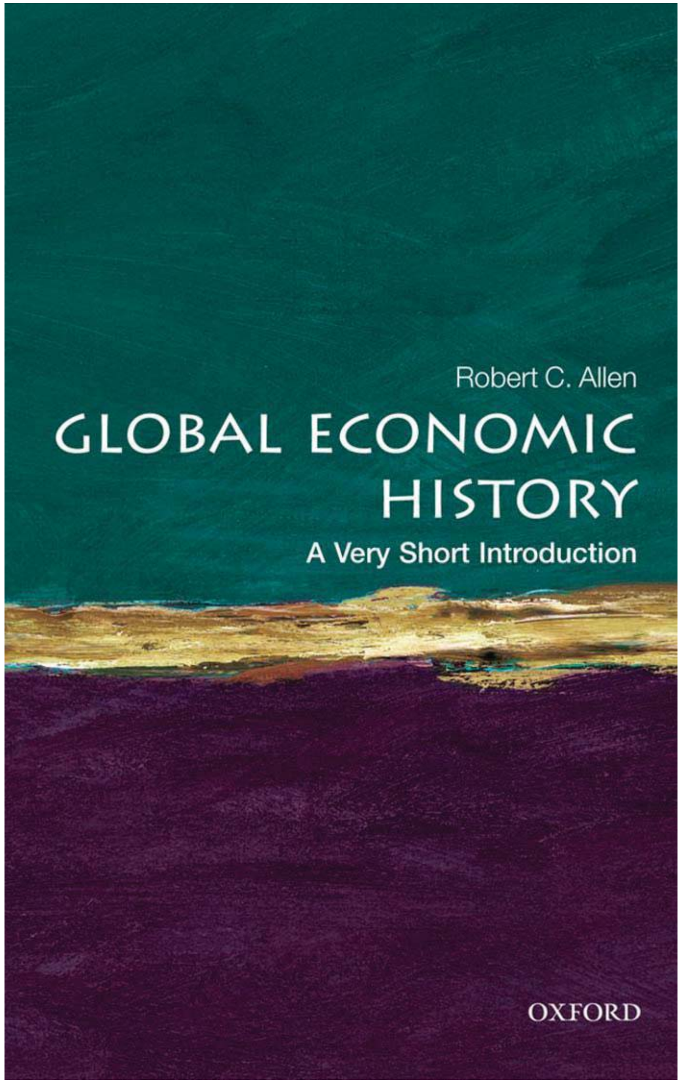
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GLOBAL ECONOMIC
HISTORY
A Very Short Introduction
OXFORD

Contents

Chapter 2
The rise of the West

Why has the world become increasingly unequal? Both 'fundamentals' like geography, institutions, or culture and 'accidents of history' played a role.

Geography is important. Malaria holds back the tropics, and Britain's coal deposits underpinned the Industrial Revolution. Geography is rarely the whole explanation, however, for its significance depends on technology and economic opportunities; indeed, one of the aims of technology is to reduce the burden of bad geography. In the 18th century, for instance, the location of coal and iron deposits determined the location of blast furnaces. Today, ocean transportation is so cheap that Japan and Korea obtain their coal and iron ore from Australia and Brazil.

Culture has been a popular explanation for economic success. Max Weber, for instance, contended that Protestantism made northern Europeans more rational and hard-working than anyone else. Weber's theory looked plausible in 1905 when Protestant Britain was richer than Catholic Italy. Today, however, the reverse is true, and Weber's theory is no longer tenable. Another cultural argument claims that peasant farmers in the Third World are poor because they cling to traditional methods and fail to respond to economic incentives. The contrary, however, is true: farmers in

poor countries experiment with new crops and methods, employ labour to the degree that it pays, adopt modern fertilizers and seeds when they are cost-effective, and shift their cropping in response to price changes like farmers in the rich countries. Peasants are poor because they receive low prices for their crops and because they lack appropriate technology – not because they refuse to use it.

While cultural explanations that invoke irrationality and laziness are suspect, there are aspects of culture that affect economic performance. In particular, widespread literacy and numeracy have been necessary (if not sufficient) conditions for economic success since the 17th century. These mental skills help trade to flourish and science and technology to develop. Literacy and numeracy are spread by mass education, which has become a universal strategy for economic development.

The importance of political and legal institutions is hotly debated. Many economists argue that economic success is the result of secure property rights, low taxes, and minimal government. Arbitrary government is bad for growth because it leads to high taxes, regulations, corruption, and rent-seeking – all of which reduce the incentive to produce. These views are applied historically by arguing that absolutist monarchies such as Spain and France or empires like those of China, Rome, or the Aztecs stifled economic activity by prohibiting international trade, threatening property or, indeed, life itself. These views, of course, echo those of Adam Smith and other 18th-century liberals. Successful economic development was due to the replacement of absolutism with representative government. The Netherlands revolted against Spanish rule in 1568 and organized itself as a republic. The country grew rapidly afterwards. The English economy suffered in the early 17th century under the rules of James I and Charles I, who imposed taxes of disputed legality and levied forced loans. Charles's attempts to rule without Parliament failed, civil war broke out, and, in 1649, the

King was convicted of treason and executed. After the Restoration, disputes between Crown and Parliament continued, however, finally culminating in the Glorious Revolution of 1688 when James II fled the country and Parliament gave the Crown to William and Mary. With Parliament supreme, absolutism was checked, and the economy boomed. So goes the economists' history.

However, as economists have been celebrating the superiority of English institutions, historians have been investigating how absolutist monarchy and Oriental despotism actually worked. The usual finding is that they promoted peace, order, and good government. Trade flourished as a result, regional specialization increased, and cities expanded. As regions became more specialized, the national income rose in a process that has come to be called 'Smithian growth'. The greatest threat to prosperity was invasion by barbarians attracted to the civilization's wealth – not expropriation or intervention by the emperor.

The first globalization

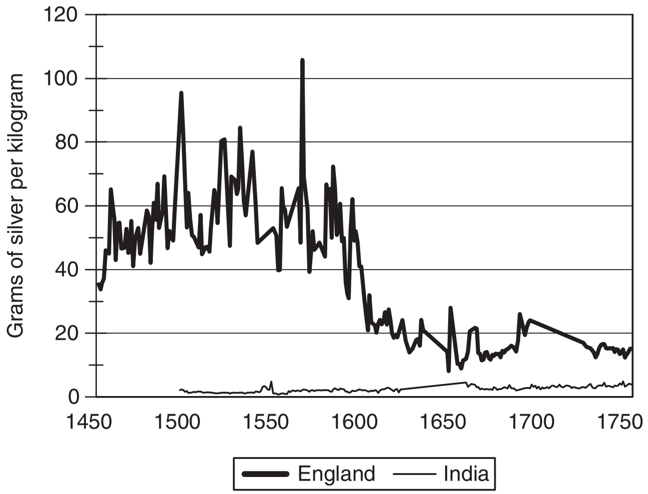
While institutions, culture, and geography always lurk in the background, technological change, globalization, and economic policy turn out to have been the immediate causes of unequal development. The Industrial Revolution itself, moreover, was the result of the first phase of globalization that began in the late 15th century with the voyages of Columbus, Magellan, and the other great explorers. The great divergence, therefore, begins with the first globalization.

