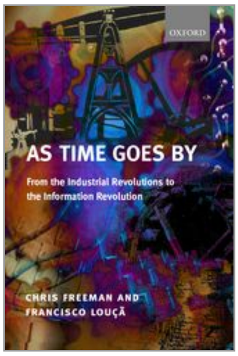

As Time Goes By: From the Industrial Revolutions to the Information Revolution
Chris Freeman and Francisco Louçã

Print publication date: 2002
Print ISBN-13: 9780199251056
Published to Oxford Scholarship Online: November 2003
DOI: 10.1093/0199251053.001.0001

The British Industrial Revolution: The Age of Cotton, Iron, and Water Power

Chris Freeman (Contributor Webpage)
Francisco Louçã (Contributor Webpage)

DOI:10.1093/0199251053.003.0005

Abstract and Keywords

The available statistics show that there was a sharp acceleration of the growth of British industrial output, investment, and trade in the last few decades of the eighteenth century, justifying the general use of the expression ‘Industrial Revolution’ and refuting the efforts of a few historians to deny its very occurrence.

In particular, the extraordinarily rapid growth of output and exports of the cotton industry was widely remarked upon both at the time and ever since, and was generally and plausibly attributed to a series of inventions and innovations, which increased productivity per hour of work by more than an order of magnitude and made possible rapidly descending costs and prices.

Only a little less rapid was the growth of the British iron industry, its rate of technical change, and its widening range of applications throughout the economy.

These exceptionally dynamic industries made an outstanding contribution to the growth of the economy as a whole based on water-powered mechanization and a new transport infrastructure of canals, rivers, and roads.

Finally, British leadership in the Industrial Revolution must be attributed not only to these changes in technology and in the economy but also to the confluence and congruence of these changes with developments in the political and cultural subsystems particularly favourable to science, technology, and entrepreneurship.

Keywords: Britain, canals, cotton, entrepreneurship, Industrial Revolution, innovation, iron, mechanization, productivity, water power

5.1 Introduction: Acceleration of Growth from 1770S

Historians[1] differ in their interpretation of the main features of the British Industrial Revolution. Some put the main emphasis on entrepreneurship, some on inventions and innovations, some on culture and science, some on transport, communications, and trade, and some on the growth and composition of market demand. However, almost all agree that single-factor explanations are inadequate, and almost all mention most or all of these together with the changes in agriculture and, of course, the accumulation of capital and mobility of labour.

Our interpretation of the picture that emerges from the major studies of the Industrial Revolution, and most notably from the eleven-volume history of *The Industrial Revolutions*, published by the Economic History Society (Church and Wrigley 1994), is summarized in Sections 5.1–5.8, followed by concluding sections on the transition from the first to the second Kondratiev (Sections 5.9 and 5.10).

Economic historians mostly agree that there was a fairly sharp acceleration of British industrial output, investment, and trade in the last few decades of the eighteenth century. In one of the early estimates, Hoffmann calculated the rate of growth of British industrial output from 1700 to 1780 as between 0.5 and 1 per cent per annum, but from 1780 to 1870 at more than 3 per cent. More recent estimates (Crafts 1994) have reduced the estimated growth rates for the later period but do not change the fundamental picture (Table 5.1; Figure 1.2). As Chapter 1 has shown, and as Landes has consistently argued, the 'revisionist' historians, although sometimes setting out to destroy what they thought of as the 'myth' of accelerated growth, actually confirmed it. Supple (1963: 35) summed up the consensus as follows: 'economic change did not experience a steady acceleration, rather there was a more or less precise point (which most historians place in the 1780s) after which innovation, investment, output, trade and so forth all seemed to leap forward'.

(p.154) Although it was the surge of growth in *industry* in the late eighteenth century that was the principal component of the acceleration in British economic growth, Deane and Cole (1962) estimated that the rate of growth in national income as a whole over the period from 1800 to 1860 was twice as high as the rate from 1740 to 1800. Estimates by Crafts (1994: 196) show somewhat slower growth for the period 1780–1800 than some of the earlier calculations: he estimates national income growth at 0.7 per cent per annum from 1760 to 1780, 1.32 per cent from 1780 to 1800, and 1.97 per cent from 1801 to 1834. This is nevertheless a very substantial change, and it marked a transition to a sustained rate of economic growth over a long period greater than any that had ever been previously achieved.

Historians also agree that the surge of growth in British industry was emphatically not simply 'balanced reproduction' ('balanced' growth of all industries simultaneously), but was characterized by the exceptionally rapid growth of a few leading sectors, above all the cotton industry and the iron industry (Table 5.1). The share of cotton in total value added of industry grew from 2.6 per cent in 1770 to 17 per cent in 1801. This was an extraordinarily rapid change of industrial structure; as Supple noted, 'in the initial decades of the British Industrial Revolution it was the cotton textile industry which experienced the most spectacular expansion. Subsequently, after 1840 railroad investment and the spread of a transportation network seemed to dominate the economy and in the third quarter of the century, the steel industry and steamship construction leapt ahead' (Supple 1963: 37).

The backward and forward linkages to other industries were of course also important, but the exceptional role of the cotton textile industry has generally been acknowledged both by contemporaries and by historians ever since. Imports of raw cotton grew from an average of 16 million pounds per annum in 1783–7 to 29 million pounds in 1787–92 and 56 million pounds in 1800 as the main source changed from the West Indies to the US slave plantations. The rate of increase in imports was described by a nineteenth-century

Table 5.1. Sectoral Growth of Real Industrial Output in Britain, 1700–1760 to 1811–1821 (% Per Year)

Years	Cotton	Iron	Building	Industrial output (weighted average)[a]
1700–1760	1.37	0.60	0.74	0.71
1770–1780	6.20	4.47	4.24	1.79
1780–1790	12.76	3.79	3.22	1.60
1790–1801	6.73	6.48	2.01	2.49
1801–1811	4.49	7.45	2.05	2.70
1811–1821	5.59	−0.28	3.61	2.42

(a) Including other industries: 1700–90 based on 1770 weights; 1790–1821 based on 1801 weights.

Source: Crafts (1994).

(p.155) historian (Baines 1835) as ‘rapid and steady far beyond all precedent in any other manufacture’. The invention of the cotton gin by Eli Whitney in the United States in 1793 ensured continuous rapid expansion of the supply of raw cotton. Baines attributed the extraordinary rise in the 1770s and 1780s directly to the effects of technical inventions and their diffusion: ‘from 1771 to 1781, owing to the invention of the jenny and the water-frame, a rapid increase took place; in the ten years from 1781 to 1791, being those which immediately followed the invention of the mule and the expiration of Arkwright's patent, the rate of advancement was prodigiously accelerated.’

It was on the basis of a whole series of inventions and improvements (Chapman 1972; Hills 1994; Mann 1958; von Tunzelmann 1995*b*) that big increases in productivity became possible, based increasingly on their exploitation in the new system of factory (mill) based production (Table 5.2(*a*)). These improvements in process technology in the cotton industry made possible the rapidly falling prices, which in turn provided the competitive strength for British exports to undercut Indian and other Asian textiles and indeed all other producers. Exports of cotton textiles reached 60 per cent of output by 1820 and became the biggest single commodity in nineteenth-century trade, accounting for over 30 per cent of British exports of manufactures in 1899, when Britain was still by far the biggest exporter.

The fall in the price of Lancashire cotton yarn was remarkable, occurring as it did in the inflationary period of the Napoleonic Wars. The price of No. 100 Cotton Yarn fell from 38/- in 1786 to 6/9*d* in 1807. Landes (1965: 109) estimates that by 1837 the price of cotton yarn had fallen to one-twentieth of its level in 1760. This cannot be mainly attributed to a fall in the price of the raw material, but must be ascribed to innovations in the processing of cotton yarn and the organization of production (Table 5.2(*b*)).

However, extraordinarily important though it undoubtedly was for the leading sectors of the British Industrial Revolution, cotton yarn hardly corresponds to the Perez definition of a ‘core input’ or ‘key factor’, since it did not have a potentially wide range of applications but concerned only the cotton industry itself. The role of ‘core input’ and ‘motive branch’ belongs rather to the other fast-growing industry of the Industrial Revolution: the iron industry

Table 5.2.(a) Labour Productivity in Cotton: Operative Hours to Process (OHP) 100 Pounds of Cotton

	OHP
Indian hand spinners (18th century)	50,000
Crompton's mule (1780)	2,000
100-spindle mule (*c*.1790)	1,000
Power-assisted mules (*c*.1795)	300
Roberts's automatic mule (*c*.1825)	135
Most efficient machines today (1990)	40

Source: Jenkins (1994: xix).

(p.156)

Table 5.2(b). Technical Changes in Cotton Spinning, 1780–1830[a]

	Spinning costs per 100 lb of cotton		Working hours for spinning 100 lb of cotton
	£	Index	Index
1780	2.10	100	100
1790	1.07	49	—
1795	0.57	23	15
1810	0.21	5	—
1830	0.13	4	7

(a) All data for English Cotton number 80.

Source: Paulinyi (1989: 66).

(Table 5.1). This section, therefore, after briefly discussing the cluster of innovations in the cotton industry, goes on to consider the key innovations in the iron industry, followed by the innovations in water power and in transport, the infrastructure of the first British Industrial Revolution.

5.2 Invention and Innovation in the Cotton Industry

The cotton industry may be more properly regarded as a 'carrier branch' in the Perez sense, or as a 'leading sector' in Rostow's terminology. As we shall see, many of the organizational as well as technical innovations in cotton were followed later by other branches of the textile industry and by manufacturing more generally.

Virtually all accounts, whether contemporary or otherwise, agree on the importance of inventions, both in the cotton industry and in other industries, for the spurt in economic growth. Indeed, they were often given pride of place in the older textbooks on English history. Like Adam Smith (1776), recent studies stress the continuous improvement of processes in the factory or workplace, as well as the original major inventions. They also sometimes stress the speed with which inventions became innovations and were then rapidly diffused, as we have seen in the case of Baines. The number of patents sealed had been about 80 per year in the 1740–9 period but increased to nearly 300 in 1770–9 and to over 600 in 1790–9 (Table 5.3). Patents are an imperfect indicator, but there were no changes in this period that might invalidate the series (Eversley 1994). A high and growing proportion of this number were in capital goods related to the cotton industry and other leading sectors of the Industrial Revolution (Table 5.3).

