eighteenth Century Lyon', in S. R. Epstein and M. Prak (eds.), *Guilds, Innovation and the European Economy* (Cambridge, 2008). On the shared and distributed character of a large body of premodern technical knowledge, see also S. R. Epstein, 'Property Rights to Technical Knowledge in Pre-Modern Europe, 1300–1800', *American Economic Review*, 94 (2004), 382–7.
38. C. M. Belfanti, 'Guilds, Patents, and the Circulation of Technical Knowledge: Northern Italy during the Early Modern Age', *Technology and Culture*, 45 (2004), 569–89.
39. S. T. McCloy, *French Inventions in the Eighteenth Century* (Lexington, Ky., 1952), 176; Coad, *Portsmouth Block Mills*; K. Alder, *Engineering the Revolution. Arms and Enlightenment in France* (Chicago, 1997); J. R. Harris, *Industrial Espionage and Technology Transfer: Britain and France in the Eighteenth Century* (Aldershot, 1998).
40. P. A. David, 'The Historical Origins of Open Science: An Essay on Patronage, Reputation, Commo n Agency Contracting in the Scientific Revolution', *Capitalism and Society*, 3 (2008), 1–103.
41. A. R. Hall, 'Engineering the Scientific Revolution', *Technology and Culture*, 2 (1961), 333–41; P. Mathias, 'Who Unbound Prometheus? Science and Technological Change, 1600–1800', in P. Mathias (ed.), *Science and Society 1600–1900* (Cambridge, 1972).
42. J. Mokyr, *The Gifts of Athena: Historical Origins of the Knowledge Economy* (Princeton, 2002). For a more comprehensive discussion we refer the reader to a special issue of *History of Science* for 2007 (45/2) which is entirely devoted to a comprehensive appraisal of On the critical role that different forms of empirical and tacit knowledge not susceptible of being fully articulated and codified played in the generation of innovations in this historical phase, see Fox, *The Arts of Industry*, and on the mutual interactions between 'expert' knowledge and other forms more susceptible of systematic codification in different technical fields, see the essays collected in L. Roberts, S. Schaffer, and P. Dear (eds.), *The Mindful Hand: Inquiry and Innovation from the Late Renaissance to Early Industrialization* (Amsterdam, 2007).
43. D. S. L. Cardwell, *The Fontana History of Technology* (London, 1994), 194; see also W. G. Vincenti, *What Engineers Know and How they Know it: Analytical Studies from Aeronautical History* (Baltimore, Md., 1990), 137–69.
44. D. S. Landes, *The Wealth and Poverty of Nations* (New York, 1998), 58–9; A. Maddison, *Contours of the World Economy, 1–2030 AD* (Oxford,: 2007), 307–20.
45. Max Weber argued that from the 17th cent., in connection with the formation of a capitalistic outlook, inventive activities became increasingly focused on cost reductions, thereby marking a discontinuity with earlier periods. 'If one scrutinizes the devices of the greatest inventor of pre-capitalistic times, Leonardo da Vinci…one observes that his urge was not that of cheapening production but the rational mastery of technical problems as such': *General Economic History* (London, 1981), 311–12.