Globalization required ships that could sail the high seas. Europeans did not have them until the 15th century. These newly invented 'full-rigged' ships had three masts – the front and middle were square-rigged and the aft was lateen-rigged. Sturdier hulls and the use of rudders instead of steering oars made ships that could navigate the globe.

Initially, the commercial impact of the full-rigged ship was felt in Europe. In the 15th century, the Dutch began shipping Polish grain from Danzig to the Netherlands and, by the late 16th century, to Spain, Portugal, and the Mediterranean. Textiles quickly followed. Italian cities had dominated the cloth industry in the Middle Ages, but English and Dutch producers contrived to make lightweight worsted cloth in imitation of Italian fabrics. By the early 17th century, the Mediterranean was flooded with these 'new draperies', and the English and Dutch drove the Italians out of business. This was a momentous change and began the relocation of Europe's manufacturing industry to northwestern Europe.

The most dramatic impact of the full-rigged ship, however, was in the Voyages of Discovery. Networks of Indian, Arab, and Venetian merchants shipped pepper and spices from Asia, across the Middle East, to Europe, and the Portuguese hoped to out-compete them with an all-water route. In the 15th century, the Portuguese sailed south along the African coast in search of a sea route to the East.

In 1498, Vasco da Gama reached Cochin in India, and filled his ship with pepper. The price in Cochin was about 4% of the price in Europe (Figure 5). The other 96% of the price difference was transport costs. By 1760, the gap between the Indian and English prices in Figure 5 had dropped by 85%, and that reduction is a measure of the efficiency gain from the all-sea route. In the 16th century, however, only Portugal benefited from the cut in transport costs since its state trading company kept the price at the medieval level and pocketed the savings as profits. It was the arrival of the English and Dutch East Indies companies in the early 17th century that broke Portugal's maritime monopoly and cut the European price by two-thirds. The real price received by Indian sellers increased by only a small amount: most of the efficiency gains from the Asian trade were reaped by European consumers.



5. Price of pepper, adjusted to price level of 1600

The Genoese sailor Christopher Columbus, of course, proposed the alternative of sailing west from Europe directly to Asia. He talked King Ferdinand and Queen Isabella of Spain into financing his expedition and landed in the Bahamas on 12 October 1492, convinced that he had reached the East Indies. But it was the Americas he had 'discovered', and that changed the history of the world.

Columbus's and da Gama's voyages set off a scramble for empire, and the Portuguese and Spanish were the early winners. In the two battles of Diu (1509 and 1538), the Portuguese defeated Venetian, Ottoman, and Asian forces and established their hegemony in the Indian Ocean. Then they pushed east towards Indonesia, establishing a string of colonies along the way. Eventually, the Portuguese reached the fabled Spice Islands (that is, the Moluccas in Indonesia), where nutmeg, cloves, and mace were indigenous. The Portuguese also accidentally discovered Brazil in 1500, which became their biggest colony.

Spain's empire was even richer. The greatest successes were the conquests of the Aztec Empire in 1521 by Hernán Cortés and the Inca Empire 11 years later by Francisco Pizarro. In both cases, small Spanish forces defeated large native armies through a combination of firearms, horses, guile, and smallpox. Looting the Aztecs and the Incas brought immediate wealth to Spain. Conquest was followed by the discovery of large silver deposits in Bolivia and Mexico. The silver flooding into Spain paid for the Habsburg armies fighting the Protestants across Europe, provided Europeans with the cash to buy up Asian goods, and unleashed decades of inflation known as the Price Revolution.

The imperial exploits of northern Europeans were modest in the 16th century. The English sent Giovanni Caboto (John Cabot) west in 1497, and he made it to Cape Breton, or Newfoundland. This counted as discovery, although Basque sailors had been fishing the Grand Banks for centuries. The French sent Jacques Cartier to Canada on three voyages in the 1530s and 1540s. Fur trading with the natives counted for little compared to Mexico or the Moluccas.

It was not until the 17th century that the northern Europeans became important imperialists. Their favourite organization was an East Indies company that combined imperialism with private enterprise. Typically, these firms were highly capitalized joint stock companies that traded in Asia or the Americas, maintained military and naval forces, and established fortified trading posts abroad. All of the northern powers had them. The English East India Company was chartered in 1600 and its Dutch counterpart two years later.

The Dutch East Indies Company created a Dutch Empire in Asia at the expense of the Portuguese. The Dutch seized the Moluccas in 1605, Malacca in 1641, Ceylon in 1658, and Cochin in 1662. They made Jakarta the capital of their Indonesian possessions in 1619. The Dutch also seized Brazil in 1630s and 1640s. They colonized sugar islands in the Caribbean, and founded New York in 1624 and the Cape Colony in South Africa in 1652.

The English also created an empire in the 17th century. In Asia, the English East India Company defeated the Portuguese in the naval battle of Swally off Surat in 1612. Subsequently, fortified trading posts were established at Surat (1612), Madras (1639), Bombay (1668), and Calcutta (1690). By 1647, the East India Company had 23 establishments in India. In the Americas, a variety of individuals and groups established colonies. Jamestown, Virginia, was the first success, in 1607. The legendary Plymouth colony followed in 1620, and the much more important Massachusetts Bay colony ten years later. The Bahamas and a string of islands were taken in the Caribbean in the 1620s and 1630s. Jamaica was added in 1655.

The English state actively expanded its empire – particularly at the expense of the Dutch. The first steps were taken by Oliver Cromwell, during the Commonwealth (1640–60), and continued after the Restoration. Expenditure on the navy was greatly increased. The first Navigation Act was passed in 1651. This mercantilist measure was intended to exclude the Dutch from trading with the English empire. The first Anglo-Dutch War (1652–4) was fought for commercial advantage, but was far from successful. After the Restoration of Charles II in 1660, the Navigation Acts were reinstated and extended, the (now Royal) Navy was expanded, and more wars were fought against the Dutch in 1665–7 and 1672–4. New York was seized in 1664. English colonies were established along the American coast from Georgia to Maine. Their economies grew rapidly by exporting tobacco, rice, wheat, and meat to England and the Caribbean. By 1770, the population of British America had reached 2.8 million, or almost half of England's.

English and Dutch trade with their colonies drove their economies forward. Cities and export-oriented manufacturing grew. The

Table 3. Percentage distribution of the population by sector, 1500–1750

	1500			1750		
	urban	rural nonagri-culture	agri-culture	urban	rural nonagri-culture	agri-culture
greatest transformation						
England	7%	18%	74%	23%	32%	45%
significant modernization						
Netherlands	30	14	56	36	22	42
Belgium	28	14	58	22	27	51
slight evolution						
Germany	8	18	73	9	27	64
France	9	18	73	13	26	61

(*continued*)

	1500 urban	1500 rural nonagri-culture	1500 agri-culture	1750 urban	1750 rural nonagri-culture	1750 agri-culture
Austria/Hungary	5	19	76	78	32	61
Poland	6	19	75	4	36	60
little change						
Italy	22	16	62	22	19	59
Spain	19	16	65	21	17	62

occupational structure changed accordingly. Table 3 divides the populations of the main European countries into three groups: agricultural, urban, and rural non-agricultural. In the Middle Ages, about three-quarters of the population was engaged in farming, most manufacturing was carried out in cities, and the 'rural non-agricultural population' consisted of village craftsmen, priests, carters, and the servants of country houses. In 1500, Italy and Spain were the most advanced economies, with the largest cities that produced the best manufactures. The Low Countries (principally modern-day Belgium) were an extension of this economy. The Dutch population was very small, and England was little more than a sheep walk.