There is some disagreement on the nature of the major inventions of the eighteenth century. Some authors argue that they were typically very simple; they 'leave the impression that the inventions were the work of obscure mill-wrights, carpenters or clock-makers, untutored in principles, who stumbled by chance on some device' (Ashton 1948). Ashton argued that 'these accounts **(p.157)**

Table 5.3. Patents for Various Capital Goods in Eighteenth-Century Britain

Patent classes	1770–79	1780–89	1790–99
Power sources (prime movers and pumps	17	47	74
Textile machinery	19	23	53
Metallurgical equipment	6	11	19

Patent classes	1770–79	1780–89	1790–99
Canals and road building	1	2	24
Subtotal	48	90	170
(% of all patents)	(16)	(19)	(28)
All capital goods patents	92	168	294
(% of all patents)	(31)	(34)	(45)
All patents	298	477	604

Source: C. MacLeod (1988).

have done harm by obscuring the fact that systematic thought lay behind most of the innovations in industrial practice' and overstressed the part played by chance. Further, 'Many involve two or more previously independent ideas or processes, which brought together in the mind of the inventor issue in a more or less complex and efficient mechanism. In this way, for example, the principle of the jenny was united by Crompton with that of spinning by rollers to produce the mule . . . ' (Ashton 1963: 154).

Landes also stresses the high skills of the mechanics, smiths, millwrights, and tool-cutters of the Industrial Revolution:

> Even more striking is the theoretical knowledge of these men. They were not on the whole, the unlettered tinkers of historical mythology. Even the ordinary millwright, as Fairbairn notes, was usually a fair arithmetician, knew something of geometry, levelling and mensuration, and in some cases possessed a very competent knowledge of practical mathematics. He could also calculate the velocities, strength and power of machines, could draw in plan and section. (Landes 1965: 296)

At the opposite extreme, some accounts give the impression that the inventions were the result of individual genius or scientific brilliance, rather than the outcome of a continuous social process. In part, these differences of interpretation arise from the fact that (as still today) there is a very wide spectrum of inventions and innovations. The vast majority, then and now, were incremental improvements to existing processes and products and, as Adam Smith observed, were often made by workers who used machines in different types of workplace.[2] They were facilitated by specialization based on division of **(p.**

158) labour, but again, as Adam Smith observed, still other inventions resulted from the work of scientists whose skill was to observe dissimilar processes.

Von Tunzelmann (1995*b*) provides evidence that the main inducement for innovators was *time*-saving, and that the savings in fixed and working capital, in labour, and in land were the indirect result of this time-saving objective, pursued within a general paradigm of relatively straightforward mechanization. He also brings out the role of focusing devices and *coordination* in the whole production system. Baines stated: ‘Replication of the particular components which represented the most constrictive bottlenecks was often carried out in addition to speeding them up. The cylinder for block printing could thus be replicated by up to five times’ (Baines 1835: 236), and ‘The same innovation strategy underlay the jenny, which multiplied the traditional spinning wheel initially to 8 and eventually to sometimes 120 within the one machine’ (p. 15).

Nevertheless, the combined effect of the inventions of Hargreaves, Arkwright, Crompton, and their predecessors and successors was revolutionary rather than gradual (Table 5.2(*a*)). The leap in labour productivity at the end of the eighteenth century reduced the number of operative hours to process (OHP) 100 pounds of cotton by much more than an order of magnitude. Table 5.2(*b*) also shows Paulinyi's (1989) estimate of the similar order-of-magnitude reduction in the *cost* of spinning 100 pounds of cotton between 1780 and 1810. The power required to operate the later innovations meant that machinery had to be installed in purpose-built premises (factories). Arkwright limited his licences to machines of a thousand spindles, but human muscle and horse power were succeeded by water power and later by steam (Jenkins 1994). He made his own fortune from his factories and not from licensing his invention. By 1788 there were over 200 Arkwright-type mills in Britain, mostly constructed in the 1780s after the first successful challenge to Arkwright's patents. Typically these mills were three or four storeys high, with about a thousand spindles and a 10 HP water wheel (Chapman 1992: 27). The dramatic impression made by this wave of factory construction can be seen from William Blake's poem ‘Jerusalem’ (1804), which became almost a second national anthem in Britain and described the new factories as ‘dark satanic mills’ in ‘England's green and pleasant land’.

The example of Arkwright, who became an extremely wealthy man, although often an unpopular one, made a deep impression on other industrialists and the cotton industry began to influence other sectors too. In his excellent monograph, Chapman cites:

> [much] undisputed evidence of the wide-ranging contribution of cotton to the growth of the British economy between 1770 and mid-nineteenth century. Arkwright's techniques were not difficult to apply to worsted spinning and worsted mills modelled on his cotton mills were soon being built in the hosiery districts of the Midlands and in parts of Lancashire, the West Riding, and Scotland. . . . In the linen industry John Marshall of Leeds inaugurated the factory system by adopting Arkwright's techniques and factory organization. (Chapman 1992: 57–8)

(p.159) Chapman goes on to describe the direct and indirect imitation of cotton industry techniques in other branches of the textile industry and the influence of cotton on the birth of new activities in other sectors of the economy, including the construction of multi-storey iron-framed buildings lit by gas, and the design and construction of specialized cotton machinery and components, using iron as well as wood. Roberts developed the standardized production of mules and looms in his Manchester factory in the 1820s, and these techniques were applied later to the manufacture of locomotives (Musson 1980: 91).

5.3 Water Power and the Rapid Growth and Multiple Applications of Iron

The smelting of iron ore with coke instead of charcoal and Cort's process for the conversion of pig iron into malleable (wrought) iron by ‘puddling’ were the two decisive innovations for the metalworking industries in the eighteenth century. Together they made possible the huge increase in the supply of relatively cheap iron which took place between 1780 and 1840 (from about 60,000 tons per annum to about 2 million tons per annum) (Figure 5.1). Many

(p.160) other incremental innovations in blast furnace technology were made locally to adapt output to local supplies of coal, coke, iron ore, and water, but Cort's innovation and the use of coke for smelting were the two decisive innovations which gave the British iron industry a clear lead in Europe by the end of the eighteenth century.

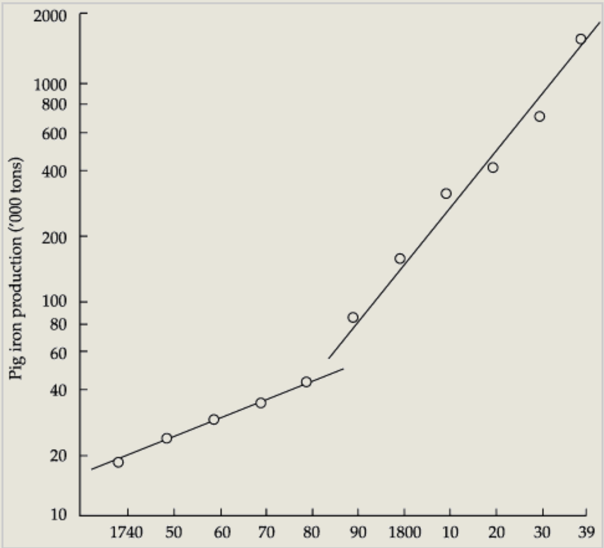

Fig 5.1. Accelerated Growth Of Iron As a Core Input: Pig Iron Production In England, 1740–1839

Source: Oxford History (1958: iv. 107).

It was as early as 1709 that Abraham Darby first used coke in a blast furnace to smelt iron ore, but further inventions were needed before the output reached a reasonably high quality. One of the important additional innovations was introduced by Joseph Smeaton in 1762. This was the use of water-driven bellows to raise the temperature in the blast furnaces.

Even with the improvements in blast furnace technology, *pig iron* remained a rather brittle material, unsuited for many applications, and its conversion to *wrought iron* by repeated heating and hammering was expensive and labour-intensive. Consequently, the next great innovations in the iron industry—the ‘puddling’ and rolling processes invented by Henry Cort (who was originally an outfitter for the Navy)[3]—were at least equally important. Patented in 1783 and in 1784 and subsequently improved, these processes made possible both a huge increase of supply in wrought iron (500 per cent between 1788 and 1815) and a fall in price, from £22 per ton to £13 per ton from 1801 to 1815. This fall was especially remarkable taking into account the huge rise in military demand for iron during the Napoleonic Wars as well as the simultaneous increase in civil demand for the numerous applications of the Industrial Revolution. The fall in price of iron continued for the next few decades, so that iron was a core input not only for the first but also for the second Kondratiev wave (Figure 5.2). It was not until after the Napoleonic Wars that Cort's puddling and rolling innovations diffused to the European continent, so that throughout the wars British manufacturers had a decisive advantage in the cost and quantity of iron, which was available for both military and civil applications. In the 1820s, the technique was diffused by the migration of skilled Welsh craftsmen to France and Germany.[4] In this later period the use of steam engines helped to reduce **(p.161)** prices further, but the early innovations of the eighteenth century in the iron industry were based on the use of water-power in the iron foundries. As the *Oxford History of Technology* (Oxford History 1958: iv. 200) observed, as early as the sixteenth century 'the water wheel was by far the most important source of power in Europe. It was the basis of mining and metallurgy and hammers and bellows driven by the water wheel were essential for the manufacture of wrought and cast iron. The hoisting, crushing and stamping of ore, the drilling of gun barrels and the drawing of wire were carried out with the aid of water wheels. Water power had also been adopted in the mining of copper and silver.' Eventually, the improved design and efficiency of steam engines led to the replacement of water wheels by steam engines in forges, rolling mills, and blast furnaces; but for most of the eighteenth century water power predominated.

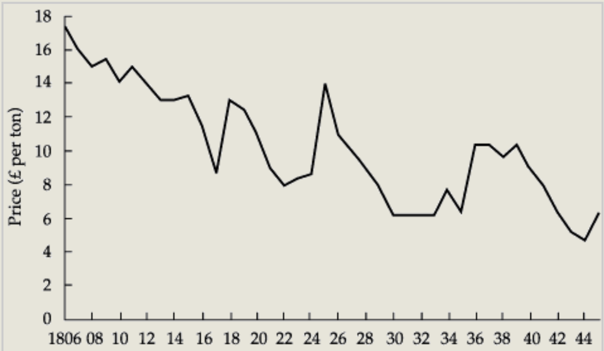

Fig 5.2. Price Of Iron: English Merchant Bar At Liverpool, 1806–1845

Source: Mitchell (1988).

Joseph Smeaton (1724–92) decided at the age of 27 to investigate ‘how the design and efficiency of water wheels could be improved. Having been apprenticed to a mathematical instrument-maker, he made a really good model with his own hands and tested it accurately’ (Oxford History 1958: iv. 203). On 3 and 24 May 1759 Smeaton presented two papers to the Royal Society entitled ‘Experimental Enquiry into the Natural Powers of Wind and Water to turn Mills’. As a consulting engineer, he designed numerous mills all over Britain. His experiments showed that the best effect was obtained when the velocity of the wheel's circumference was a little more than 3 ft/sec. It became a general rule to design overshot water wheels at their circumference of 210 feet per minute.