46. R. C. Allen, *The British Industrial Revolution in Global Perspective*: (Cambridge, 2009), and R. C. Allen 'Why the Industrial Revolution was British: Commerce, Induced Innovation and the Scientific Revolution', *Economic History Review*, 64 (2011), 357–84. How Commerce Created the Industrial Revolution and Modern Economic Growth' (University of Oxford mimeo, 2006).
47. See also C. MacLeod, 'The European Origins of British Technological Prominence', in L. Prados de la Escosura (ed.), *Exceptionalism and Industrialisation: Britain and its European Rivals* (Cambridge, 2004), 111–26.
48. G. Dosi, 'Sources, Procedures, and Microeconomic Effects of Innovation', *Journal of Economic Literature*, 26 (1988), 1142–3; U. Gragnolati, D. Moschella, and E. Pugliese, 'The Spinning Jenny and the Industrial Revolution: a reappraisal', *Journal of Economic History*, 71 (2011), 455–60, revise some of Allen's computations and argue that the Spinning Jenny could be also profitably adopted in the French economic context. For Allen's response, see R. C. Allen, 'The Spinning Jenny: a Fresh Look', ibid., 461–4.
49. The development costs of Hargreaves's spinning jenny were probably in the region of £500. While the development of Richard Arkwright's water-frame cost about £13,000 (for both figures, Allen, *British Industrial Revolution*, 191, 203. In the field of steam engineering, the development of the Newcomen engine required about ten years of experimentation (L. T. C. Rolt and J. S. Allen, *The Steam Engine of Thomas Newcomen* (Hartington, 1977), 39–43), whereas the costs of developing Watt's engine were probably in the region of £10,000–£13,000. These are all remarkable figures, taking into account that the yearly salary of a skilled craftsman in the second half of the 18th cent. was around £50: F. M. Scherer, 'Invention and Innovation in the Watt-Boulton Steam Engine Venture', *Technology and Culture*, 6 (1965), 169–70.
50. K. G. Persson, *Pre-Industrial Economic Growth, Social Organisation and Technological Progress in Europe* (Oxford, 1988).
51. Landes, *Unbound Prometheus*, ch. 1; K. Pomeranz, *The Great Divergence: Europe and the Making of the Modern World Economy* (Princeton, 2000).
52. E. L. Jones, *The European Miracle: Environments, Economies and Geopolitics in the History of Europe and Asia* (Cambridge, 3rd edn., 2003).
53. D. C. North and R. P. Thomas, *The Rise of the Western World: A New Economic History* (Cambridge, 1973); North, *Structure and Change in Economic History*. A somewhat similar argument for the case of British state intervention in the economy during the 18th cent. has been proposed by Brewer, *Sinews of Power*, and by P. K. O'Brien, 'The Nature and Evolution of an Exceptional Fiscal State and its possible significance for the precocious commercialization and Industrialization of the British economy from Cromwell to Nelson', *Economic History Review* 64 (2011), 408–46. For a revealing study of the impact of government interventions on the early mechanization of the English cotton spinning industry, see P K O'Brain, T. Griffiths, and P. Hunt, 'Political components of the Industrial Revolution: Parliament and the English cotton textile industry, 1660–1774, *Economic History Review*, 44 (1991), 395–423.
54. H. J. Habbakuk, 'The Historical Experience of the Basic Conditions of Economic Progress', in L. H. Dupriez and D. Hague (eds.), *Economic Progress* (London, 1955), 86.

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CHAPTER 27

REVOLUTION

MICHAEL RAPPORT

In 1814, as the Napoleonic Empire teetered on the brink of destruction, Bertrand Lhodiesnière, a veteran revolutionary from Normandy, told his fellow-citizens that when the Bourbon monarchy returned, 'you will have to pay tithes and feudal dues again, and after dark, they will make you keep the frogs quiet so that milord and milady can get a good night's sleep'.[1] This dire warning reflected how far French society had changed since the collapse of the absolute monarchy in 1789. There had been no set programme of radical reform right at the start. Yet the force of circumstances combined with the revolutionaries' ideology to create an impetus which left no area of eighteenth-century life untouched. The elected representatives of the people, the National Assembly, were confronted with the challenge of restoring order to the country, tackling the monarchy's financial woes and establishing a viable political framework for the kingdom. The founding deeds of the French Revolution were therefore at once a pragmatic response to the crisis and an expression of the new order's fundamental principles.

The first dramatic break with the past came in the night of 4 August 1789. In an emotional session pregnant not only with symbolism, but also with real transformative potential for the whole kingdom, the National Assembly abolished what it called 'feudalism'. The deputies, many of them property owners, were urgently trying to pacify the insurgent countryside by renouncing seigneurial rights, but, emboldened by a potent brew of alarm and idealism, they went even further. In a crescendo of zeal, they renounced one privilege after another, levelling individual, corporate, and provincial privileges which made up the very fabric of social differentiation in the Ancien Régime. The tithe, seigneurial justice, and venality were abolished, alongside other vestiges of 'feudalism'. A popular uprising had spurred France's revolutionary elite into razing the old order, leaving the Revolution with the immense task of building a new regime.

The principles which were meant to guide the revolutionaries in this next challenge were expressed in the Declaration of the Rights of Man and the Citizen on 26 August. 'Men are born and remain free and equal in rights', the first electrifying article rang out. These rights included 'liberty, property, security and resistance to oppression'. 'Liberty'