By the eve of the Industrial Revolution, there had been far-reaching changes. England was the most transformed country. The fraction of the population in agriculture had dropped to 45%. England was the most rapidly urbanizing country in Europe. London grew from 50,000 in 1500 to 200,000 in 1600 to 500,000 in 1700 and, finally, to one million in 1800. The 'rural non-agricultural share' of the population was 32% in 1750. Most of these people were engaged in manufacturing industries, and their products were shipped across Europe and, sometimes, around the world. Artisans in Witney, Oxfordshire, for instance, sold blankets to the Hudson Bay Company, which swapped them for fur with the natives of Canada. The economy of the Low Countries developed along similar lines. The Netherlands were even more urbanized than England and also had large, export-oriented rural industries.

The rest of Europe was much less transformed. The great continental countries saw a small reduction in the share of their populations in agriculture and a corresponding increase in rural industry with little extra urbanization. Spain and Italy look stationary, with no change in the distribution of their populations.

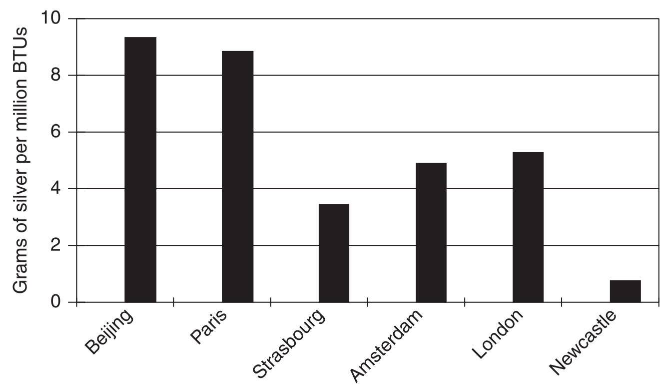
Spain was particularly unlucky. In the 16th century, it looked like the most successful imperialist, for Latin America yielded so much silver. Silver imports, however, led to much greater inflation in Spain than elsewhere. As a result, Spanish agriculture and manufacturing became uncompetitive. The constancy in the share of the urban population in Spain masks great changes – the populations of old industrial cities collapsed while Madrid expanded on the basis of American loot. Globalization spurred northwestern Europe forward but held southern Europe back.

Success in the global economy had major implications for economic development, including:

First, the growth in urbanization and rural manufacturing increased the demand for labour and led to tight labour markets and high wages. Living standards were high in London and Amsterdam (Figure 3).

Second, growing cities and a high-wage economy put great demands on agriculture for food and labour. The result was agricultural revolutions in both England and the Netherlands. Output per farm worker increased by about 50% in both countries and reached the highest levels in Europe.

Third, growing urban demand also led to energy revolutions in both England and the Netherlands. In the Middle Ages, charcoal and firewood were the principal fuels burned in cities. As the cities grew, wood prices skyrocketed, and substitute fuels were developed. In the Netherlands, the alternative was peat; in England, it was coal. Coal was mined in Durham and Northumberland and shipped down the coast to London. England was the only country in the world with a large coal-mining industry in the 18th century, and that also gave it access to the cheapest energy in the world, as Figure 6 indicates.



6. Price of energy

Table 4. Adult literacy, 1500 and 1800. Percentage of the adult population that could sign its name

	1500	**1800**
England	6	53
Netherlands	10	68
Belgium	10	49
Germany	6	35
France	7	37
Austria/Hungary	6	21
Poland	6	21
Italy	9	22
Spain	9	20

Fourth, the high-wage economy generated a high level of literacy, numeracy, and skill formation in general. Table 4 shows estimates of literacy (measured by the ability to sign one's name rather than make a mark) in 1500 and 1800. Literacy rose everywhere in Europe, but the growth was greatest in northwestern Europe. The Reformation does not explain the rise, as is often assumed, for literacy was as high in northeastern France, Belgium, and the Rhine Valley – all Catholic areas – as in the Netherlands or England. The rise in literacy was due to the high-wage, commercial economy. The expansion of commerce and manufacturing increased the demand for education by making it economically valuable; at the same time, the high-wage economy provided parents with the money to pay for schooling their children.

Chapter 3
The Industrial Revolution

The Industrial Revolution (roughly 1760 to 1850) was a turning point in world history, for it inaugurated the era of sustained economic growth. The Revolution was not the abrupt discontinuity that its name suggests but was the result of the transformations of the early modern economy discussed in the last chapter. The rate of economic growth achieved in the century after 1760 (1.5% per year) was very low by the standards of recent growth miracles in which GDP has grown by as much as 8–10% per year. However, Britain was continuously extending the world's technology frontier, and that is always slower going than catching up to the leader by importing its technology, which is how countries have grown very rapidly. Moreover, the great achievement of the British Industrial Revolution was that it led to continuous growth, so that income compounded to the mass prosperity of today.

Technological change was the motor of the Industrial Revolution. There were famous inventions like the steam engine, the machines to spin and weave cotton, and the new processes to smelt and refine iron and steel using coal instead of wood fuels. In addition, there were a host of simpler machines that raised labour productivity in unglamorous industries like hats, pins, and nails. There was also a range of new English products, many of which, like Wedgwood porcelain, were inspired by Asian manufactures.

In the 19th century, engineers extended the 18th-century mechanical inventions across the board. The steam engine was applied to transportation with the invention of the railway and the steamship. Power-driven machinery, whose use was initially restricted to textile mills, was applied to industry generally.

The question is: why was the revolutionary technology invented in England rather than the Netherlands or France or, for that matter, China or India?

Cultural and political context

The Industrial Revolution took place in a particular political and cultural context that was favourable to innovation, and that may help to explain it.

The English constitution has been a model for European liberals and modern economists alike. It was far from democratic: only 3–5% of the English could vote and even fewer of the Scots. Much power remained with the Crown – in particular, the power to make war and peace. While Parliament had a constitutional right to refuse funds for war, it never did.

The English constitution had many features that promoted economic growth, although they were not the ones stressed by modern economists, who emphasize restrictions on taxation and the security of property. Parliamentary supremacy actually resulted in the reverse. While French monarchs claimed to be absolute, they could not increase taxes without consent, and it was a crisis in public finances that precipitated the Revolution by forcing Louis XVI to convene the États généraux in 1789. The nobility in France were exempt from taxation, but the English Parliament introduced a land tax in 1693 that was imposed on peers as well as commoners. Most tax revenue, however, was raised from excise duties on consumer goods like beer and imports like sugar and tobacco. These taxes were borne primarily by

workers, who were not represented in Parliament. Parliament may have checked the Crown, but, in the absence of democracy, who checked Parliament?

In the event, the English state collected about twice as much per person as the French state and spent a larger fraction of the national income. It is arguable that these expenditures promoted economic growth. Most of the money was spent on the army and the navy. The former was occasionally directed abroad but was always available to maintain domestic order by suppressing assemblies opposed to machinery or in favour of democracy. The navy was directed to expand Britain's empire and promote the country's commerce. Even the workers gained from this since imperialism was the basis of the high-wage economy, which in turn led to growth by inducing labour-saving technical change. Had Louis XIV had the power to levy taxes, he might have advanced French prosperity by maintaining the French navy in a permanent state of readiness rather than enlarging or contracting it in response to the swing between war and peace.