Smeaton was consulting engineer to the Carron Ironworks, by far the largest producer of cast iron in Europe, and was able therefore to experiment with and develop the use of cast iron parts for machinery, one of his greatest contributions to mechanical engineering. His first cast iron water wheel axle **(p.162)** was made in 1769 for the Carron No. 1 furnace blowing engine. Cast iron gearing was used for Brook Mill, Deptford in 1778 and frequently afterwards.

> Smeaton's designs mark the end of an era of wooden water wheel construction which had lasted for eighteen centuries. His numerous improvements enabled him to reach the limit of power that could be generated and transmitted by wooden wheels . . . After his death, revolutionary developments in design took place, the most important being all-metal construction. (Oxford History 1958: iv. 209)

What Tylecote (1992: 42) designates as ‘the Smeaton Revolution’ must have reduced the cost per unit of available energy for a best practice wheel around 1780 to about 20 or 30 per cent of what it had been in 1750. This reduction was due to a combination of the effects of the falling price of iron, the increased efficiency and size of wheels, and their reduced maintenance costs.

The life and work of Joseph Smeaton demonstrate very well the fruitful interplay between design, consultancy, and entrepreneurship which was a feature of the newly industrializing sectors of the British economy. It shows too that the divide between 'science' and 'technology' was not of great significance at that time in Britain for either scientists or technologists, and that they moved easily between factory, construction site, and laboratory. The award of the Royal Society Medal for his two scientific papers complemented his numerous practical innovations.

The use of iron in water wheels was of course only one of innumerable new applications of this versatile material in the eighteenth and nineteenth centuries. It may truly be regarded as the typical core input for the Industrial Revolution since it had so many applications in so many industries. As Mokyr points out, 'It is possible to imagine an industrial revolution based on water power and linen or wool. In fact in many places that is precisely what happened. There was no substitute for iron, however, in thousands of uses, from nails to engines. As its price fell, iron invaded terrains traditionally dominated by timber, such as bridges, ships and eventually buildings' (in Floud and McCloskey 1994: 29).

Iron became the essential material for new applications of both water power and steam power. It was only when Boulton and Watt entered into an arrangement with the iron-master, John Wilkinson, that their new enterprise could build engines suitable for applications other than pumping. Wilkinson, who was both an inventor and an entrepreneur, had taken out a patent in 1775 for a cylinder-boring machine. Although originally designed for boring cannons, it proved equally effective for boring the cylinders of Boulton and Watt engines to a much higher degree of accuracy. Some of the first engines were actually made by Wilkinson himself for use in his own blast furnaces. He also introduced the first steam-hammer in 1782. He was such an enthusiast for iron that he was known as 'iron-mad' Wilkinson and even made an iron coffin for his own burial. (In the event, by the time he died in 1808, he was too fat to fit in this coffin.) He also made the first **(p.163)** wrought-iron boat in 1787 and was associated with the initiative for the first famous 'Ironbridge', although he did not build it himself.

As metal components and machines were increasingly substituted for wooden ones, the cotton industry itself, as well as the other textile industries, became increasingly dependent on the metalworking industries and the skills of the toolmakers.

Among the numerous other applications of iron were the following:

Rails for mines	Winding gear for mines
Gears and other components for water wheels	Pumps for mines
	Blowing cylinders
First cast iron cog wheels from Carron foundry 1760	Cutlery
	Clocks and instruments
Complete water wheels	Bridges
Ships' anchors and chains	Grates and stoves
Munitions and weapons	Machinery for locks on canals
Vessels and pipes for the chemical industry	Rollers for various industries
	Textile machinery
Hammers and other tools for the metallurgical and construction industry	Iron frames for multi-story cotton mills and warehouses from 1795
Shovels and picks for the mines and construction	Cast iron water pipes and tanks
	Cooking utensils
Nails	Furniture
Iron ploughs and other farm implements	Ornamental objects
Steam engines of various types	

While iron had been used for centuries, the scale of use for old applications was greatly expanded while the range of new applications widened enormously. Maxine Berg (1998) has pointed out that there was an important interaction between design and invention for consumer products, including ornamental and fashion-driven metal products and the design of capital goods. Military applications were of course especially important during the Napoleonic Wars, and it was no wonder that the victor of Waterloo, the Duke of Wellington, was nicknamed the ‘Iron Duke’. As Prussia in subsequent decades began to catch up with industrialization, the young Otto von Bismarck convinced his fellow Junkers that Germany would be unified not by parliamentary majorities but by ‘blood and iron’.

The rapidly falling price of iron in the late eighteenth and early nineteenth centuries satisfied the third criterion proposed by Carlota Perez for the core inputs of a long wave, as well as the criteria of universal availability and multiple applications. The falling price was due mainly to technical innovations but also in some parts of the country to falling transport costs following the construction of a network of canals between 1750 and 1800. It is to these transport innovations that we now turn. They facilitated a reduction in costs of all kinds of commodities but especially of the bulkiest and heaviest materials.

(p.164) 5.4 The Transport Infrastructure: Canals and Roads

The Industrial Revolution is often associated with railways as well as with steam engines, but their widespread use outside coal mines came only in the 1830s and 1840s. The first wave of industrialization depended upon water power, canals, and much better roads known as turnpike roads. These networks were the focus of what was in those days a heavy investment (Figure 5.3). From 1700 to 1750 Parliament had been passing Turnpike Acts at the rate of eight a year, but in the 1760s and 1770s this increased to a rate of forty per annum.

(p.165)

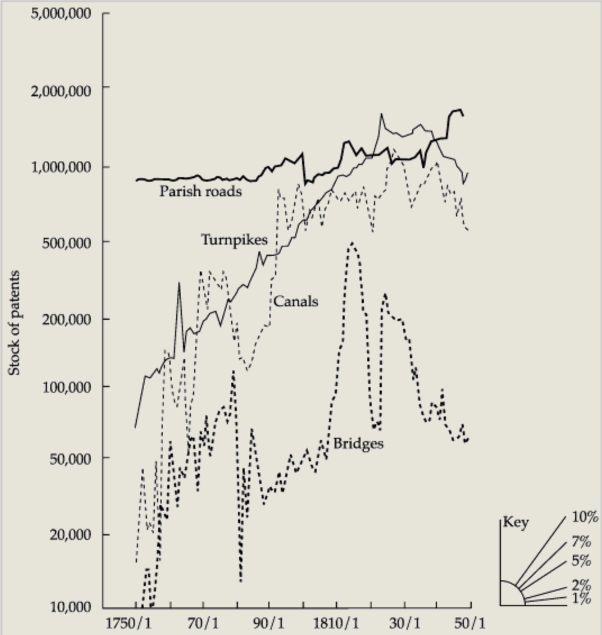

Fig 5.3. Transport and Social Overhead Capital, 1750–1850

Note: Expenditure On Creating, Improving, and Maintaining Canals and Roads, Etc. 1750–1850 (Current Prices).

Source: Hawke and Higgins (1981: 230).

Table 5.4. Investments in Canals and Railways in the Eighteenth and Nineteenth Centuries (% Of Nominal Capital Invested)

	Canals 1755–1815 (1)	Railways 1820–1844 (2)	Canals 1755–1780 (3)	Railways ‘early years’ (4)	Canals 1780–1815 (5)	Railways ‘later years’ (6)
1. Peers, gentry, ‘gentlemen’, etc.	22	28	41	22	22	37
2. Land: farmers, graziers, etc.	2	—	1	—	2	—
3. Commerce: merchants, traders, tradesmen, etc.	39	45	27	52	40	38
4. Manufacturers	15	11	8	15	15	7
5. Professions, including clergymen	16	9	16	8	16	10
6. Women	6	5	8	2	6	8
	100	100	100	100	100	100

Source: Hawke and Higgins (1981).

Transport infrastructure is surprisingly neglected in many studies of the Industrial Revolution, including the otherwise comprehensive Volumes 2 and 3 of the Economic History Society set of papers (Hoppit and Wrigley 1994). However, in his chapter on the supply of raw materials, Wrigley (1994) refers to the supply of coal, iron, and other minerals as being the main driving force for canal building in the late eighteenth century. This view is supported by information on the role of landlords as investors (Table 5.4) as well as statistics of the value of freight carried and the geographical pattern of canal construction.

The sea transport of coal from Newcastle to London was established long before the Industrial Revolution, but the wave of canal and turnpike road construction from the 1760s onwards reduced the cost of transporting coal to many areas of Britain by about 50 per cent.[5] One of the earliest canals—the Duke of Bridgewater's Canal from Worsley to Manchester—was already demonstrating this cheapening of coal prices in the 1760s. It became famous because at the Worsley end it went underground almost to the coal face, while it crossed the River Irwell on an aqueduct. The canal was designed and built by James Brindley, one of the early millwrights, who engineered both waterwheels and canals.

These improvements benefited all industries and services by widening markets as well as improving supplies. Hobsbawm (1968) points out that the **(p.166)** ‘wide scattering’ of British industry through the countryside, based on the putting out system, the coal-mining regions, the new industrial textile regions, the ‘village industries’, and London as a huge centre of population, trade, and services (the largest in Europe), had two major consequences. First,

> [it] gave the politically decisive class of landlords a direct interest in the mines which happened to lie under their lands, (and from which, unlike the Continent, they, rather than the King, drew royalties) and the manufactures in their villages. The very marked interest of the local nobility and gentry in such investments as canals and turnpike roads was due not merely to the hope of opening wider markets to local agricultural produce, but to the anticipated advantages of better and cheaper transport for local mines and manufactures. (Hobsbawm 1968: 16)

The second consequence was that manufacturing interests could often determine government policy, unlike other European countries and even the Netherlands, where merchant and landed interests were still dominant. The oligarchy of landed aristocrats in England was unlike the feudal hierarchies of other European countries in several ways. They were a ‘bourgeois’ aristocracy, with an interest in profitable investments. Their contribution to investment in the new transport infrastructure was remarkable (Table 5.4), but the contribution of merchants was as great or even greater. Both landlords and merchants appreciated the value of canals, and they were able to take advantage of a fairly well developed capital market. This had already developed on a significant scale in the seventeenth and early eighteenth centuries, mainly on the basis of accumulation from trade and government debt. As Mathias pointed out:

> Investment in an inland transport system, shipping and ports is one of the prerequisites for industrial growth; yet to create such a system, there must be extensive prior mobilization of capital and the agencies to effect it . . . Financing canals and turn-pikes showed how plentiful capital was in eighteenth century England and how favourable the social context was for investment. (1969: 105–7)

This ‘prior mobilization’ of capital was described by Adam Smith as ‘previous’ accumulation and more graphically by Marx (1867*a*/1938) as ‘primitive accumulation’. In the final chapter of his first volume of *Kapital* he has a vivid indictment of its nature: ‘The discovery of gold and silver in America, the extirpation, enslavement and entombment in mines of the aboriginal population, the beginning of the conquest and looting of the East Indies, the turning of Africa into a warren for the commercial hunting of black skins, signalised the rosy dawn of the era of capitalist production’ (p. 775).