Growth was also promoted by Parliament's power to take people's property against their wishes. This was not possible in France. Indeed, one could argue that France suffered because property was too secure: profitable irrigation projects were not undertaken in Provence because France had no counterpart to the private acts of the British Parliament that overrode property owners opposed to the enclosure of their land or the construction of canals or turnpikes across it. What the Glorious Revolution meant in practice was that the 'despotic power' of the state that 'was only available intermittently before 1688…was always available thereafter'.

In addition to a favourable political system, the Industrial Revolution was sustained by the emerging scientific culture. The Scientific Revolution of the 17th century led to a handful of discoveries about the natural world that were applied by inventors in the 18th. In addition, the success of natural philosophy lent credibility to the scientific method, that is, the view that the world is governed by laws that can be discovered by observation and applied to the improvement of human life. Newton's model of the Solar System was the greatest achievement, and it inspired a reorientation of upper-class ideas about religion and nature.

How much popular culture shared in this reorientation is an open question. There are important examples of working-class inventors adopting the Newtonian model. John Harrison, for instance, was lent a copy of Saunderson's lectures on natural philosophy, a Newtonian tract, by a clergyman, and made a copy of it. Did this early interest in Newton dispose Harrison to invent the chronometer? On the other hand, there was continued popular enthusiasm for witchcraft, which was the medieval alternative to science. It is likely that more people believed in witchcraft than in Newton's laws of motion. John Wesley's preaching was attracting millions of followers, and he was of the view that the 'giving up of witchcraft is, in effect, giving up the Bible'.

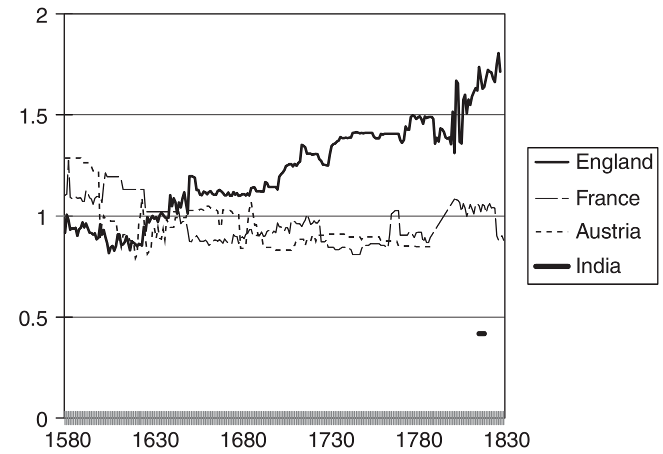
Popular culture was more directly transformed by social changes than by Newton's *Principia Mathematica*. The most powerful changes were urbanization and the growth of commerce. They encouraged the spread of literacy and numeracy by increasing their value. By the 18th century, most sons of craftsmen, artisans, shop keepers, and farmers, and a smaller share of the sons of labourers, received several years of primary education. Many girls were also schooled. The result was a public that read newspapers and followed politics to an unprecedented degree. It was a new world when a radical like Tom Paine could achieve celebrity by selling hundreds of thousands of copies of *The Rights of Man*.

Explaining the Industrial Revolution

Scientific discoveries were known across Europe, and upper-class enthusiasm for natural philosophy was universal. These cultural developments, therefore, cannot explain why the Industrial

Revolution was British. Instead, the explanation lies in Britain's unique structure of wages and prices. Britain's high-wage, cheap-energy economy made it profitable for British firms to invent and use the breakthrough technologies of the Industrial Revolution.

In Chapters 1 and 2, we saw that wages in Britain were sufficiently high for most people to eat bread, beef, and beer, instead of subsisting on oatmeal. More to the point, so far as technology is concerned, British wages were high relative to the price of capital (Figure 7). In the late 1500s, the wage rate relative to the price of capital services was similar in southern England, France, and Austria, which are representative of continental Europe. By the middle of the 18th century, however, labour relative to capital was 60% more expensive in England than on the continent. In the early 19th century, which is the first time a comparison can be made with Asia, labour was even cheaper relative to capital in India than it was in France or Austria. The incentive to mechanize production was correspondingly less in India.



7. Wage relative to price of capital services

It was the same story with energy. Britain, especially on the coal fields in the north and in the midlands, had the cheapest energy in the world. Consequently, energy was much cheaper compared to labour in Britain than it was anywhere else.

As a result of these differences in wages and prices, businesses in England found it profitable to use technology that saved on expensive labour by increasing the use of cheap energy and capital. With more capital and energy at their disposal, British workers became more productive – the secret of economic growth. In Asia and Africa, the cheapness of labour led to the opposite result.

The cotton industry

Eric Hobsbawm famously wrote: 'Whoever says Industrial Revolution says Cotton.' From tiny beginnings in the mid-18th century, the industry grew to be Britain's largest, accounting for 8% of GDP in 1830 and 16% of British manufacturing jobs. Cotton was the first industry to be transformed by factory production. The growth of cotton led to the explosive growth of Manchester and many smaller cities in the north of England and Scotland. Britain's expansion came at the expense of India, China, and the Middle East. When these countries eventually began to re-industrialize, cotton was one of the first industries they turned to.

In the 17th century, China and India had the world's largest cotton industries. Bengal, Madras, and Surat shipped cotton cloth across the Indian Ocean and as far as West Africa. Cotton was also produced in small centres across Asia and Africa. The various East Indies companies began to ship cotton calicoes and muslins to Europe in the late 17th century where they successfully competed against linen and wool, the principal European textiles. Cotton was so successful that France prohibited its import in 1686, and the English restricted its domestic consumption. However, there was a large export market in West Africa, where cotton cloth was

bartered for slaves. In this market, English cloth competed against Indian cloth.

International competition was the spur that led to the mechanization of cotton spinning. The finer the cotton, the more time it took to spin. Wages were so high in England that competition with India was only possible in the coarsest fabrics. There was a large market in finer fabrics, but England could only compete if machines were invented to reduce labour. The stakes were considerable: in 1750, Bengal spun about 85 million pounds of cotton per year, while Britain managed only 3 million. There were numerous attempts to mechanize production. James Hargreaves' spinning jenny, developed in the mid-1760s, was the first commercially successful machine, followed closely by Richard Arkwright's water frame. Samuel Crompton's mule, invented in the 1770s, married the jenny and the water frame (hence its name) and became the basis of mechanical spinning for a century.

These machines owed nothing to scientific discoveries. None involved great conceptual leaps; instead, they required years of experimental engineering to come up with designs that worked reliably. Thomas Edison's remark that 'invention is 1% inspiration and 99% perspiration' is on the mark for the cotton industry.

The crux in explaining why the Industrial Revolution was invented in Britain is, therefore, explaining why British inventors spent so much time and money doing R&D (Research and Development, that is, Edison's 'perspiration') to operationalize what were often banal ideas. The key is that the machines they invented increased the use of capital to save labour. Consequently, they were profitable to use where labour was expensive and capital was cheap, that is, in England. Nowhere else were the machines profitable. That is why the Industrial Revolution was British.

Cotton yarn was manufactured in three stages. First, the bales of raw cotton were broken open and the dirt and debris removed.

Second, the cotton was carded, that is, the strands of cotton were aligned into a loose strand called a roving by dragging the cotton between cards studded with pins. Third, the roving was spun into yarn. Before machines, the whorl and drop spindle was used to make fine yarn, while the spinning wheel made coarse yarn. In each case, the roving was stretched to thin it, then twisted to strengthen it, and, finally, the yarn was wound on a spindle to send to weavers.

All of these stages were mechanized, and, indeed, Richard Arkwright's greatest achievement was to design a mill (Cromford Mill No.2) in which machines were laid out in a logical sequence, and which became the model for the early cotton mills in Britain, the USA, and the continent. Spinning was the crux of the problem, and inventors had worked on it since at least the 1730s. Lewis Paul and John Wyatt were on the right track in the 1740s and 1750s with their system of roller spinning, but their mill in Birmingham always lost money. James Hargreaves' spinning jenny, invented in the 1760s, was the first commercially successful spinning machine. It elaborated the spinning wheel by running many spindles off one wheel and using draw bars and linkages to mimic the movements of the spinner's hands. Arkwright employed clockmakers for five years in order to perfect his water frame that used rollers. With roller spinning, the roving was stretched by pulling it through successive pairs of rollers, which, like mangles, dragged the cotton forward. Each pair of rollers moved faster than the previous, so they lengthened and thinned the yarn by pulling against each other.

Crompton's mule was the last great spinning machine. It combined the draw bars of Hargreaves' jenny with the rollers of Arkwright's water frame to make a machine that could spin yarn far finer than any of the other machines. The jenny and the water frame made England competitive with Indian producers in coarse yarn; the mule made England the low-cost producer in fine yarn as well.

The economics of these machines were similar. All of them reduced the hours of labour needed to produce one pound of yarn. At the same time, they increased the capital required per pound. As a result, the cost saving from mechanical spinning was higher where labour was more expensive. In the 1780s, the rate of return to building an Arkwright mill was 40% in England, 9% in France, and less than 1% in India. With investors expecting a 15% return on fixed capital, it is no surprise that about 150 Arkwright mills were erected in Britain in the 1780s, 4 in France, and none in India. Relative profitability was similar with the spinning jenny, as was the result – 20,000 jennies were installed in England on the eve of the French Revolution, 900 in France, and none in India. There was no point in spending much time or money to invent mechanical spinning in France or India since it was not profitable to use it there.

The situation did not remain like this, which is why the Industrial Revolution spread to other countries. Arkwright's mills created an integrated series of machines that cut costs by more than Hargreaves' jenny. Crompton's mule cut the cost of spinning fine yarn. A long list of inventors improved the mule over the next half century. They economized on capital as well as on labour. By the 1820s, improved cotton machinery could be profitably installed on the continent, and by the 1850s, it proved profitable to install even more improved machinery in low-wage economies such as Mexico and India. By the 1870s, factory cotton production began to shift into the Third World.

The steam engine

The steam engine was the most transformative technology of the Industrial Revolution since it allowed mechanical power to be used in a wide range of industries as well as in railways and ocean ships.

Steam power was a spin-off of the Scientific Revolution. Atmospheric pressure was one of the hot topics of 17th-century physics. It was investigated by famous scientists across Europe, including Galileo, Torricelli, von Guericke, Huygens, and Boyle. By the middle of the century, Huygens and von Guericke had shown that, if a vacuum was created in a cylinder, then the pressure of the atmosphere would force a piston into it. In 1675, the Frenchman Denis Papin used this idea to make a crude, proto steam engine. A practical engine was completed by Thomas Newcomen in 1712 in Dudley, after 12 years of experimentation. Newcomen's engine involved boiling water to make steam, filling a cylinder with it, and then injecting cold water into the cylinder to condense the steam so that the pressure of the atmosphere depressed a piston into the cylinder. The piston was connected to a rocker beam that raised a pump as the piston was depressed.

The steam engine emphasizes the importance of economic incentives in inducing invention. The science of the engine was pan-European, but the R&D was conducted in England because that was where it paid to use the steam engine. The purpose of the Newcomen engine was to drain mines, and Britain had many more mines than any other country due to the large coal industry. In addition, the early steam engines burned vast quantities of coal, so they were cost-effective only where energy was cheap. John Theophilus Desaguliers wrote in the 1730s that the Newcomen engines were 'now of general use … in the Coal-Works, where the Power of the Fire is made from the Refuse of the Coals, which would not otherwise be sold'. They were scarcely used anywhere else. Despite the scientific breakthroughs, the steam engine would not have been developed had the British coal industry not existed.

Steam power became a technology that could be applied to many purposes and used around the world, but only after the engine was improved. This was not accomplished before the 1840s. Engineers like John Smeaton, James Watt, Richard Trevithick, and Arthur Woolf studied and modified the engine, reducing its energy requirements and smoothing its delivery of power. Coal

consumption per horse power-hour of power was cut from 44 pounds in the Newcomen engines of the 1730s to one pound in the triple expansion marine engines of the late 19th century. The genius of British engineering undid the country's competitive advantage by improving its technology to the point that it could be profitably used around the globe. This allowed the Industrial Revolution to spread abroad and the whole world to industrialize.

Continuing invention

The greatest achievement of the Industrial Revolution was that the 18th-century inventions were not one-offs like the achievements of earlier centuries. Instead, the 18th-century inventions kicked off a continuing stream of innovations.

Cotton continued to be a focus of effort. While the 18th-century inventions had turned spinning into a factory system, weaving was still done on hand looms in cottages. This was changed by the Reverend Edmund Cartwright, who spent decades and wasted his fortune perfecting a power loom. He was inspired by automatons like Jacques de Vaucanson's mechanical duck that wowed the court in Versailles by flapping, eating, and defecating&(Voltaire quipped: 'Without Vaucanson's duck, you have nothing to remind you of the glory of France.') If a mechanism could poop like that, couldn't it also do useful work? Cartwright thought so and patented his first loom in 1785 and an improved version in 1792. It was not commercially viable, however. Many inventors improved it piecemeal. By the 1820s, the power loom was displacing hand looms in England, but they continued in use until the 1850s. The power loom greatly increased capital costs while reducing labour costs, so its adoption was sensitive to factor prices as well as the relative efficiency of the two methods. It is singularly important that the power loom was taken up more rapidly in the USA than it was in Britain. By the 1820s, wages were already higher in the USA, and the pattern of technological innovation reflected that difference.

Cotton also led the way in the application of steam power to factories. Experiments had been made earlier, of course. In 1784, Boulton and Watt invested in the Albion Flour Mill, the first large-scale steam-powered factory, to promote their engines. The next year, steam was applied to a cotton mill for the first time. However, most factories were driven by water power until the 1840s. It was only then that the fuel consumption of steam engines had dropped sufficiently to make them a cheaper source of power. After that, the use of steam to power industry expanded continuously.