Using the records of the East India Company, the trial of Warren Hastings, and many other official and first-hand accounts of the looting and corruption that accompanied eighteenth-century colonialism of the British and other European powers, Marx showed how the proceeds of this ‘primitive accumulation’ flowed back to the mother countries. Thackeray's *Vanity Fair* **(p.167)** shows from a novelist's perspective how the ‘Nabobs’ of the East India Company and their new-found wealth had affected English society by the time of the Napoleonic Wars. The Nabobs derived their wealth and power from the monopoly contracts awarded to the employees of the East India Company for salt, opium, betel, and other commodities, and from their monopoly of the China trade. As Marx sarcastically remarked, they 'received contracts under conditions whereby they, cleverer than the alchemists, make gold out of nothing. Great fortunes sprang up like mushrooms in a day; primitive accumulation went on without the advance of a shilling. The trial of Warren Hastings swarms with such cases' (Marx 1867*a*/1938: 777).

Equally important, in both Marx's account and those of other historians, was the establishment of the Bank of England in 1694 and the rise of the National Debt in Britain with the regular trade in government bonds. The availability of substantial private capital seeking profitable investment was demonstrated by the South Sea 'Bubble' of 1720, which attracted speculation from poets such as Alexander Pope, as well as aristocrats and shopkeepers. It was the existence of this well developed capital market that made possible the finance of infrastructural investment, and not the contribution of industrialists, which was relatively small. The cotton industry itself was not the main source of funds for investment in the new infrastructure, for reasons that Wrigley makes clear:

> The movement of cotton presented no great difficulties to the methods of goods transport which had been in use for centuries. The movement of raw cotton was measured by the million pounds rather than the million tons and bore a far higher value per unit weight than, say, coal . . . The fact that many early mills were built in quite remote Pennine valleys close to a head of water, underlines this point. (Wrigley 1994: 103)

At this time the landed aristocracy and merchants were still by far the wealthiest part of the community so that their active involvement in the new infrastructural investment was a major factor. The new textile industrialists were struggling to raise sufficient capital for their own investments in machinery and mills, small though these investments still were. However, the fact that manufacturers made a much smaller contribution to infrastructural investment than either landed gentry or merchants (Table 5.4) does not mean that they were unaffected or that they did not perceive its immense importance. On the contrary, an industrialist such as Josiah Wedgwood was enthusiastic in his promotion of canals and roads in the Midlands, for he realized very well that his ambitions to export his pottery all over the world depended upon this new investment.

However, infrastructural investment, especially in canals, differed from the industrial investment of those times in its scale and its 'lumpiness'. As Peter Mathias (1969: 105) pointed out, 'A large transport project needs to be complete before its benefits accrue to the economy or before any income can be created', and it therefore required extensive prior mobilization of capital. **(p.168)** The rewards could be very great, as the Duke of Bridgewater's canal from Worsley to Manchester showed in 1761. Hobsbawm (1968: 30) estimated that canals cut the cost per ton between Liverpool and Manchester or Birmingham by 80 per cent in the eighteenth century; but there could also be failures. The fluctuations in expectations led to the typical phenomena of euphoria and 'mania', as in the canal boom of the 1790s, alternating with periods of pessimism. These bandwagon and bubble phenomena were to become typical of the very fast-growing sectors in each successive Kondratiev wave, indicating the co-existence of very great perceived opportunities for profit with a high level of uncertainty for the individual project and a cyclical pattern of growth.

5.5 The Entrepreneurs of the First Kondratiev Wave and the New Techno-Economic Paradigm of Industrialization

Sections 5.1–5.4 above have outlined in a very condensed form some of the main features of a constellation of fast-growing sections of the British economy from the 1770s to the 1820s. The cotton, iron, and construction industries, as a result of this high growth, accounted for about half of all value added in industry by 1831, compared with about one-fifth of the total in 1770. It is true that agriculture still accounted for about a quarter of total employment and output, but industry and construction had already overtaken agriculture by 1810. In our view, this fully justifies the use of the expression 'Industrial Revolution'.

This Industrial Revolution was a question not just of changes in the share of output, but also of social, organizational, and cultural changes in industry and in the economy as a whole.

This is not the place to consider it, but agriculture itself was becoming an industry organized on capitalist lines with tenant farmers employing hired labour and producing for the market. The cotton industry outgrew all other branches of industry, but they were also changing. Whereas from 1770 to 1801 the cotton industry and the iron industry were growing at several times the rate of all industry, by 1831 their growth rate had slowed a little and other industries were growing faster (Table 5.5).

Some other industries, such as the pottery industry, had grown almost as fast as the leading sectors from the 1760s onwards, taking full advantage of the new infrastructure for the transport of their heavy materials and their final products. No one expressed better than Josiah Wedgwood, the leading entrepreneur in the pottery industry, the aspirations and ideals of the new group of entrepreneurs who were reorganizing production on a factory basis and marketing their products world-wide. In his letters to his partner, Thomas Bentley, and in other writings and speeches, he articulated the main principles of the new techno-economic paradigm of industrialization. At this stage it was the individual entrepreneurs themselves who organized and managed most aspects of the business. **(p.169)**

Table 5.5. Structural Changes in the First Kondratiev (Annual % Growth Rates)

Sector	Pre-industrial	Industrial Revolution	
	1700–60	1770–1801	1801–31
Cotton	1.4	9.0	6.0
Iron	0.6	5.0	4.5
Construction	0.7	3.2	2.9
of which, canals	1.0	6.0	3.0
Total, all industries	1.0	2.0	2.8

Source: Crafts (1994), except canals (authors' estimates).

Wedgwood was responsible not only for numerous design and process innovations, but also for many organizational innovations. He was motivated by ideals of political and social change as well as technical change and capital accumulation. He was very active in promoting the construction of canals and turnpike roads in his own native county of Staffordshire, and he had a vision of the reforming, even revolutionary, role of himself and his fellow industrial entrepeneurs. He wrote to Thomas Bentley as early as 1766:

> Many of my experiments turn out to my wishes and convince me more and more of the extreme capability of our manufacture for further improvement. It is at present (comparatively) in a rude uncultivated state, and may easily be polished, and brought to much greater perfection. Such a revolution, I believe, is at hand, and you must assist in and profit by it. (quoted in Jacob 1988: 136)

Among the many interesting features of this letter are his emphasis on ‘experiments’ and his description of his innovations as a ‘revolution’. In another letter to Bentley he outlined his principle of factory organization and division of labour: ‘to make such machines of the Men as cannot err’. This often quoted phrase sums up the efforts of many entrepreneurs of that age to rationalize the sequence of operations in the new factories and overcome human error, whether arising from ignorance, incompetence, laziness, drunkenness, boredom, or fatigue. It was a project that is today by no means exhausted, as the experience of Taylorism and many current tendencies in computerization and robotics amply testify; and it was an objective that was seized upon by the critics of industrial capitalism, from Marxists to romantic poets and artists, to denounce the dehumanizing tendencies of industrialism, which made men and women mere appendages of machines, and where, as Werner Sombart put it, ‘the soul should be left in the cloakroom on entry’. Wedgwood also introduced an elaborate system of fines and penalties to maintain discipline and correct hours of work in his factories.

However, it would be a profound mistake to portray Josiah Wedgwood as an inhuman slave-driving boss. True it was that he and other entrepreneurs were very much concerned with the pace of work and the coordination of the various operations of the new machines in their new factories. Wedgwood's friend Erasmus Darwin (grandfather of Charles Darwin) was **(p.170)** the founder and leading spirit of the Derby Philosophical Society, which brought together scientists, inventors, and entrepreneurs to discuss such topics as the ideal factory with a central observation point from which all workshops and workers could be seen. But they also discussed town lighting, central heating, indoor toilets, and even the French Revolution and republicanism (Jacob 1988: 167).

These men saw themselves as idealistic but practical reformers, harnessing science, capital, and machinery to usher in a new age of material improvement which would benefit everyone (Briggs 1960). Wedgwood's imaginative vision of the future of his industry extended to almost all aspects of his enterprise, and his skills and innovations as a potter, a designer, an engineer, and a factory manager are often and rightly cited as a part of his success story. He was himself the thirteenth son of a poor potter, and many historians (e.g. Ashton 1948, 1963; C. Wilson 1955) stress that social mobility was much greater in Britain than in other countries at that time. The entrepreneurs came from very diverse backgrounds, and the role of 'dissenters' (Quakers and adherents of other unorthodox religious denominations) is frequently mentioned. Ashton states that it is not easy to distinguish inventors, 'contrivers', industrialists, and entrepreneurs and that they came from every social class and from all parts of the country.[6]

One reason why Dissenters were so prominent in entrepreneurship may well have been their nonconformist outlook and often their rationalism. However, Ashton also points out that the exclusion of Dissenters from the universities and from office in government forced many to make their careers in industry. Moreover, the non-conformist zeal for education led them to establish their own schools, and the non-conformists 'constituted the better educated section of the middle classes'. Presbyterian Scotland provided an unusually high proportion of the leading inventors (Watt and most of his assistants, Sinclair, Telford, Macadam, Neilson, and many others) at a time when Scotland had by far the best primary education system in Europe and some of the best universities. 'It was not from Oxford or Cambridge, where the torch burnt dim, but from Glasgow and Edinburgh, that the impulse to scientific enquiry and its practical application came' (Ashton 1963: 157). The Dissenters' academies, established in English towns such as Bristol, Manchester, Warrington, Northampton, etc., did for England much of what the universities did for Scotland.

(p.171) 5.6 The New Proletariat and Hours of Work

The rise of the new industrial proletariat was not simply a question of landless agricultural labour being obliged to seek work in towns, but was a more complex process. The removal of constraints on mobility from very early times was certainly a unique and important feature of English industrialization, as was the early rise of wage labour relationships in rural areas as well as in towns. In addition, the special features of the demographic revolution must be taken into account as well as immigration. The demographic changes were also very important in the growth of the home market in the late eighteenth century, as per capita incomes apparently did not increase by much between 1780 and 1820.

The increased supply of labour for the Industrial Revolution was not just a question of men, women, and children going to work in factories, but also of course of hours of work, work organization, and discipline. Indeed, some theorists (notably Marglin 1974) explain the rise of factory work mainly in terms of the maintenance of labour discipline rather than economic or technical factors. The techno-economic explanation of Landes still appears far more plausible, but whatever the explanation, once the factory system was established, it had its own dynamic in terms of the shift in investment from working capital to fixed capital, the coordination of many operations, and the organization of shifts and division of labour (von Tunzelmann 1995*b*). Circulating capital continued to be very important, even after new investment in machinery. The time spent in transporting materials, holding stocks, and getting wares to market meant that the reduction of working capital was among the main motives for infrastructural investment. (See Javary (1999) for an original analysis of the theory of time, power, and capital accumulation.)

The importance of *time* in the context of work discipline has been brilliantly illustrated by Edward Thompson (1994). He starts his paper with a quote from the nineteenth century novel of Thomas Hardy, *Tess of the D'Urbervilles*: ‘Tess . . . started on her way up the dark and crooked lane or street not made for hasty progress; a street laid out before inches of land had value and when one-handed clocks sufficiently sub-divided the day’(p. 448).

The metaphor of ‘one-handed clocks’ (sun-dials) serves to introduce a beautiful account of the way in which notions of time changed over the centuries and how older concepts of time based on the seasons, the sun, the cockerel, and even the direction of the wind gave way to the tyrannical two-handed clock, the waker-up (knocker-up), and later the alarm clock, the second hand, the stop-watch, time and motion study, 'clocking on' (and later still the micro-seconds of contemporary computer technology). Thompson observes: 'the irregularity of the working day and week were framed, until the first decades of the nineteenth century within the larger irregularity of **(p.172)** the working year, punctuated by its traditional holidays and fairs' (E. P. Thompson 1994: 468).

In view of the prevalence of these 'pre-industrial' attitudes towards time,[7] it is hardly surprising that the growth of factory industry was accompanied by an enormous cultural and organizational change and acute social conflicts about working hours. In the eighteenth century complaints about the licentiousness, drunkenness, laziness, ill-discipline, and debauchery of the English 'lower class' were commonplace, and schools were seen as one of the main ways of inculcating time discipline, in addition to factory penalties of the kind implemented even by paternalistic employers, such as Josiah Wedgwood.

The pressures to increase working hours were strong in the first period of industrialization, and early in the nineteenth century gas lighting was one of the technical inventions that facilitated the use of longer hours and shift work in factories, but the resistance of the new factory proletariat was also strong and led to the prolonged efforts of the unions to reduce working hours. These efforts at reform were resisted by Senior and other classical economists on the grounds that profit depended on the 'last hour' of the working day. John Stuart Mill, however, supported the advocates of a ten-hour day for women and children on 'higher than commercial grounds'.

However, it was not only the new trade unions and reformers, such as Lord Shaftesbury, who were appalled by the long hours of work, but also more enlightened industrialists such as Robert Owen, Josiah Wedgwood, and Samuel Whitbread. These entrepreneurs, who were among the most successful, argued that technical and organizational innovations, together with improved education and training, and paternalistic reforms in the enterprise would raise productivity more than the crude lengthening of the working day. Trade unions were already common in the second half of the eighteenth century, although records are very incomplete, because they suffered from legal penalties and intolerance and were sometimes short-lived (Laybourn 1992). The more successful unions were those of the most skilled craft workers, whose bargaining position was relatively stronger and who were able to reach a working understanding with their employers. Robert Owen's sympathies with the workers went much deeper than this and he promoted a ‘Grand National Consolidated Trade Union’ (GNCTU) in the 1830s, which aspired to organize all workers, including the unskilled, in one big union. It had only very limited success, but nevertheless the experience of this and other short-lived unions, as well as the more durable and stable craft unions and friendly societies, served to create a sense of solidarity and a working class culture, which also found expression in the very strong support for the ‘People's Charter’ in the 1830s and 1840s. This marked the **(p.173)** recognition that universal suffrage and other political objectives offered the best hope for amelioration of the often lamentable suffering of the new urban working class. Some limitations on working hours for women and children were indeed achieved by legislation promoted by Lord Shaftesbury and other reformers, as well as by the struggles of the unions themselves. In his study of *The Factory Question and Industrial England 1830–1860*, Robert Gray (1996) attributes the main credit for the 1847 legislation, reducing working hours for young people and women to ten hours per day, to the influence of Chartism itself.

These movements and the numerous conflicts over factory discipline serve to remind us that the Industrial Revolution was by no means a conflict-free consensual transition. The resistance of those who suffered most reached a peak in 1842–3, when numerous riots, the first General Strike, and actual insurrections in several towns in England and Wales brought Britain quite close to social revolution.

A profound cultural and social change in attitudes towards time was an essential feature of the Industrial Revolution. The combination of von Tunzelmann's work on time-saving technical change with Thompson's work on attitudes towards time in pre-industrial and industrial societies brings out one of its most crucial features. E. P. Thompson concludes:

> Mature industrial societies of all varieties are marked by time-thrift and by a clear demarcation between 'work' and 'life' . . . The point at issue is not that of the 'standard of living'. If the theorists of growth wish us to say so, then we may agree that the older popular culture was in many ways otiose, intellectually vacant, devoid of quickening and plain bloody poor. Without time-discipline we could not have the insistent energies of industrial man; and whether this discipline comes in the form of Methodism, or of Stalinism, or of nationalism, it will come to the developing world. What needs to be said is not that one way of life is better than the other, but that this is a place of the most far-reaching conflict; that the historical record is not a single one of neutral and inevitable technological change, but is also one of exploitation and of resistance to exploitation; and that values stand to be lost as well as gained. (Thompson 1967: 93–4)

Finally, it is necessary to keep in mind that, although factory production became the norm for the most rapidly growing leading sectors of the economy, such as cotton, these still accounted for a relatively small minority of *total* employment until well into the nineteenth century.

The growth of the British economy in the 1770s and 1780s, although certainly significant, was still very narrowly based in a few leading sectors. From the 1790s to the 1820s industrialization affected a growing number of industries, notably cotton weaving as well as spinning and other branches of the textile industry, such as wool and linen. The great majority of cotton mills were still using water power in 1800 but steam engines were slowly diffusing in this and a few other industries. As von Tunzelmann (1978) showed, the really widespread diffusion of the steam engine and the mechanization of many other industries depended on greatly improved high **(p.174)** pressure steam engines, which became available in the 1830s and 1840s (see Section 6.4 below).

Despite the narrow base of the first Kondratiev wave, we cannot improve on the successive endorsements of Landes's summary:

> numbers merely describe the surface of the society and even then in terms that define away change by using categories of unchanging nomenclature. Beneath the surface, the vital organs were transformed; and although they weighed but a fraction of the total—whether measured by people or wealth—it was they that determined the metabolism of the system. (1965: 20; see also Lloyd-Jones and Lewis 1998: 20)

The social innovation of factory production was one of the most fundamental changes of 'metabolism' in the Industrial Revolution. Landes (1965) stresses that neither the workers nor the older class of merchant capitalists, who organized cottage production systems, welcomed this change. It was a radical leap, made possible by an exceptional combination of favourable circumstances in eighteenth and early nineteenth-century England, sufficient to overcome the inertia and active resistance of older institutions and attitudes. Landes maintains that the adoption of the factory system of production was driven not only by its much greater profitability, but also by a crisis of the cottage-based system.

Recent work by economic historians has increasingly recognized the role of cultural and political change, as well as the more traditional emphasis on technical change and more narrowly economic factors. Particularly notable in this connection is the work of Berg and Bruland (1998) and the earlier work of Edward Thompson (1963) on *The Making of the English Working Class*. Thompson argued that 'collective self-consciousness' of the working class was indeed the 'great spiritual gain of the Industrial Revolution', and that this was

> perhaps, the most distinguished popular culture England has known. It contained the massive diversity of skills, of the workers in metal, wood, textile and ceramics, without whose inherited 'mysteries' and superb ingenuity with primitive tools the inventions of the Industrial Revolution could scarcely have got further than the drawing board. From this culture of craftsmen and the self-taught there came scores of inventors, organizers, journalists and political theorists of impressive quality. It is easy enough to say that this culture was backward-looking or conservative. True enough, one direction of the great agitations of the artisans and outworkers, continued over fifty years, was to resist being turned into a proletariat. When they knew that this cause was lost, yet they reached out again, in the Thirties and Forties, and sought to achieve new and only imagined forms of social control. (Thompson 1963: 831)

(p.175) 5.7 Changing Patterns of Demand

The emphasis in this chapter so far has been on the 'supply' side—on product innovations, process innovations, and organizational innovations. This does not mean, of course, that changes in demand, in consumer habits, and in tastes played no part. An influential piece of work on this topic was that of Elizabeth Gilboy, first published in 1932 and reprinted in three other independently edited collections of papers since (Church and Wrigley 1994). She argued that the role of demand had been neglected and pointed to contemporary accounts of the role of fashion, imitation, and changing tastes in stimulating demand for new goods, as well as old ones. As Marx had also suggested, these might at first be described as 'luxuries' but would come to be accepted later as 'necessities'. She summed up her position in these words:

> Theoretically, then, it is possible to conclude that far-reaching and widespread industrial changes cannot occur except in a society in which demand and consumption standards are undergoing swift and radical readjustment. Such a society is characterised by mobility between classes, the introduction of new commodities leading to the development of new wants, and a rise in real income of the people as a whole. (Gilboy, in Church and Wrigley 1994: 361)

Her argument about the role of 'keeping up with the Joneses' has been generally accepted by many authors since, notably Eversley (1994) and Landes (1969). (For other references to the reiteration of her theory, see Mokyr 1994*a*.) However, it has been very heavily criticized by Mokyr (1994*a*) in rather the same manner that Mowery and Rosenberg criticized the exaggerated claims for *demand*-led innovation in the 1960s.