Steam power also revolutionized transportation in the 19th century. Everyone who invented a high-pressure steam engine (Cugnot, Trevithick, Evans) used it to power a land vehicle, but they were all unsuccessful since they could not negotiate the unpaved roads. One solution was to put the engine on rails. Coal and ore had long been hauled in carts rolling on primitive wooden rails laid in mines. In the 18th century, iron rails replaced wood, and the lines were extended. In 1804, Richard Trevithick built the first steam locomotive for a railway at the Penydarren Ironworks in Wales. From then on, colliery railways became the testing ground for steam locomotives. The 26-mile Stockton and Darlington Railway (1825) was planned as a coal railway but showed there was money to be made in carrying general freight and passengers. The first general-purpose railway was the 35-mile Liverpool and Manchester Line, opened in 1830. It was a great success and set off a frenzy of railway promotion in Britain. Almost 10,000 kilometres of track were open by 1850, and 30 years later, the network reached 25,000 kilometres.

Steam power was also applied to water travel – another way of avoiding bad roads! Invention was international from the start. The first working vessels were French – the *Palmipède* (1774) and *Pyroscaphe* (1783) – and the first commercially successful ship was Robert Fulton's *Clermont*, which plied the Hudson River from

1807. Two years later, John Molson, the Canadian brewer, sailed steamships on the St Lawrence River using engines built in Trois-Rivière, Québec.

By the middle of the 19th century, steam was displacing sail in ocean transportation. Britain became the centre of world shipbuilding in view of its pre-eminence in iron and engineering. Brunel's *Great Western* (1838) marked a breakthrough, for it established that a ship could carry enough coal to cross the Atlantic, and his *Great Britain* (1843) was the first ship to be built of iron and to use a propeller instead of paddle wheels. It took another half century, however, for steam to vanquish sail. The reason was that ships still had to carry their own coal, so they lost much of their cargo space on long voyages. The first routes to shift to steam were consequently short. As the coal requirements of steam engines were reduced, ships could sail longer distances with the same amount of coal, and the distance for which steam could undercut sail lengthened. The last routes to fall were those from China to Britain where clipper ships survived until the end of the 19th century.

Steam power is an example of a general-purpose technology (GPT), that is a technology that can be applied to a variety of uses. Other GPTs include electricity and computers. It takes decades to develop the potential of GPTs, so their contribution to economic growth takes place long after their invention. That was certainly true for steam. As late as 1800, almost a century after Newcomen's invention, steam power made only a minute contribution to the British economy. By the middle of the 19th century, however, the potential of steam was finally being realized as it was applied widely to transportation and industry. Half of the growth of labour productivity in Britain in the mid-19th century was due to steam. This long-run pay-off is an important reason that economic growth continued through the century. Another reason was the growing application of science to industry, which we will consider in the next chapter.

Chapter 4
The ascent of the rich

Between 1815 and 1870, the Industrial Revolution spread from Britain to the continent with remarkable success. Not only did the West European countries catch up to the leader, but they joined the leader in forming a group of innovators that has jointly advanced the world's technology frontier ever since. Of course, North America also industrialized in the 19th century and soon joined the innovation club. The USA, indeed, has become the world's technological leader, but its performance should be thought of as 'first among equals' – the latter including the West Europeans and the British.

Whether Western Europe's success is a surprise depends on one's view of the Industrial Revolution. Some historians think that the Revolution was as likely to have happened in France or Germany as in Britain and that the big problem, therefore, is explaining why it occurred in Europe rather than Asia. For them, it is obvious that the continent would quickly industrialize. Other historians, however, think that there were fundamental differences in institutions or incentives between Britain and the continent, in which case, the industrialization of Western Europe requires an explanation.

Institutionalists believe that continental development in the 18th century was held back by archaic institutions. These were swept

away by the French Revolution, which was exported to most of Europe by the armies of the Republic and Napoleon. Everywhere the French conquered, they remodelled Europe in their new image, which included the abolition of serfdom, equality before the law, a new legal regime (the *Code Napoléon*), the expropriation of monastic property, the creation of national markets by the abolition of internal tariffs and erection of a common external tariff, a rationalized tax system, universal secular primary education and the extension of modern secondary schools, technical institutes and universities, the promotion of scientific societies and culture. Countries like Prussia that were defeated by Napoleon but not incorporated into his empire also modernized their institutions. Napoleon's wars prevented these reforms from having immediate effect, but, after Waterloo, Europe was ripe for industrial take-off.

Another line of explanation emphasizes the incentives to adopt the new industrial technology. First, Britain's early start meant that British manufacturers could out-compete those on the continent, and, second, the technology of the Industrial Revolution was inappropriate for continental countries where wages were lower and energy prices generally higher than in Britain. Continental industrialization required the invention of appropriate technology and protection from British competition while that took place.

While Britain did not have a policy to 'industrialize', most countries since have had a strategy to emulate its success. In the 19th century, a package of development policies emerged that many countries followed. These policies were originally worked out in the USA (see Chapter 6) and then promoted in Europe by Friedrich List, a German who lived in the USA from 1825 to 1832 and then returned to Germany to write *The National System of Political Economy* (1841). The standard development strategy, which built on Napoleon's institutional revolution, had four imperatives: create a large national market by abolishing internal tariffs and improving transportation; erect an external tariff to protect 'infant industries' from British competition; create banks to stabilize the currency and provide business with capital; and, finally, establish mass education to speed the adoption and invention of technology. This development strategy helped continental Europe to catch up to Britain.

Germany is a good example. In the Middle Ages, it was divided into hundreds of independent political units. The number was whittled down to 38 at the Congress of Vienna in 1815. Prussia, which was the largest German state, instituted universal primary education in the 18th century. Other states followed. By the middle of the 19th century, primary education was close to universal across Germany.

Prussia also took the lead in creating a national market by forming the *Zollverein* (customs union) in 1818 to unify its territory. Other German states gradually joined. The *Zollverein* both abolished internal traffics and created a common external tariff to keep out British manufactures. The economic union formed the basis of the German Empire created in 1871.

The integration of markets was reinforced by building railways. The first German railway (6 kilometres long) was built from Nuremberg to Fürth in 1835, just five years after the Liverpool to Manchester Railway. Mainline railways were laid out in the 1850s and branch lines in the next decades. About 63,000 kilometres were open in 1913.

Investment banks, which played no role in British industrialization, were prominent on the continent. The earliest experiment was the *Société Générale pour favoriser l'Industrie Nationale des Pays-Bas* founded in 1822 to promote industrial development in the Low Countries. German private banks began to do the same thing. The *Crédit Mobilier*, established in France in 1852 to finance railways and industry, was a giant step forward.

The following year, it spun off the Bank of Darmstadt, which popularized the joint-stock investment bank in Germany. By 1872, all of the giant German banks (Commerzbank, Dresdner, Deutsche, etc.) were founded. They had many branches to assemble the capital of many depositors. They formed lasting relationships with industrial clients, providing them with long-term funds as current account overdrafts at low rates of interest. Often these loans were secured with mortgages on industrial property, and bank representatives served as directors of the industrial firms. These banks financed the great expansion of German industry between 1880 and the First World War.

Between 1815 and 1870, all of the major industries of the Industrial Revolution were established on the continent on a profitable basis. Spinning jennies and early Arkwright mills had not been profitable in France before the Revolution, but subsequent technical progress cut the cost of producing coarse yarn by 42% by the mid-1830s. These cost declines made the new-style mills profitable to erect. By 1840, France was spinning 54,000 tons of cotton per year, compared to Britain's 192,000. Production had begun in Germany (11,000 tons) and Belgium (7,000). It is worth noting that the USA at this time was already processing 47,000 tons of raw cotton.

A modern iron industry was also established on the continent by 1870. Charcoal was the fuel used to smelt and purify iron before the 18th century. Charcoal was replaced by coke, a refined form of coal, in one of the most famous innovations of the Industrial Revolution. This technique was put into practice by Abraham Darby at the Coalbrookdale Iron Company in 1709. Coke iron, however, was not cost-effective in the manufacture of rolled iron products (bars, plates, rails) until after 1750, so its early use was limited to a specialized casting process patented by Darby. Between 1750 and 1790, coke iron replaced charcoal iron in making rolled products. Coke iron was still too expensive to oust charcoal smelting on the continent, however, for countries like

France were endowed with extensive forests providing cheap charcoal and suffered from scarce and expensive coal. It took a further 50 years of improvement in blast furnace design to raise the productivity of coke furnaces sufficiently for them to out-compete charcoal in continental Europe. That transition occurred rapidly in the 1860s as French and German firms built blast furnaces of the most advanced design. They leapt, in other words, to the cutting edge of iron technology since that was the only form of the technology that was competitive there.

Likewise, the continent did not lag behind Britain in the new industries of the mid-19th century. Western Europe built railways, and Europe's locomotives were as advanced as Britain's. The same was true of steel. Before 1850, steel was an expensive – and minor – product of the iron industry, which mainly produced plates and rails from wrought iron refined from pig iron in the puddling furnace. The technical problem in steel production was to melt pure pig iron, so that the addition of other elements including carbon could be precisely controlled. A temperature in excess of 1500° C was required. The first solution was the converter, invented independently around 1850 by Henry Bessemer and William Kelly. An alternative solution was pioneered by Sir Carl Wilhelm Siemens, who built a regenerative furnace in the 1850s that could reach very high temperatures. In 1865, Pierre-Émile Martin used the Siemens furnace to melt pig iron to make steel. The so-called open hearth furnace proved superior to the Bessemer converter in the production of plates, sheets, and structural shapes, and became the dominant technology until it was superseded by the basic oxygen process in the 1960s. The important point is that the four inventors of mass-produced steel were an Englishman, an American, a German living in England, and a Frenchman. There was no international lag there.

While Western Europe had overcome its most glaring technological deficiencies by 1870, production levels on the continent were still far behind those of Britain. This changed by

the First World War, however, as both Western Europe and the USA overtook Britain in manufacturing. In 1880, Britain produced 23% of the world's manufactures, while France, Germany, and Belgium together produced only 18%. By 1913, the three continental countries had out-paced Britain as their share rose to 23% and Britain's share dropped to 14%. At the same time, the North American share grew from 15% to 33% of world manufacturing. Britain did best in the cotton textile industry, processing 869,000 tons of raw cotton per year in 1905–13, against the USA which reached 1,110,000 tons, Germany 435,000, and France 231,000. British performance was far weaker in heavy industry. In 1850–4, Britain smelted 3 million tons of pig iron versus 245,000 in Germany and about 500,000 in the USA. By 1910–13, Britain was producing 10 million tons, while Germany smelted 15 million, and the USA 24 million.

The changes in manufacturing production had important political implications. In the middle of the 19th century, Britain was the 'workshop of the world', producing most of the world's exported manufactures. The USA and Germany, in particular, increased their production of manufactures by increasing their exports, and the changes in trade performance were widely discussed. Britain continued to hold its own in selling to its empire, and the value of empire demonstrated in that way led to a scramble for colonies among the industrial economies. Germany's overtaking of Britain in steel production had implications for armaments manufacture. The Anglo-German trade rivalry stoked international tensions in the approach to the First World War.

Not only did continental Europe and North America overtake Britain in industrial output between 1870 and 1913, but they manifestly joined it in technological competence. The USA, indeed, surpassed Britain, becoming the world's technological leader. In most industries, however, important discoveries were made in all of the leading industrial economies. From the global perspective, what is striking is the difference between the rich countries, who, as a group, pushed technology forward, and the rest of the world, which seemingly made no innovations at all.

An important feature of the late 19th century was the development of entirely new industries – automobiles, petroleum, electricity, chemicals. All of the rich countries were involved in creating these industries. The first vehicle powered by a gasoline engine was built by Siegfried Marcus, an Austrian, in 1870. He also invented a magneto ignition system and rotating brush carburettor that have become standards. Karl Benz built the first practical automobile in 1885, closely followed by Gottlieb Daimler and Wilhelm Maybach. They were Germans. William Lanchester built the first British auto in 1895 and invented the disc brake and electric starter. The first company organized expressly to manufacture autos was Panhard et Levassor in France in 1889. They also invented the four-cylinder engine. Renault introduced drum brakes in 1902. In 1903, Jacobus Spijker of the Netherlands built the first four-wheel-drive racing vehicle. Automobiles required a range of innovations covering engines, starting systems, brakes, transmissions, suspensions, electrics, and so forth. The modern auto is the result of inventions made by people in all of the leading industrial countries. By 1900, all of the industrial countries had firms manufacturing autos. Innovation was a collective activity among them.

Another feature of the new industries was that many were related to developments in the natural sciences. Countries with strong university programmes in these areas reaped economic benefits. Germany is the pre-eminent example before the 1930s. Its physicists and chemists won many Nobel Prizes. Key technical personnel in industry were trained in universities, and their academic staff made important discoveries that improved industrial processes and led to new products. Fritz Haber's discovery of the process to convert atmospheric nitrogen to ammonia, made when he was at the University of Karlsruhe and

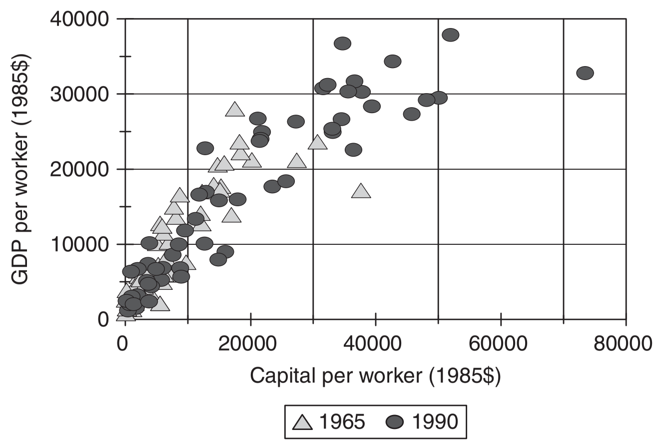
for which he received a Nobel Prize, is one of the most famous, but far from unique.

Hitler, the Second World War, and post-war division derailed German science. The lead in university research passed to the USA, which had been developing a very large higher education sector. University research in the USA floated on a sea of government money. This was directed towards the military during the Cold War, but many of the projects brought benefits to the economy as a whole. Funding was also directed towards medicine, space exploration, and even the humanities and social sciences. This funding underpinned America's global leadership.

The macro-economic character of technological progress

Most R&D has been carried out in today's rich countries. They have developed technologies that they anticipated would be profitable. Therefore, the new products and processes that they pioneered were addressed to their needs and suited to their circumstances; in particular, the high wages of rich countries induced them to invent products that economized on labour by increasing the use of capital. This led to an ascending spiral of progress: high wages induced more capital-intensive production that, in turn, led to higher wages. This spiral underlies the rising incomes of rich countries.

A consequence of Western Europe and the USA doing all of the world's R&D is that there is a world 'production function' that defines the technological options of all countries. A 'production function' is the mathematical relationship that indicates how much GDP a country can produce with its labour and capital. Figure 8 shows the world production function by plotting GDP per worker against capital per worker for 57 countries in 1965 and 1990. The points bracket the function. It has the feature that more capital per worker translates into more output per worker. Moreover, the



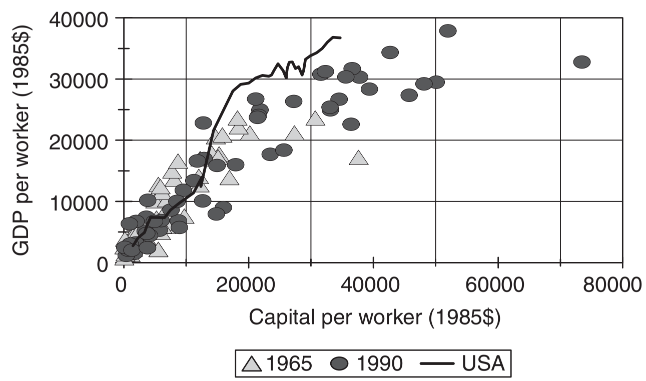
8. World production function

relationship flattens out at high levels of capital per worker because of the law of diminishing returns: more and more capital yields less and less additional output. Finally, different icons are used for the 1965 and the 1990 data. A country with $10,000 of capital per worker produced no more output in 1990 than it did in 1965. It experienced no technical progress, in other words. The change in the world's technology consisted in getting more output per worker by pushing capital per worker to levels higher than those reached before. The beneficiaries of these improvements were the rich countries operating with highly capital-intensive technologies in 1965. These were also the countries that invented the new technologies of 1990. These improvements did not automatically trickle down to poorer countries.

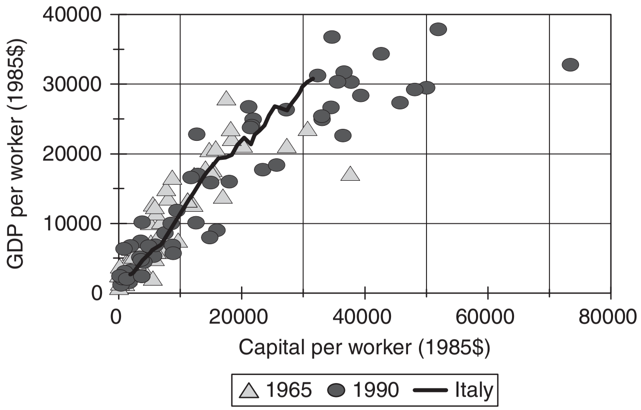
For some of these countries, we can measure output per worker and capital per worker back to the Industrial Revolution. With these data, we can compare what has happened *over time* to what happens *across space*. For instance, the line in Figure 9 labelled 'USA' connects the points representing capital per worker and

output per worker for the USA from 1820 to 1990. The trajectory of the USA's development follows the same pattern as rich and poor countries in 1965 and 1990. It is the same story for all other rich countries: growth over time looks like differences across space today. Figure 10 shows this for Italy, and Figure 11 for Germany. There are some idiosyncrasies in these histories – the USA, as befits the world's technological leader, has usually got a bit more output from its capital and labour than other countries, while Germany, perhaps because of the importance of investment banks, has accumulated more capital per worker – but the fundamental dynamics are the same. The correspondence between growth over time and differences across space is a direct consequence of the fact that the technological possibilities in the world today were created by the rich countries as they developed.

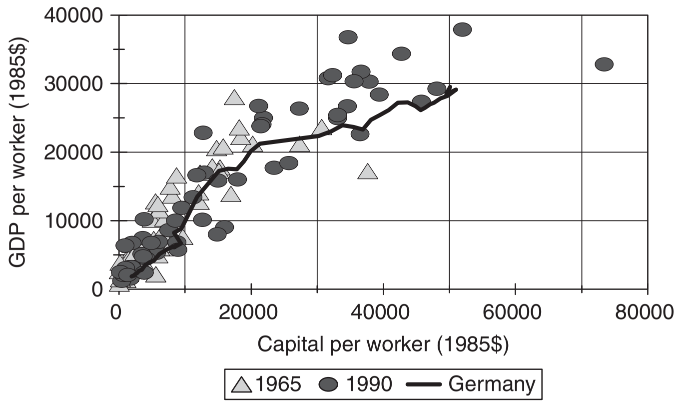
The reason that poor countries are poor is because they use technology that was developed by rich countries in the past. The most successful industry of many developing countries is the manufacture of clothing. The key technology is the sewing machine. The treadle sewing machine was first produced commercially in the 1850s, and the electric sewing machine was



9. US growth trajectory



10. Italian growth trajectory



11. German growth trajectory

introduced in 1889. Export success in most developing countries today is based on 19th-century technology.

The statistics in Figure 8 make the same point. Why is Peru relatively poor? In 1990, capital per worker in Peru was $8,796 and output per worker was $6,847. These figures are almost

identical to Germany's in 1913: $8,769 and $6,425, respectively. Less capital today throws you further back in time. In 1990, for instance, Zimbabwe had $3,823 of capital per worker, and each worker produced $2,537 per year. Not bad for 1820. Malawi had $428 of capital, and GDP per worker was $1,217 – about the same as India early in the 19th century, and considerably below the levels realized in the UK, USA, and Western Europe at the same time. Even in 1990, capital per worker in India had increased only to $1,946 and output per worker had reached $3,235 – putting India on a par with Britain in 1820.

The obvious question is why Peru, Zimbabwe, Malawi, and India do not adopt the technology of the Western countries and become rich themselves. The answer is that it would not pay. Western technology in the 21st century uses vast amounts of capital per worker. It only pays to substitute that much capital for labour when wages are high relative to capital costs. This is shown in all Figures by the flattening out of the relationship between output per worker and capital per worker. When capital per worker is high, it takes a lot more capital per worker to increase output per worker by $1,000 than is required when capital per worker is low. Labour has to be very expensive to make it worthwhile to build all that extra capital. The Western countries have experienced a development trajectory in which higher wages led to the invention of labour-saving technology, whose use drove up labour productivity and wages with it. The cycle repeats. Today's poor countries missed the elevator. They have low wages and high capital costs, so they make do with archaic technology and low incomes.

Industrial history provides examples of these principles. In the last chapter, we discussed the invention of the power loom and the way it was brought into use in the USA – a very high-wage country – and then in Britain, once it was perfected. The power loom was never cost-effective in low-wage countries, where people continued to weave with hand looms. Their situation became even more difficult later in the 19th century when the USA became the economic leader with the highest wage economy. American technology reflected that circumstance. In the 1890s, an English immigrant named James Henry Northrop made a series of inventions that resulted in a fully automatic loom. It greatly increased labour productivity but required substantial investment. These looms were profitable to install in America where wages were very high, but they were too expensive to use in Britain – even though Britain was a high-wage economy by world standards. The Northrop loom was even less appropriate in poor countries. The process of technical change, in which inventors in the leading economies sought to save high-wage labour, resulted in machinery that further increased the competitive advantage of rich countries without conferring any advantage on the poor countries of the world.