It should be noted that Elizabeth Gilboy's own argument for stressing the role of demand was modestly presented and did not deny the Schumpeterian view that in the early stages of radical innovation entrepreneurs must create their own market demand, since consumers can have no prior knowledge of the product. She did not attempt to use statistical sources to justify her position with empirical evidence; but Eversley (1994) did so, stressing especially the expansion of *home* market demand in the period from 1750 to 1780, based on rising population and rising living standards. He gave various examples of contemporary descriptions of changing tastes and evidence of a more varied pattern of consumption, facilitated by big developments in the infrastructure, especially canals:

> we can cite a mass of contemporary sources alleging the prevalence of 'luxurious habits' amongst the 'poor'; a complaint shorn of its moralising overtones, means nothing more than that some labourers liked tea with sugar even when both were heavily taxed; that women decked themselves out in clothes considered too good for them; and that in some cottages you might find a bit of carpet or even a piano. What seems necessary for growth is that the very exceptional expenditure should become **(p.176)** a little less so, that articles described by Nassau Senior as 'decencies', half-way between luxuries and necessities, should spread through some more of the 'middling sorts of people' and that some labourers should take it into their heads (according to their betters) as to go short of food and put themselves into debt for a looking glass or a pair of gilt buckles for their Sunday shoes. (Eversley 1994: 294)

As an example of the kind of goods he is talking about, Eversley quotes the example of the inventory of goods for the cottage of Richard Wainwright, a nailer who as early as August 1739 possessed: a fire shovel, a coal hammer, a toasting iron, bellows, a copper can, wooden furniture, scissors, a warming pan, two iron pots, a brass kettle, a pail, two barrels, two bedsteads, a sieve, candlesticks, a rug, a blanket, a kneading tub, a brass skimmer and basting spoon, linen, glass bottles, and various other kitchen utensils (Eversley 1994: 319). This inventory of modest household possessions shows that it is not accurate to regard ‘consumerism’ simply as the product of the twentieth century. It is this changing composition that matters.

Eversley believed that the construction of the Midlands canal network and the Lancashire canals in the third quarter of the eighteenth century brought down the price of food as well as coal and other commodities in many towns, especially Birmingham. The improvements in regularity and speed of mail and passenger travel on the coaches in the 1770s also facilitated the creation of larger regional markets for new goods, especially simple metal products. The first regular stage coach services from London to and from other cities were launched in the 1780s.

More recently, Maxine Berg (1998: 153) has argued that industries such as decorative metal products and furniture have been neglected not only from the demand side but also from the supply side. She recalls that Adam Smith already pointed to the importance of ‘fashion and fancy products’ for the metal industries of Birmingham and Sheffield and argues that product innovation in such industries merits much greater consideration by historians along with the traditional emphasis on process innovations in machinery. She analyses patent statistics from 1627 to 1825 to show that patents for ornamenting, engraving, painting, and printing, as well as for buckles and fastenings, were of considerable importance among the inventions of the Industrial Revolution. Even more importantly, she points to the interactions between those firms and trades designing and producing ornamental and decorative products and those producing machines and instruments. In particular, she points to the strong mutual influence between Boulton and Wedgwood.

Many authors, including of course Adam Smith, on the basis of his extensive travels in Europe, maintained that standards of living in eighteenth-century Britain were well above those in other European countries. In particular, this was held to be true for a larger and wealthier middle class. Habbakuk (1963: 115) advances this as one of the main explanations of the British Industrial Revolution: ‘average per capita incomes were higher than on the Continent. There were larger numbers of people with a reasonable **(p.177)** margin of subsistence for the consumption of manufactured goods. The inducement to expand an individual industry was not therefore impeded by the very inelastic demand which faces an industry in the poorer countries of the modern world.'

5.8 Congruence of Culture, Politics, Economy, Science, and Technology

Despite this acknowledgement of the points made by Elizabeth Gilboy and Maxine Berg, and the earlier emphasis on cultural and political changes, the account given in this chapter may appear to some as 'technological determination' or as 'techno-economic determinism', but we would stress that the innovations could be made, financed, and diffused only in a hospitable cultural and political climate. It was the *congruence* of favourable developments in all the main subsystems of British society and their positive mutual interaction that made it possible for this fast growth constellation to emerge and diffuse. This point about congruence confirms the analysis of Part I.

Supple provides an admirably terse summary of this favourable congruence of economic, technological, scientific, political, and cultural characteristics in Britain:

> Britain's economic, social and political experience before the late 18th Century explains with relatively little difficulty why she should have been an industrial pioneer. For better than any of her contemporaries Great Britain exemplified a combination of potentially growth-inducing characteristics. The development of enterprise, her access to rich sources of supply and large overseas markets within the framework of a dominant trading system, the accumulation of capital, the core of industrial techniques, her geographical position and the relative ease of transportation in an island economy with abundant rivers, a scientific and pragmatic heritage, a stable political and relatively flexible social system, an ideology favourable to business and innovation—all bore witness to the historical trends of two hundred years and more, and provided much easier access to economic

> change in Britain than in any other European country.
> (Supple 1963: 14)

Adam Smith's book *The Wealth of Nations*, appearing as it did in 1776, exemplified the political and cultural foundations of the British Industrial Revolution, just as it provided an extremely influential economic ideology. This doctrine was so powerful that it persuaded the British prime minister (William Pitt) to declare to Adam Smith: ‘We are all your pupils now.’ Smith's extraordinary influence was due to the fact that he provided an almost perfect rationalization for the profit-seeking activities of the new industrialists and merchants. They could believe that what they were doing was serving the community through the pursuit of their own self-interest.

The very title and main theme of his book shifted the focus of economic inquiry from trade to growth and from agriculture to productive industry. It meant that the pursuit of growth, capital accumulation, and national **(p.178)** prosperity became to some extent the shared objective of the State, the industrialists, the aristocracy, and the merchants. Thus it was that, despite the fact that the landlords were still by far the most wealthy and politically influential class, economic policies were followed that promoted the interests of the rapidly growing but still small new industries. The reduction of the power of local monopolies and of restrictions on trade, advocated so eloquently by Adam Smith, was by no means a conflict-free process and only reached its denouement in the 1840s with the repeal of the Corn Laws. In the late eighteenth century, a non-interventionist *laissez-faire* policy reducing state involvement with industry and trade was welcome to many landlords as well as industrialists. Small-firm competition became a reality in late eighteenth-century Britain, and the opening of domestic and foreign markets did indeed promote technical and organizational change and productive investment in the way that Smith advocated. His language was not far removed from the general culture of society and was intelligible to a broad readership, which is unfortunately often no longer the case with economics today.

The broad social consensus exemplified by Smith's *Wealth of Nations* did not of course amount to unanimity. It expressed a rationalization above all of the interests of the industrialists and merchants. However, the rent income of landlords was justified by Smith in a way it certainly never was forty years later by Ricardo. Smith attacked monopoly 'conspiracies' against the public interests, whether by unions to raise wages or by merchants to raise prices, yet he was very much concerned with the improvement of the living standards of the poor. In his day, *laissez-faire* doctrine did not yet carry the uncaring stigma that it acquired as a result of a half-century of intensive urbanization and industrialization, the social critique of two generations of poets and novelists, and the resistance of many workers to inhuman conditions of work. The 'collective intentionality' that emerged in eighteenth-century Britain was a consensus that did not embrace the still illiterate and poor majority, but their acquiescence could be obtained with a relatively limited amount of violent repression, despite the fact that living standards for many of them improved little, if at all. The Combination Acts of 1799 and other earlier Acts were used to limit the powers of trade unions, and more severe penalties were used against the Luddites.

The consensus necessary to harmonize many differing individual purposes was of course not exclusively dependent on the widespread acceptance of a particular type of economic theory or rationalization. It was far more broadly based on the general culture of the time. The Renaissance, the Scientific Revolution and the Reformation of the sixteenth and seventeenth centuries all contributed directly or indirectly to the prevalence of a pragmatic, individualistic, empiricism that is hard to measure, but is widely recognized as characteristic of eighteenth-century Britain. Moreover, although the English Civil War of the 1640s ended with the Restoration of the Monarchy and no other monarch suffered the fate of Charles I, the eighteenth century **(p.179)** monarchy was very different from that of the sixteenth century or the absolutist monarchies still strongly entrenched on the Continent of Europe. *De facto* parliamentary sovereignty without a written constitution was firmly established from 1688 onwards. The tradition of parliamentary government, with the give and take of political debate and the toleration extended to organized opposition, set the example for many other institutions, high and low. Trial by jury, the common law, the establishment of national newspapers, the philosophic tradition of Bacon, Locke, and Hume, the 'Dissenting Academies', and the non-Conformist sects were among the many institutions, that if not entirely unique to England, were in combination impressive evidence of a democratic culture providing a fertile soil for the flowering of local initiatives in all parts of the country.

This general culture both contributed to and was strongly influenced by the Scientific Revolution of the seventeenth and eighteenth centuries. The influence of science is underestimated by many historians in much the same way as economists today still often underestimate the contribution of science to contemporary innovation. Some Marxist historians have been inclined to overstate the contribution of technology to economic growth by comparison with science, although others, such as Needham and Marx himself, have not been. Eighteenth-century science was, of course, very different from twentieth-century science. Nevertheless, even though the expression 'scientist' had not been coined in his time, and even though men of science or natural philosophers were very few in number, Adam Smith was well aware of their great importance and emphasized it in the opening pages of *The Wealth of Nations*.

Ashton (1948), Musson and Robinson (1969) are among the historians who have done most to demonstrate both the direct (especially Musson) and the indirect (especially Ashton) contribution of science to technology and the general culture of English and Scottish society. While von Tunzelmann (1981) may be right in emphasising that French science was ahead of British science in some respects, this does not undermine the basic argument that an experimental, enquiring, rational spirit and approach was a necessary condition for the work of scientists and inventors alike. In fact, von Tunzelmann points out that 'the scientific revolution, dated either at the foundation of the Royal Society in 1660 or earlier in the century (Webster 1975), *preceded* the financial revolution, the commercial revolution, the transport revolution and the Industrial Revolution, as these overlapping changes are conveniently dated' (von Tunzelmann 1981: 148). Furthermore, he also stresses the positive influence of science on the general climate of ideas, within which inventors worked. Ashton insists that:

> The stream of English scientific thought, issuing from the teaching of Francis Bacon, and enlarged by the genius of Boyle and Newton, was one of the main tributaries of the Industrial Revolution. Newton indeed was too good a philosopher and scholar to care whether or not the ideas he gave to the world were immediately 'useful', but the belief in the possibility of achieving industrial progress by the method of observation and experiment came to the eighteenth century largely through him. (Ashton 1948: 155)

(p.180) Like Musson and Robinson, Ashton gives numerous examples of the ways in which the leading physicists, chemists, and geologists of the day were in intimate contact with the leading figures in British industry. A good example of this was the chemist, Joseph Priestley, discoverer of oxygen and inventor of soda-water, whose brother-in-law was the iron-master, John Wilkinson, and who was a scientific adviser to Wedgwood. As we have seen in the case of Smeaton, men like him or James Watt, William Reynolds, and James Keir were as at home in the factory as in the laboratory. The various scientific societies of the day, including especially those in Manchester and Birmingham, but also the Royal Society in London, were another forum for contact between scientists and inventors. As Ashton points out, even taking into account the growth of scientific specialization that Adam Smith observed, the language of science had not yet become so esoteric as to preclude contact with the language, culture, and practice of ordinary people. Thus, despite the fact that science had its own institutions, procedures, and publications, it certainly influenced both technology and the general culture of society in ways highly favourable to technical change and innovation.

It is often said today that United States culture has been especially favourable to innovation, and a contrast is frequently made between this intellectual and business environment and that of contemporary Britain, supposedly now far more conservative and unreceptive to innovation. While these attitudes are extraordinarily hard to measure, it should be noted that many eighteenth-century observers believed that British society was at that time exceptionally favourable to innovation. With typical caustic wit, Dr Johnson gave the bizarre example of techniques of hanging to illustrate this point: 'The age is running mad after innovation . . . all the business of the world is to be done in a new way; men are to be hanged in a new way. Tyburn [the site at which executions were held] itself is not safe from the fury of innovation . . .'

A later American equivalent of Dr Johnson could have cited the electric chair as an equally gruesome example of the spirit of innovation that pervaded the United States, as it became the next major example of a country leading the world in technical innovation in the late nineteenth century and twentieth century (see Chapter 7).

This chapter has attempted to show that the surge of economic growth and structural change in the British economy in the late eighteenth century was propelled by a constellation of innovations, both radical and incremental, based primarily on iron as a core input, on water wheels providing power, on canals providing cheap transport for heavy materials, on turnpike roads facilitating movement of people and lighter commodities, and on the new factory style of organization with a series of mechanizing innovations in the leading fast-growth cotton industry. This constellation of innovations could be introduced and could flourish as nowhere else because of an exceptionally favourable congruence of political and cultural changes in Britain—changes **(p.181)** that were to prove even more important in the second phase of the Industrial Revolution.

5.9 The British Transition from the First to the Second Kondratiev

There is very broad agreement about the acceleration of British economic growth in the late eighteenth and early nineteenth century but there is rather less agreement about the period from 1815 to 1845. This was a period of falling prices and, following Jevons, was taken by most of the earlier writers on long cycles as the 'downturn' of the first long cycle (see Chapter 3). However, later research on output showed that there was little evidence of a serious down-swing in the growth rate of *production* in this period, so authors such as Solomou used these data to argue that they demonstrated the non-existence of Kondratiev waves, at least in the first half of the nineteenth century.[8]

However, in our approach the problems of precision in GDP measurement in this period are not so acute, since we are concerned primarily with *structural* and *qualitative* changes.

What this concluding section of the chapter will seek to show is that the period was characterized in the first place by the rapid growth of a new constellation of fast-growing industries, services, and technologies and, in the second, by social turmoil and heavy unemployment as a result of the structural changes engendered by these developments. It may well be the case that the aggregate growth of British GDP did not slow significantly, if at all.

The main features of the new fast growth constellation were a new infrastructure (railways), a new source of power (steam engines), and new machine tools and other machinery which had the effect of spreading the Industrial Revolution to new areas of the country and to industries hitherto less affected by the first Kondratiev wave, as well as improving the productivity of some that had already been industrialized. In some ways, therefore, the first two Kondratiev waves may be seen in Britain as two successive phases of the Industrial Revolution, the first based primarily on water-powered mechanization and the second on steam-powered mechanization, but both sharing the core inputs of iron and coal. In countries other than Britain, especially in continental Europe, it was the second Kondratiev wave that brought industrialization and structural transformation. The catch-up process combined features of the first and second waves.

(p.182) The evaluation of the effects of the Napoleonic Wars on the growth of the British economy and on continental Europe is a complex problem and still a matter of controversy among historians. However, despite difficulties in some areas of British trade with the European Continent over relatively short periods, there is little doubt that the British economy emerged from these wars in much better shape than its main continental rivals, including, of course, France. In his book on *The Rise and Fall of the Great Powers*, Paul Kennedy sums up the British gains at the expense of France:

> the seizure of Santo Domingo—which had been responsible for a remarkable three quarters of France's colonial trade before the Revolution—was by the late 1790s, a valuable market for *British* goods and a great source of *British* re-exports. In addition, not only were these overseas markets in North America, the West Indies, Latin America, India and the Orient growing faster than those in Europe, but long-haul trades were usually more profitable and a greater stimulus to the shipping, commodity-dealing, marine insurance, bill-clearing, and banking activities which so enhanced London's position as the new financial centre of the world. (Kennedy 1988: 179)

Despite some disruption, total British exports increased from £21.7 million in 1794–6 to £44.4 million in 1814–16 and the key sectors of the economy (especially iron and cotton) continued to grow rapidly throughout this period. The period from the 1780s to 1815 should therefore certainly be classified as one of *upswing* and boom. Paradoxically, this was confirmed by the difficulties experienced when the Napoleonic Wars ended and the exceptional demand for such products as iron fell sharply. Social distress was widespread as the economy moved to a new pattern of peacetime output. Nevertheless, the impetus from the Industrial Revolution was sufficient for the aggregate growth of the economy to continue to outpace all other European countries (Tables 5.6 and 5.7).

In the chapter of his book entitled ‘Continental Emulation’, Landes emphasized how far other European countries lagged behind Britain:

> At mid-century then, continental Europe was still about a generation behind Britain in industrial development. Whereas in 1851 about half of the people of England and Wales lived in towns, in France and Germany the proportion was about a quarter. . . . The occupational distribution tells a similar story. At mid-century, only a quarter of the British male working force (twenty years and older) was engaged in agriculture. For Belgium, the most industrialised nation in the Continent, the figure was about 50 per cent. Germany took another 25 years to reach this point; indeed, as late as 1895, there were

> more people engaged in agriculture than in industry.
> (Landes 1969: 187–8)

For this reason, our account continues to concentrate on technological and industrial developments in Britain as the leading country, at least down to the 1870s, when the United States began to emerge as the new technological leader (Chapter 7). This should certainly not be taken as an underestimation of the importance of new developments in technology and science in a number of other European countries, especially France, Sweden, the **(p.183)**

Table 5.6. Relative Shares of World Manufacturing Output, 1750–1900 (%)

	1750	1800	1830	1860	1880	1900
Europe as a whole	23.2	28.1	34.2	53.2	61.3	62.0
United Kingdom	1.9	4.3	9.5	19.9	22.9	18.5
Hapsburg Empire	2.9	3.2	3.2	4.2	4.4	4.7
France	4.0	4.2	5.2	7.9	7.8	6.8
German states/ Germany	2.9	3.5	3.5	4.9	8.5	13.2
Italian states/ Italy	2.4	2.5	2.3	2.5	2.5	2.5
Russia	5.0	5.6	5.6	7.0	7.6	8.8
United States	0.1	0.8	2.4	7.2	14.7	23.6
Japan	3.8	3.5	2.8	2.6	2.4	2.4
Third World	73.0	67.7	60.5	36.6	20.9	11.0
China	32.8	33.3	29.8	19.7	12.5	6.2
India/Pakistan	24.5	19.7	17.6	8.6	2.8	1.7

Source: Kennedy (1988: 190); Bairoch (1982: 294).

Table 5.7. Per Capita Levels of Industrialization, 1750–1900 (Relative to UK in 1900 100)

	1750	1800	1830	1860	1880	1900
Europe as a whole	8	8	11	16	24	35
United Kingdom	10	16	25	64	87	[100]
Hapsburg Empire	7	7	8	11	15	23
France	9	9	12	20	28	39
German states/ Germany	8	8	9	15	25	52
Italian states/ Italy	8	8	8	10	12	17
Russia	6	6	7	8	10	15
United States	4	9	14	21	38	69
Japan	7	7	7	7	9	12
Third World	7	6	6	4	3	2
China	8	6	6	4	4	3
India	7	6	6	3	2	1

Source: Kennedy (1988: 190); Bairoch (1982: 294).

Netherlands, and various German and Italian states before the unification of those countries. Despite the fact that the main changes in industry during the Industrial Revolution took place in the North and in Scotland, London also played a key role in bringing knowledge of Continental inventions and technologies into Britain. For example, the earliest water-powered silk mills in Britain were built at Derby in 1705–7 by Thomas Cotchett, a London silk reeler, based on Dutch technology. Another Londoner and silk merchant, Thomas Lombe, improved and extended these mills with technology from Leghorn, where silk-reeling mills were well established. Lombe succeeded in making the mills profitable because of his knowledge of up-to-date Italian **(p.184)** technology and because of his management of the 300 employees. The Derby mills and their work organization were copied in ten other mills in the North of England between 1732 and 1769 (Chapman 1972/1992: 14). According to Chapman's account, these influenced the early development of the factory system in the British cotton industry because Arkwright's partner in Derby, Jebediah Strutt, copied the organization of the silk mills and the Stockport and Sheffield silk mills were converted to cotton production (p. 15). Other similar examples could be quoted, and Chapman comments: ‘London also played an important role in technical innovation in the cotton industry, acting as a nursery for techniques brought from the Continent or from India, until they were ready for transplanting to the provinces. . . . ’ (p. 12).

There were 1,500 Dutch looms in use in large workshops in Manchester by 1750, and this could reasonably be regarded as the first step in the transition to the factory system (Wadsworth and Mann 1931). All of these examples show that technologies from countries outside Britain were important in the Industrial Revolution, and it is certainly not our intention to belittle these contributions or the influence of foreign markets and the experience of foreign trade. We concentrate our account on Britain, and later on other leading countries, because we contend that it was the capacity to innovate at home, and to combine this with the input of foreign technology, that distinguished the technological leaders and the congruence of political, cultural, and economic circumstances that enabled them to do this.

5.10 The Structural Crisis of Adjustment

In Britain the process of industrialization proceeded in two distinct phases, and the birth-pangs of the second phase were in some respects more painful than those of the first, especially with respect to unemployment in the severe recessions of the 1830s and early 1840s. The GDP estimates tell us little about unemployment and the harsh treatment of the unemployed following the introduction of the 'New Poor Law' in the 1830s. Yet we do know from several sources that these social problems were much more severe in the 1830s and 1840s than in the earlier period of industrialization from the 1780s to the 1820s.

A major feature of the structural crisis of adjustment in the 1830s was the increasing unemployment in rural as well as urban areas. The increase in population was not immediately accompanied by rural depopulation, and according to Mathias (1969: 238), 'Rural pauperism proved to be the greatest single scourge of the 1820s and 1830s'. Poor rates rose to a peak in the early 1830s, and the 1834 Poor Law Act was particularly designed to combat the evils of rural destitution by encouraging, if necessary in a brutal way, migration away from areas where employment did not offer a living minimal wage for a family.

(p.185) This harsh new Poor Law, offering to the destitute and unemployed relief only in institutions known as 'workhouses' (although often no work was done there) replaced the 'Speenhamland' system introduced in 1795 and so-called because it was started by the justices in the county of Berkshire meeting in Speenhamland at the Pelican Inn. These justices decided to subsidize the wages of labourers through a system of 'outdoor relief' in accordance with a scale dependent upon the price of bread. The system became general during the Napoleonic Wars and persisted after the end of the war. It became increasingly expensive as the population grew and farmers paid lower wages in the expectation of supplementary relief in times of high food prices. These were kept high by the Corn Laws restricting imports of grain. The thorny problem of the repeal of the Corn Laws was not confronted by Parliament until the 1840s, but the solution attempted in the New Poor Law was at the expense of the poorest part of the population. It led to increases in unemployment and in emigration and, again according to Mathias (1969: 238), it 'assumed a quite false diagnosis of the ills of industrial society, for unemployment in cyclical depressions or from technological and structural change was involuntary rather than a deliberately chosen option'.

While there are no national statistics of unemployment comparable to those available in the twentieth century, there were local statistics of the numbers of 'paupers' in the main industrial areas. As Hobsbawm (1994) has shown, in the main industrial districts of Lancashire and Yorkshire (the heartland of the Industrial Revolution) unemployment rates as high as 20–30 per cent of the adult male population were by no means rare in the worst recession years. The new 'cyclical' unemployment of modern industry related to fluctuations in investment and trade, and especially to the fluctuations in railway investment in the 1830s and 1840s, and to the ruin of the handloom weavers.

Even more revealing than retrospective estimates of unemployment, based on the Poor Law statistics and local records, are the accounts of contemporary novelists and historians. Novels such as Dickens's *Hard Times* or Mrs. Gaskell's *North and South* are in many ways more impressive than these statistics. In particular, Elizabeth Gaskell's heroine from a comfortable home in the South confronting the realities of the industrial North for the first time leaves an indelible impression. Perhaps most vivid of all contemporary accounts is that of Thomas Carlyle in 1843, confronting the paradox of large-scale cyclical unemployment in an industrial society for the first time:

> England is full of wealth, of multifarious produce, supply for human want in every kind . . . with unabated bounty the land of England blooms and grows; waving with yellow harvests; thick-studded with workshops, industrial implements, with fifteen millions of workers . . . Of these successful skilful workers some two millions, it is now counted, sit in Workhouses, Poor Law prisons; or have 'outdoor relief' . . . the Workhouse Bastille being filled to bursting . . . They sit there these many months now; their hope of deliverance as yet small. In Workhouses, pleasantly so-named because work cannot be done in them. Twelve hundred thousand workers in **(p.186)**

> England alone . . . sit there, pent up, as in a kind of horrid enchantment; glad to be imprisoned and enchanted that they may not perish starved. (Carlyle 1843: 1–2)

Following an account of the expressions on the faces of men who would like to work but are condemned to idleness, even in the so-called ‘work’ houses, Carlyle goes on to describe the poverty in Scotland, then without a Poor Law, where ‘there are scenes of woe and destitution and desolation, such as, one may hope, the sun never saw before in the most barbarous regions where men dwelt’. He concludes: ‘Things, if it be not mere cotton and iron, things, are growing disobedient to man. . . . We have more riches than any Nation ever had before; we have less good of them than any Nation ever had before. Our successful industry is hitherto unsuccessful; a strange success if we stop here! In the midst of plethoric plenty, the people perish . . .’ (Carlyle 1843: 5).

The spectacle of mass unemployment (estimated by Carlyle apparently at nearly 15 per cent of the total labour force) in what was then the wealthiest and most prosperous country in the world clearly struck him as an extraordinary paradox, and it is difficult not to feel that this was a period of turbulent transition rather than one of steady prosperous growth, conveyed by some of the adherents of smoothed trends in reconstructed estimates of GDP growth. Particularly interesting is Carlyle's brief suggestion that, whereas ‘cotton and iron’ may be ‘obedient to man’, the rest of the economy is not so ‘obedient’. Here again is the impression of a period of turbulent structural change rather than one of smooth progression.

Finally, there is the evidence of the social and political turmoil of the 1830s and 1840s. This was the only period in the nineteenth century when Britain came close to a social revolution. Armed rebellions did actually take place in several towns and general strikes in many. The demonstrations of hundreds of thousands of workers in the northern towns in support of the Chartist demands for universal suffrage were greater than any seen before or since, while trade union organization and activity also reached its highest point in the century in the 1830s, despite the legal inhibitions. All of this followed the wave of Luddite machine-breaking during and soon after the Napoleonic Wars. Working people no longer saw a halt to industrialization as a realistic possibility but sought, as an alternative, redress by new forms of regulation through political pressure and legislative reforms.

This impression of the period that culminated in the repeal of the Corn Laws in 1846 as one of great turbulence and structural change is further confirmed by the most recent work of Lloyd-Jones and Lewis (1998: chapter 3). They describe the period as one that illustrated ‘both an enthusiasm for and a resistance to the degree of change at the structural level of the economy’ (p. 33). The structural crisis of the 1830s and 1840s led to a new political mode of coordination in the concessions made by the landlord class to the now stronger class of industrialists and merchants. The conflict of interests had now become acute between the landlords, who wanted to maintain protection **(p.187)** of agriculture, and the industrialists, who wanted repeal of the Corn Laws in order to lower the cost of food, put downward pressure on wages, and alleviate discontent in the industrial towns. Whereas Adam Smith had smoothed over this conflict, Ricardo had placed it at the centre of his analysis, and his view was reinforced by Malthusian pessimism about the growth of population and the availability of fertile land for agriculture. Economics, which in Smith's day had been relatively optimistic in tone, now became the ‘dismal science’. The free traders had the bit between their teeth and succeeded in enlisting widespread popular support for the repeal of the Corn Laws, so that ultimately the Tory Party itself was split and its leader, Robert Peel, acquired a parliamentary majority for repeal.

British industry could now derive great benefits from its leadership in many branches of production and its domination of the world shipping industry. So strong was this position that Britain not only could gain many advantages from this spread of free trade practices around the world, but also could safely repeal the Navigation Acts in 1849, which had restricted the carriage of goods to British vessels. A political *modus vivendi* was achieved for the mid-Victorian boom.

We turn now in Chapter 6 to the main features of the fast growth constellation which was at first less ‘obedient to man’ than cotton and iron, but ultimately led to the prolonged period of Victorian prosperity in the 1850s and 1860s.

Notes:

(1) e.g. Ashton (1948); Supple (1963); Deane (1965); Hobsbawm (1968); Habbakuk (1963); Floud and McCloskey (1981, 1994); Rostow (1960); Mathias (1969); Landes (1969); von Tunzelmann (1978, 1995*a*); Paulinyi (1989); Mokyr (1994*b*); Hoppit and Wrigley (1994); Berg (1994); Lloyd-Jones and Lewis (1998), Berg and Bruland (1998).

(2) Hills (1994: 112), basing his comments on experience of actually running spinning machines in the North Western Museum of Science and Industry, stresses the trajectory of *improvement* exploited by Hargreaves and Arkwright: many of the inventions were based on adapting the old techniques of cottage industry to the new conditions of factory production.

(3) Cort himself was not a foundry man, but as an outfitter for the Navy he had a good knowledge of the price and quality of British iron products in the 1770s, which at that time made the Navy reluctant to use iron. However, in 1775 he acquired a small foundry from a business partner in settlement of a debt. At this foundry in Fontley, near Portsmouth, he was able to conduct various experiments in the production of iron, and when he received a big order from the Navy in 1780 he enlarged his works, so that he had both a forge and a rolling mill. Instead of the usual Swedish iron, he innovated in local production, leading to his key patents in 1783 and 1784. He and his skilled craftsmen then helped to design six puddling and rolling works in South Wales and Shropshire. His technique became the most important in the iron industry for nearly a century (Paulinyi 1989: 125–8; Mott 1983). The grooved rollers were as important as the puddling itself, although both patents had been anticipated by predecessors in Sweden and England (Schubert 1958: 106).

(4) After the defeat of Napoleon, British puddlers went to Belgium, France, and Germany to teach their craft. The first puddling and rolling works in France were installed in 1818–19 and in Germany in 1824–5. In all of these the British puddlers who were employed came from South Wales (Schubert 1958: 107).

(5) Canals linked the North and Irish Seas with the navigable reaches of the major rivers—the Mersey, the Ouse, the Severn, the Thames, the Trent, the Clyde, and the Forth—and the

growing centres of population in the Midlands, the North, and Scotland in the second half of the 18th cent.

(6) They included aristocrats like Coke of Holkham Hall, who innovated in agriculture, or the Duke of Bridgewater in canals. Clergymen and parsons, such as Cartwright and Dawson innovated new ways of weaving cloth and smelting iron. Doctors of medicine, such as John Roebuck and James Keir, took to chemical research and became industrialists. ‘Lawyers, soldiers, public servants and men of humbler station than these found in manufacturing possibilities of advancement far greater than those offered in their original callings. A barber, Richard Arkwright, became the wealthiest and most influential of the cotton-spinners; an inn-keeper, Peter Stubbs, built up a highly esteemed concern in the tile trade; a schoolmaster, Samuel Walker, became the leading figure in the North of England iron industry’ (Ashton 1963: 156).

(7) ‘In seventeenth-century Chile time was often measured in ‘credos’; an earthquake was described in 1647 as lasting for the period of two credos; while the cooking time of an egg could be judged by an ‘Ave Maria said aloud’ (Thompson 1994: 450).

(8) It should be noted that there are great difficulties in the precise measurement of output in Britain before 1850. Retrospective estimates of GDP are notoriously difficult to calculate, whether from the income side, the expenditure side, or the physical output side. Crafts commented that estimates of GDP before 1850 can be little more than ‘controlled conjectures’. One of the leading early scholars who worked on these statistics, Phyllis Deane (1948), commented on the serious weaknesses of the income estimates which had led her and other researchers to concentrate on estimates from the expenditure side, although the methodological problems in this area were almost as great as from the output side.

Access brought to you by: