THE NEW INDUSTRIAL REVOLUTION

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CONSUMERS, GLOBALIZATION AND THE END OF MASS PRODUCTION

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YALE UNIVERSITY PRESS
NEW HAVEN AND LONDON

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Set in Minion Pro by IDSUK (Data Connection) Ltd
Printed in Great Britain by TJ International Ltd, Padstow, Cornwall

Library of Congress Cataloging-in-Publication Data

Marsh, Peter, 1952
The new industrial revolution: consumers, globalization and the end of mass production / Peter Marsh.
p. cm.
ISBN 978-0-300-11777–6 (cl : alk. paper)
1. Industrialization—History—21st century. 2. Manufacturing industries—Technological innovations. 3. Consumption (Economics)—Social aspects. 4. Consumers' preferences. 5. Globalization—Economic aspects. I. Title.
HD2321.M237 2012
338—dc23

2012009769

A catalogue record for this book is available from the British Library.

10 9 8 7 6 5 4 3 2 1

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Preface

This book would have been impossible to write without the assistance of a great many people. Special thanks should be given to my colleagues at the *Financial Times*. For much of the time since I started working at the newspaper in 1983 I have covered the activities of industrial companies and technology researchers. The information I have acquired in thousands of conversations in 30 countries has provided a treasure trove of anecdotes and experiences that have provided an important framework for the book. Without my work at the *Financial Times* gaining access to these people would have been difficult, if not impossible.

Particular thanks are due to the four editors of the *Financial Times* during the time I have worked there. In their different ways Sir Geoffrey Owen, Sir Richard Lambert, Andrew Gowers and Lionel Barber have all been supportive. It is important to acknowledge those news organizations with the imagination and financial commitment to employ journalists keen to investigate how the world works. In this regard the *Financial Times* stands out.

Thanks also to Arthur Goodhart, my literary agent while the book was being conceived and written. In the late 1990s I talked to Arthur about a work on 'modern manufacturing'. I felt a comprehensive book on this topic had yet to be written, yet deserved to be and that I was in a good position to try to produce such a volume. As the book went through many changes, Arthur has been a great source of guidance. Without his contribution, the book would probably never have been written. Robert Baldock of Yale University Press, who at the outset had sufficient interest in the topic to ask me to write the book, has displayed considerable faith in my abilities to finish it.

People in many industrial companies and other organizations have provided me with what amounts to extended tutorials on different areas of manufacturing. I owe special thanks to Giovanni Arvedi, Mike Baunton, Daniel Collins, Eddie Davies, the late John Diebold, Wolfgang Eder, Sir Mike Gregory, Federico Mazzolari, Peter Marcus, Heinrich von Pierer, Hermann Simon, Martin Temple, the late Walter Stanners and Sir Alan Wood. My friend Peter Chatterton and my brother David Marsh have provided encouragement and support. Stephen Bayley, Bob Bischof, Steve Boorman, Andrew Cook, Gideon Franklin, Branko Moeys, Chris Rea and Hal Sirkin read all or part of the book and gave me useful feedback. On economic data I received much help from Prem Premakumar and Mark Killion at IHS Global Insight. For details of steel production going back to 1900, thanks to Steve Mackrell and Phil Hunt at the International Steel Statistics Bureau.

I gained useful guidance on economic trends throughout history from Bob Allen, Steve Broadberry, Kenneth Carlaw, Nick Crafts, Ruth Lea, Tim Leunig, Richard Lipsey, Joel Mokyr, Nathaniel Rosenberg, Bob Rowthorn, Andrew Sharpe, Eddy Szirmai and Tony Wrigley. Fridolin Krausmann was extremely helpful on data related to working out the environmental impact of manufacturing through its use of materials. Any errors and failures to draw the correct conclusions from the evidence of history are down to me. I owe much to the generosity of spirit of my wife Nikki and sons Christopher and Jonathan. They have put up with my discursions over the dinner table into the more obscure details of the world of making things and have even found some of them to be interesting.

Peter Marsh, London, April 2012

CHAPTER 1

The growth machine

In the beginning

> 'Gold is for the mistress – silver for the maid –
> Copper for the craftsman cunning at his trade.'
> 'Good!' said the Baron, sitting in his hall,
> 'But Iron – Cold Iron – is master of them all.'[1]

So wrote Rudyard Kipling, the celebrated English writer who – for much of his life – lived in the home of a seventeenth-century ironmaster. Kipling's words are as true today as they were when he was at the peak of his fame in the early 1900s and became the youngest ever person to receive the Nobel Prize for Literature. Since the beginning of civilization to 2011, the human race has created goods containing about 43 billion tonnes of iron.[2] Of this huge amount of metal, which has ended up in products from nuclear reactors to children's toys, almost half has been made since 1990. Most iron now used reaches its final form as steel, a tougher and stronger form of the metal containing traces of carbon.

Of the earth's mass of some 6,000 billion billion tonnes, about a third – so scientists estimate – is iron.[3] Most of it is too deeply buried to be accessible. Even so, there is enough iron available fairly close to the surface to keep the world's steel plants fed with raw materials for the next billion years, assuming 2011 rates of output.[4] Iron is almost always found as a compound. The most common are iron oxides, found in minerals such as hematite and magnetite. In these materials, iron and oxygen are linked in different combinations. To make iron from iron oxide requires a process called smelting. Smelting is what happens when minerals containing oxide-based ores are heated in a furnace with charcoal. In a chemical process called reduction, the charcoal combines with oxygen in the ore, producing carbon dioxide, and leaving the metal in a close to pure state.

Smelting has been known about for 5,000 years. It was originally useful in making copper and tin, the constituents of bronze. But it was a long time before anyone used smelting to make iron in large quantities. The reason for this lies in iron's chemical and physical characteristics. The temperature required for a smelting reaction is related to the melting point of the metal. Iron melts at 1,530 degrees centigrade, much higher than the equivalent temperature for copper or tin. Also, removing impurities, resulting from the presence in the ore of extraneous substances such as assorted clays and minerals, is more difficult in the case of iron than for other metals.

A breakthrough was made around 1200 BCE, probably either in or close to Mesopotamia – the name then for the region loosely centred on modern Iraq. Methods were devised to keep furnaces hot enough – probably at about 1,200 degrees centigrade – to make the iron smelting process work.[5] Furthermore, better processes were developed for separating out the impurities – called 'slag' – through pounding with a hammer. The developments were quickly replicated in many areas around the eastern Mediterranean. As iron became easier to make, more of it became available. This led to its price falling, by about 97 per cent in the 400 years to 1000 BCE.[6]

Steel was discovered at around the same time. It is a 'Goldilocks' material – the amount of carbon and other elements in the mix for a specific use has to be neither too much, nor too little, but just right. It was found that iron mixed with too little carbon gave a material that was quite soft, but could be shaped fairly easily. If the carbon concentration was too high, the metal was harder but brittle. In current terminology, iron with a small proportion of carbon (below 0.5 per cent) is called wrought iron.

When the amount of carbon is fairly high (above about 1.5 per cent), the result is pig (or cast) iron. Steel is not a single alloy but a range of variants on iron, with properties dependent on its chemistry. In steelworks today, adding small, specified quantities of elements such as vanadium, chromium and nickel is very important. Such switches in composition change the properties of the steel, for instance making it more corrosion-resistant, or better at conducting electricity. The period that started in around 1200 BCE is called the Iron Age. Historians generally regard it as having run its course after about 1,300 years. In truth, however, the Iron Age has never really ended.[7]

In early times, to define the composition of steel accurately was close to impossible. For all aspects of iron- and steel-making, progress was slow and empirical. However, for more than 1,000 years, one country – China – stood out as the leader in steel-making. China was well ahead in producing so-called blast furnaces – which employed bellows to blow in the air needed for smelting, using pistons driven by water power. The country knew how to build blast furnaces as early as 200 BCE, or 1,600 years ahead of Europe. For most of the Middle Ages, China's iron production was well ahead of Europe's, both in total output and on a per capita basis. But by the late seventeenth century, Britain was emerging as the place where the key events in iron- and steel-making would occur.[8]

Forging ahead

At the centre of the changes was Sheffield, a city in northern England. It had the benefit of proximity to three sets of natural resources. The hills of the Pennines provided convenient sources of iron ore. The River Don flowing through the city provided a source of water power for blast furnaces. The city was also adjacent to large coalfields. Coal had by now replaced charcoal as the vital reducing agent for smelting.

Benjamin Huntsman was a locksmith and clockmaker, originally from Doncaster, who moved to Handsworth, a village near Sheffield, in 1740. He was initially less interested in making iron and steel than in using it in his products. But after becoming dissatisfied with the quality of the steel then available, he decided to try to find a new way to make the metal.[9]

Huntsman tackled the two critical issues that had confronted the iron-makers of Mesopotamia: increasing the temperature, and influencing the composition of an iron/carbon/slag mix.

Huntsman's advance was built around the design of special clay pots or crucibles capable of being heated to about 1,600 degrees centigrade without cracking or losing shape. A hot iron/carbon mixture, from a blast furnace, was poured into the crucible, together with small amounts of other materials – including some fragments of good-quality so-called blister steel. Impurities could be drained out through holes in the base of the crucible. The rate at which different substances were added or removed controlled the rate of formation of steel, and also its properties. Huntsman started using this 'crucible process' in about 1742. There were some drawbacks. The technology made steel in small quantities, suitable for such items as tools, cutlery and components for watches and clocks. It was a 'secondary' process: it relied on some small amounts of previously made blister steel if it was to work. Yet the procedure was repeatable: it followed a prescribed route that could be operated many times. Huntsman's was one of the first such techniques used in any industry. Even though it took more than a century for anyone to effect a real improvement on Huntsman's ideas by combining product quality with high speed, the technique pointed the way forward.

Huntsman's advance came when Britain had only a small share of world manufacturing. In 1750, the leader in global manufacturing was China, responsible for a third of output,[10] followed by India, with a quarter. The leading country in Europe was Russia, with 5 per cent of the world total, followed by France. The share for Britain and Ireland of 1.9 per cent resulted in a lowly tenth position in the league table.[11] But change was on the way.[12] In 1769, the Scottish engineer James Watt patented another 'big idea', not in materials but in providing power.[13] Improving on earlier designs, Watt invented a steam engine, useful both for pumping water from mines and for driving machinery. The steam engine is now regarded as one of the best examples of a 'general purpose technology':[14] a specific technology capable of extremely wide application, plus the ability to be improved on. The advent of Watt's engine fitted in with other key events that influenced industrial progress. 'About 1760, a wave of gadgets swept over England' was how one historian described the changes.[15] The manufacturing-related 'gadgets' included new machines for use in textiles and metals production.[16] Meanwhile, the advances in technology coincided with other changes more connected to society and economics. They included the first efforts to organize factories on a large scale; an increasing population, which was also healthier and better educated; the opening up of world trade; and the birth of joint stock companies that helped to encourage entrepreneurship.

As a result of these changes, between 1700 and 1890 the proportion of the British workforce employed in industry rose from 22 per cent to 43 per cent, while the comparable figure for agriculture declined from 56 per cent to 16 per cent.[17] In Britain and Ireland, manufacturing output per person rose eightfold between 1750 and 1860, four times as much as in France and Germany, and six times as much as in Italy and Russia. In China and India, manufacturing output per person fell. In 1800, Britain accounted for just over 4 per cent of world manufacturing production, making it the world's fourth biggest industrial power, behind China, India and Russia. But by 1860 it had become the largest in manufacturing output, accounting for almost 20 per cent of the world total, just ahead of China. The United States was in third place, with nearly 15 per cent.[18]

In Britain, manufacturing became part of the language. The word is derived from the Latin *manus* meaning 'hand', and *facio*, meaning 'to do'. While it was first recorded in around 1560, its use was rare. Shakespeare, who died in 1616, used neither 'manufacturing' nor 'factory' in any of his plays.[19] But from around 1800 the word became commonplace.[20] The seven decades of change from roughly 1780 to 1850 added up to the first age of manufacturing organized on a large scale, and was concentrated in Britain. It came to be known as the first industrial revolution, usually called *the* Industrial Revolution.[21] Of all the events that shaped the world in the final 500 years of the second millennium, the Industrial Revolution was the most important.

Bridges to the future

Charles Babbage was a child of this period of change. Born in London in 1791, Babbage spent much of his childhood in Totnes, a small town in

Devon. After studying mathematics at Cambridge University, he became a fellow of the Royal Society at the age of 24. In a paper in 1822, Babbage described a calculating machine called a difference engine. The design of the machine involved several mechanical columns that could each move a series of wheels. Through a system of levers and gears, the wheels and columns could be manipulated so as to perform calculations. Babbage tried to build a working version of the machine but such was its complexity that he found the task beyond him.[22] Undaunted, he began the development of an even more advanced calculating machine that he called the analytical engine. Since the analytical engine was intended to be a 'universal computing device', capable of performing an extremely wide range of tasks depending on how it was programmed, the machine is often considered the forerunner of the modern computer. But like the difference engine, the analytical engine was not built in Babbage's lifetime. Both machines were too complicated for the engineering capabilities of the day. Babbage also found time to write one of the first treatises on manufacturing. In *On the Economy of Machinery and Manufactures*, published in 1832, he commented that behind every successful manufactured item was 'a series of failures, which have gradually led the way to excellence'.[23]

Sir Henry Bessemer would have agreed with this observation. But due to his greater practical skills, Bessemer was more likely than Babbage to make a success of theoretical ideas, by getting the engineering right. Born in a village near London in 1813, Bessemer followed the career of an inventor, working on novel printing systems, fraud-proof dies for stamping government documents, and processes to make high-value velvet for the textiles industry. He wrote of his approach: 'I had no fixed ideas, derived from long-established practice, to control and bias my mind, and did not suffer from the general belief that whatever is, is right.'[24]

Bessemer's biggest challenge came in the 1850s, the time of the Crimean War. He had been encouraged by Napoleon III, an ally of Britain at the time, to work on new types of cannon. Military engineers had found they could control the trajectory of shells more easily by 'spinning' them in the barrels of guns. But the spiralling motion of the projectiles added extra stresses, which were likely to make the gun shatter as it was fired. Iron needed replacing with a higher-strength material. Steel was the obvious choice. However, if it was to be used, Bessemer realized he would have to find an improved method of manufacturing the metal.[25]

Since Huntsman's day, Britain had become the world leader in steel-making. Out of the 70,000 tonnes made in 1850, Britain was responsible for 70 per cent, with Sheffield alone making half the global total.[26] Most of this steel was produced by a laborious process called 'puddling' – invented in 1768 by Henry Cort, a Hampshire ironmonger. This involved converting pig iron into wrought iron by removing carbon from a hot mix of metal, carbon and various impurities. It required a skilled, and strong, worker who had to continually stir the mixture with a metal rod. Then more carbon had to be added in the form of charcoal to create the correct form of steel alloy. Puddling was in a sense a side-step from the Huntsman technique. It was a way to make steel in larger quantities than the crucible method – albeit no more than about 30 kilograms at a time – but it had many shortcomings. As Bessemer wrote in his autobiography, 'at that date [the early 1850s] there was no steel suitable for structural purposes [capable of being made into large sections] . . . The process was long and costly.'[27]

Bessemer set out to make steel from pig iron in a single step. He did this by blowing cool air into the molten pig iron. The oxygen in the air mopped up some (but not all) of the carbon atoms present in the pig iron, by converting them into carbon dioxide, leaving behind steel. Because the reaction produced heat, the temperature rose as more air was blown in, so adding to the efficiency of the process. In 1856, Bessemer published the details in a paper given to the British Association. The new process used 'powerful machinery whereby a great deal of labour will be saved, and the [steelmaking] process [will] be greatly expedited'. He added that the Bessemer process would bring about a 'perfect revolution . . . in every iron-making district in the world'.[28]

In 1859, Bessemer chose Sheffield for the world's first steelworks based on 'converter' technology. The plant was a success. He licensed his ideas to metals entrepreneurs in both Britain and other countries. Bessemer's ideas were also improved on. The Siemens-Martin 'open hearth' process, introduced in 1865, led to closer control of the steel-making reactions, leading to a better-quality product.[29] Andrew Carnegie, the Scottish-born US industrialist, was among those influenced by Bessemer's thinking.

After emigrating to the US in 1848 when he was 13, Carnegie immediately gained work as a 'bobbin boy' – bringing raw material to the production line in a cotton works. After deciding to go into business for himself, Carnegie started manufacturing bridges, locomotives and rails, an activity that took him into steel-making. Having met Bessemer on a visit to England in 1868, Carnegie introduced Bessemer converter technology into the US soon afterwards. By 1899, his Pittsburgh-based Carnegie Steel was the biggest steel producer in the world, with an output in that year of 2.6 million tonnes.[30] (Two years later, Carnegie sold his company to J. P. Morgan for $400 million, creating US Steel, and making him the world's richest person.) Because Bessemer's technology, aided by complementary advances, made it possible to produce steel more quickly and easily, its price fell by 86 per cent in the 40 years to 1900. In 1900, world output of steel was 28.3 million tonnes, 400 times higher than half a century earlier.[31]

Global manufacturing production expanded considerably faster in the final 20 years of the nineteenth century, when the benefits of cheap steel were being fully felt, than in earlier periods. World industrial output climbed 67 per cent between 1880 and 1900, as compared to 42 per cent in the two decades prior to this, and just 22 per cent in the 1830–60 period. One consequence of the rate of global expansion was that the UK lost its position as the world's leading manufacturer. By 1900, the US took over, with nearly 24 per cent of world output, compared to the UK with 18.5 per cent, and Germany with 13.2 per cent.[32] Britain's role as the 'workshop of the world' had lasted for only 40 years. (By the end of the nineteenth century, the UK had also fallen from being the biggest steel-maker to number three, behind the US and Germany.)[33]

Among the factors behind the wider economic changes, one of the most important was cheap steel. It made possible new and improved products, from cars and farm equipment to steel-framed buildings. Machinery made from steel enabled higher output of other products such as chemicals, textiles and paper. In a final effect, use of all these products boosted growth in other, non-manufacturing parts of the economy, such as retailing, travel, banking and agriculture. In this way, cheap steel acted as a 'growth catalyst' for the world economy.[34]

History's curve

The evolution of the steel industry is a specific example of a general rule of manufacturing: as experience in making a product increases, its cost goes down, while its quality (or sophistication) goes up. Another way to depict the rule is to talk about the 'experience' or 'learning' curve. As more affordable and better products become available, their impact on the rest of the economy becomes greater. While engineers tend to be most interested in how products are made, what really counts is how they are used.

Since the Industrial Revolution, there have been three similar eras. The 'transport revolution', which took place from approximately 1840 to 1890, is regarded as the second industrial revolution.[35] Overlapping slightly with the Industrial Revolution, the period was marked by new machines for transportation, including the steam-driven railway locomotive and the iron- or steel-hulled ship. The changes cut travel times both for people and for goods, boosting trade and the exchange of information. The key to their economic impact was not just their invention, but the fact that over time they improved, so generating more growth in the wider economy. Faster railway engines that broke down less often are an example. The products helped whole industries to expand, in both manufacturing and services.

The transport revolution was followed by – or merged with – the 'science revolution' which occurred between 1860 and 1930. Cheap steel was one product from this time. Others include the steam turbine, the electric motor and the internal combustion engine, together with a range of items made by new chemicals and materials industries, ranging from dyes to aluminium.[36] All these products appeared as a result of various bursts of innovation. But the processes that led to their availability did not end there. New knowledge was acquired which continued to have an impact on how the products were made, and influenced their characteristics.

Theodore Paul Wright, an engineer working at the Curtiss-Wright aircraft company in New York during the 1930s, was the first person to analyse in detail the relationship between production volumes, manufacturing capabilities and costs.[37] In 1936, Wright examined the impact on aircraft production of specific factors such as new designs, better materials and improved machining processes. The fact that more and better-quality aircraft could be built with improved production techniques was not surprising. What was more interesting was the finding that the best way to improve manufacturing capabilities was to increase output.[38]

As a result of more time spent doing something, technical prowess was more or less guaranteed to improve. Along the way costs would fall, while quality would rise. Wright discovered that every time aircraft output doubled, the costs of making a single unit declined 20 per cent. It was the first detailed evidence that the experience curve worked in real life. If manufacturers could make this work for a variety of other products, they could cut prices in line with costs, so outselling competitors and boosting market share and profitability. If at the same time product sophistication also increased, so much the better. Bruce Henderson, a US engineer and former Bible salesman, grasped the implications. In 1963, Henderson set up the Boston Consulting Group. He and his colleagues produced a range of studies showing that the experience curve worked for many industries apart from aircraft. 'It seems clear', Henderson wrote in 1972, 'that a large proportion of business success and failure [in manufacturing] can be explained simply in terms of experience curve effects.'[39]

Another person who understood the connections was Vannevar Bush. An electrical engineer and former maths teacher, Bush was in 1941 appointed the first director of the US's Office of Scientific Research and Development. In a 1945 paper describing the manufacture of radios, Bush illustrated how the experience curve worked.

> Machines with interchangeable parts can now be constructed with great economy of effort . . . [A radio set] is made by the hundred million, tossed about in packages, plugged into sockets – and it works! Its gossamer parts, the precise location and alignment involved in its construction would have occupied a master craftsman of the guild for months; now it is built for thirty cents. The world has arrived at an age of cheap, complex devices of great reliability; and something is bound to come of it.[40]

After Babbage

One of the projects financed by Bush's office was a computer development programme at the University of Pennsylvania's of Moore School of Electrical Engineering. Out of this emerged the Electronic Numerical Integrator Analyser and Computer (Eniac). It was created by John Mauchly and J. Presper Eckert, two of the school's top theoreticians. The Eniac – unveiled in 1946 – was the first general-purpose electronic computer, a modern version of Babbage's analytical engine. Mauchly and Eckert took more than two years to design and build the machine. The Eniac contained 17,468 thermionic valves or vacuum tubes, 70,000 resistors, 10,000 capacitors, 1,500 relays, 6,000 manual switches and 5 million soldered joints. It covered 167 square metres of floor space, weighed 30 tonnes and consumed 160 kilowatts of electricity. The machine was used primarily for military projects related to the 'cold war'. It worked out the trajectories of ballistic missiles, as well as calculations needed for the hydrogen bomb. In one second, the Eniac could perform 5,000 mathematical calculations, 1,000 times more than any previous machine.[41] In 2010 prices, the Eniac cost $6 million.[42]

While the building of Eniac was a breakthrough, an even bigger advance was soon to follow. Semiconductors are electronic devices in which many single components capable of acting as electric 'switches' are packed onto a small piece of material. The basic job of each component is either to let electricity through, or block it, with its exact behaviour governed by electronic instructions fed via a software program. By being either 'on' or 'off', the switch can handle the digital language of computer code. The reason these devices have their name is that they are built from materials such as silicon or germanium which can either behave as an insulator or a conductor as regards electricity flow – hence *semi*conductor.

In 1947, the world's first semiconductor device was invented. It was a particularly simple form of semiconductor called a transistor, equivalent to a single electrical 'switch' embedded in a piece of germanium. (Silicon became the preferred material for semiconductors a few years later.) Transistors became prime candidates to replace the valves used to perform calculations in early computers such as the Eniac. However, semiconductors were never going to be hugely useful if each contained just one component. What made them of greater interest was the integrated circuit: a semiconductor device capable of having more than one switch embedded in it. The world's first integrated circuit – a piece of germanium containing two circuits – was described in February 1959 in a patent filed by Jack Kilby of the US electronics company Texas Instruments.

Helped by the growing use of semiconductors, the number of computers in the US rose from 250 in 1955 to nearly 70,000 by 1968.[43] Transistors were still expensive. But as engineers learned how to squeeze more circuits on to a small 'chip' of material, the capabilities of semiconductors increased. Also, in step with extra expertise gained with greater experience, prices fell. This was illustrated by the unveiling in 1971 of the first microprocessor: a collection of circuits on a chip capable of performing like a fully fledged 'central processing unit' of a computer. Made by Intel, the first microprocessor – called the 4004 – contained 2,200 transistors. Weighted by the amount of computing power that it contained, the 4004 had a price 95 per cent lower than that of a comparable semiconductor chip of four years earlier.

Over the next 40 years, semiconductor companies spent tens of billions of dollars building ever more sophisticated factories, containing equipment capable of cramming more 'transistor equivalents' on to the same small area of silicon. In this effort, the semiconductor industry proved the veracity of 'Moore's law'.[44] In 1975, Gordon Moore, one of Intel's co-founders, predicted that the number of transistors per semiconductor would double every two years. He assumed costs would also fall at a corresponding rate. In 2010, an Intel X3370 microprocessor, containing 820 million transistors, sold for just over $300. The value of each transistor in the device was roughly 1/30,000th of a cent. In just over 60 years, the price of a transistor had fallen by a factor of 30 million. Moore's law has turned out to be largely correct, providing more evidence of the validity of the experience curve.

The huge reduction in prices of silicon-embedded electronic circuitry fuelled an explosion in the use of computers. This drove on the so-called 'computer revolution' that took place from 1950 to 2000, the fourth big period of change sparked by manufacturing. According to one estimate, in 1946 the world contained just 10 computers, counting machines roughly comparable to the Eniac. In 2010, the world contained about 2 billion computers, counting desktop and portable machines, plus other computing devices such as 'smart phones' and computerized switching systems that are part of telecommunications networks. On the basis of these numbers, the 'stock' of computers had risen by 200 million in less than 70 years. A standard personal computer in 2010 could handle 3 billion instructions a second, 600,000 more than the Eniac. It sold for about $650, or 1/17,000th of the price of the first machine of its type.

The invitation

On Friday, 13 January 2006, Lakshmi Mittal held a small dinner party in London.[45] A steel industry entrepreneur and chief executive of Mittal Steel, Mittal was one of the world's wealthiest men. His main guest was Guy Dollé, chief executive of Luxembourg-based Arcelor. The setting was Mittal's neo-Palladian mansion in Kensington, which the Indian billionaire had bought in 2004 for £57 million from the motor racing magnate Bernie Ecclestone.

While industry rivals, Mittal and Dollé shared an all-consuming interest in the steel industry and the products it made possible. A former amateur footballer, the fiercely competitive Dollé had worked his way to the top of Arcelor in a smooth progression from engineering jobs to senior management.[46] Arcelor had resulted from the 2001 combination of three leading steel-makers based in France, Luxembourg and Spain, and was regarded as a jewel of European industry. Mittal grew up in Rajasthan in north-west India. For much of his early life, he lived in a house with bare concrete floors and no electricity. Mittal's first foray into the steel industry came in childhood. During breaks in the school holidays, he worked in a small steel plant run by his father in Calcutta. In the 1970s, Mittal set up a steelworks in Indonesia, using his father's money. Then came a series of acquisitions in countries including Trinidad and Tobago, Mexico, Kazakhstan and Romania.[47] In 2004, he announced the $4.5 billion purchase of International Steel Group, a US steel supplier. The deal made Mittal Steel the world's biggest steel-maker, inching ahead of Arcelor. To mark the occasion, Dollé sent him a note of congratulation.[48]

Over pre-dinner drinks, Mittal let slip what lay behind his invitation. He asked Dollé if he would agree to a merger between their two companies. That was how he put it anyway. What he meant was that he wanted to acquire Arcelor and integrate the two businesses, with Mittal firmly in control. 'If we linked up, we could accomplish many of the things that we both want, but we'd be on the same side,' Mittal said. 'Why don't we do it?' There was some logic to the idea. Uniting Mittal Steel with Arcelor would create a giant company with more than 300,000 employees, making steel on five continents. It would account for close to 10 per cent of global steel production, and have an annual output three times greater than its closest rival.[49]

Control over such a large part of the market would allow a merged company to dictate terms to customers, keeping prices and profits high. It would also be able to pool knowledge about the best steel-making techniques, and use its buying power to push down prices of raw materials when negotiating with suppliers of iron ore and coal. Mittal was especially keen to take over Arcelor's technologically advanced, albeit high-cost, factories in Western Europe. The plants had good relationships with many key customers, particularly in the car industry. There could be special benefits through linking these facilities with the units run by Mittal Steel in such places as Central Asia, Latin America and Eastern Europe. The two sets of plants had different attributes – the first operating at the top level of technology, the second making more basic kinds of steel with the help of low costs – and so could learn from each other. A combined company would be in a better position to fight the challenges facing the steel industry in the growing effort to reduce emissions of carbon dioxide – of which steel-making is one of the biggest producers – as part of broader moves to combat environmental threats. It would also have a potentially stronger role in carving out a leadership position in the 'emerging' regions of China, India and Brazil. But the words that Mittal might have conveyed to Dollé to express why a merger was a good idea went unsaid. The Frenchman quickly killed any discussion with a terse rejoinder: 'I'm not interested.' Dollé was keen to strengthen his company, but on his own terms, not Mittal's. He was not sure he could work jointly with Mittal. Dollé also suspected that fitting together two companies with such differing patterns of plants and corporate structure might lead to insoluble stresses.

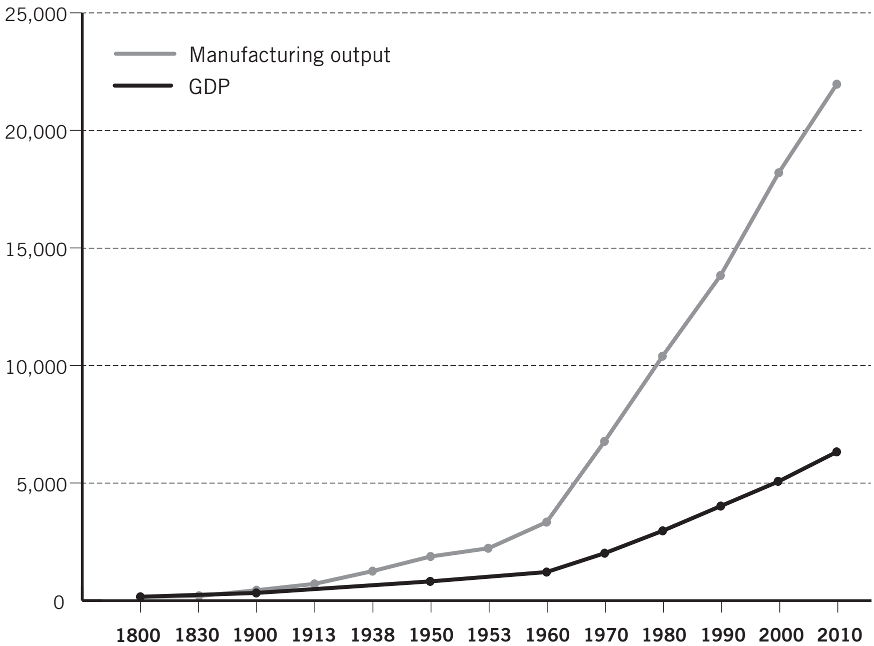
The talk at the dinner moved on to less controversial topics, and the evening ended amicably enough. But two weeks later, Mittal – unmoved by Dollé's opposition – went public with his plan, unveiling an unsolicited $22.5 billion takeover offer for Arcelor. What followed was a bitter, five-month fight.[50] It was marked by relentless sparring between the two companies, political interventions by several European governments, plus a series of orchestrated moves by each company's investment banking teams to sway shareholders. Throughout the battle, Dollé kept up a barrage of invective against his rival, with Mittal generally trying to occupy the higher moral ground by insisting a merged company would be good for its workers and the communities where they lived, as well as shareholders. Ultimately, Mittal raised his bid to $33.6 billion, some 50 per cent above his original offer. Money talked, and on 25 June, with Dollé still opposing the deal, the Arcelor board accepted.[51]

The shape of the future

Having fought the takeover with such ferocity, Dollé could hardly accept Mittal's offer of a job in the new company. Within a few days of the deal's conclusion, the Frenchman announced his retirement. Taking over at the helm of ArcelorMittal, as the merged company was called, Mittal now had the chance to reflect on what lay ahead. As president and main shareholder, he was in a strong position.

For all the talk about the world moving into a 'post-industrial' age, factories in the early twenty-first century are turning out considerably more goods than ever before. In 2010, manufacturing output was roughly one and a half times higher than in 1990, 57 times above what it had been in 1900, and 200 times in excess of the output in 1800 (see Figure 1). Between 1800 and 2010, world manufacturing output rose by an average of 2.6 per cent a year, as against the comparable 2 per cent annual increase in gross domestic product – measuring the productive effort of the entire global economy – over the same period. The average annual rate of growth of manufacturing output between 2000 and 2010 was 1.8 per cent, a figure

Figure 1 World manufacturing output and GDP, 1800–2010
(output measured as an index where 1800 = 100)



Notes: manufacturing output calculated in value-added; both sets of data use constant 2005 dollars.

Sources: P. Bairoch (as quoted in Paul Kennedy, *The Rise and Fall of the Great Powers*), IHS Global Insight, World Trade Organization, 2011 Annual Report (http://www.wto.org/english/res_e/statis_e/its2011_e/its11_appendix_e.pdf), UN data base, Maddison, *The World Economy Historical Statistics*, author's estimates.

that appears considerable, given the slump that much of the world's factory production suffered during the deep economic recession of 2008–9. Allowing for inflation, the selling price for steel in 2010 was 25 per cent lower than a century previously, following a period in which production had risen more than fortyfold.[52] This record indicates that the experience curve is working, at least for steel. All the signs are that this will continue for other products as well.

Across manufacturing, technology – the application of science to industry – is playing an ever bigger role. In the nineteenth and early twentieth centuries, changes in manufacturing had been driven by developments in a relatively small number of technologies, including steam power, metalworking, electricity generation and chemicals. In the twenty-first century, the number of technologies exerting an impact on manufacturing has expanded. The list now includes electronics, biotechnology, the internet and lasers, with many subdisciplines within these main areas. Meanwhile, the pace of change in these different fields is increasing, as a result of more scientists and engineers, and more money being directed by governments and companies to research and development. Also technology is being treated as a *system* of ideas in which advances in disparate fields are capable of being linked to create a wider variety of new products and processes, in fields from medical hardware to consumer electronics.

Another change concerns the general characteristics of products. In the past, manufacturers concentrated on making goods to meet a broad range of requirements, within the boundaries of keeping quality high and prices reasonably low. The idea of 'bespoke' manufacturing – creating different products to satisfy individual tastes – was regarded as being outside the province of most companies. Now, driven by the demands of consumers, plus shifts in technology that make it easier to accommodate their requirements, the idea of tailoring products to suit different needs is becoming more central.

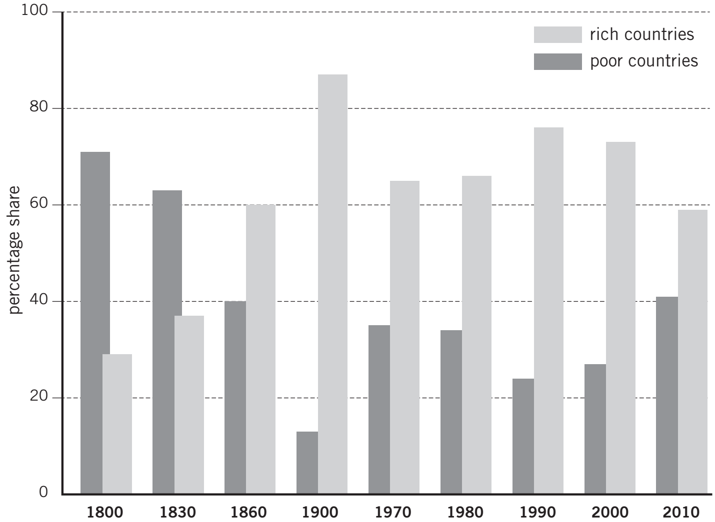
What constitutes a successful manufacturer is also being redefined. Up to about 1990, production was considered by far the most important part of the work of a manufacturing business. Parcelling this out for other companies to take care of was rarely contemplated. But in the early years of the twenty-first century, the realization grew that making products is just one part of the 'value chain' of company operations. Others include design and development, and the way products are maintained or 'serviced' after installation. To be considered a great manufacturer, companies do not now need to make anything, even though they will almost certainly know a lot about what this entails. Increasingly, elements of the value chain are being left to a variety of businesses in different countries. The management of this mix is becoming a highly prized skill.

In many product areas, opportunities are opening up as a result of convergence of technological changes, globalization and the use of the internet as a marketing tool. These have provided the basis for new 'niche industries' – sectors that concentrate on narrow types of products, often aimed at small groups of customers around the world. The companies that supply goods in these niches are frequently barely known. Yet in many cases, they are expanding sales and profits quickly, and exerting an increasing influence on people's lives, even in ways that are largely invisible.

In a further broad trend, the concept of 'sustainable manufacturing' is becoming critical. Driven by concerns about global warming and materials depletion, the world has become more aware of the environmental damage caused by humankind's activities, many of them linked to manufacturing. As a result, there is more interest in making manufacturing processes less environmentally damaging, and creating new products that help to reduce use of materials and energy. From being considered a key cause of the world's environmental ills, production industries are increasingly viewed as part of the possible solution.

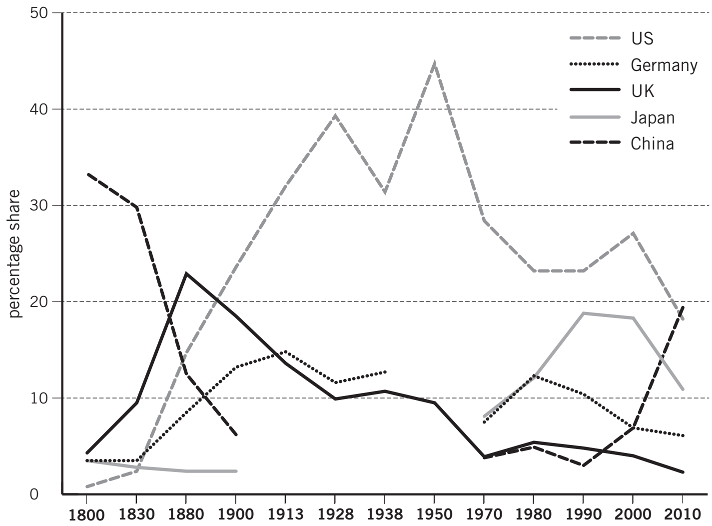
Meanwhile the most important locations for industrial production are broadening out. The list of 'manufacturing-capable' countries is now much longer than the limited number that had a role in the four industrial revolutions to date. In 2010, the proportion of world manufacturing that took place outside the conventionally defined 'developed' nations reached 41 per cent, compared with 27 per cent in 2000 and 24 per cent in 1990 (see Figure 2).[53] The list of 'emerging' economies is headed by China.[54] After staying on the sidelines of global manufacturing for 150 years, China started to catch up in the 1990s. The rate of growth was such that in 2010 China reclaimed the position of the world's biggest manufacturing country by output, overtaking the US which had been the number one for more than a century.[55] Other nations that for most of the twentieth century had only a minor impact on global industry also began to make their presence felt. Among such countries are India, Brazil, South Korea and Russia. Even with the increasing role of these fast-expanding economies, there remain many opportunities for companies located in the main developed countries. Many of these businesses are part of 'clusters' of enterprises that operate in the same industry and are based in the same small area. Even in a world of dispersed value chains in manufacturing there remains a place for companies that stress local linkages.

Figure 2 Shares of world manufacturing since 1800
a) Showing the split between rich and poor countries
(calculated as value-added in 2005 dollars.)



Notes: Rich countries are N. America, W. Europe, Japan, Australia. Poor countries are all those that are not rich. Japan is counted as "poor" until 1970; rich after 1970. Russia is counted as rich until this date; poor afterwards.

b) For five leading nations



Sources: P. Bairoch, 'International Industrialisation Levels from 1750 to 1980'; IHS Global Insight, 'Global manufacturing output data 1980–2010'; UN, Stephen Broadberry, *The Productivity Race*.

These features – covering technology, choice, value chains, niches, the environment, the new manufacturing nations and clusters – are all important. But their biggest impact is in the way they are becoming increasingly intertwined. The results will be a mix of opportunities and threats. They will be apparent not only to powerful industrialists such as Mittal but to people running much smaller production businesses in virtually every sector. The resulting shifts will be felt by just about everyone. Picking apart what is likely to happen will not be easy. But of the magnitude of the changes there is little doubt. A new industrial revolution has begun.

CHAPTER 2

The power of technology

Role play

In 1685, Louis XIV – the Sun King – granted permission to the Marquis Charles Henri Gaspard de Lénoncourt to construct an ironworks at Dillingen, a village near Saarlouis in what was then a corner of eastern France.[1] The plant produced raw iron together with finished products such as ovens and chimney plates – and also small amounts of steel, made in a labour-intensive refining process. Over the following century, the works gradually improved its technology, in particular with the introduction of better methods to specify the mix of iron and carbon in steel to improve quality.

In the late 1700s, new processes in the technology of 'steel rolling' were developed in Britain. These involved passing relatively thick sections of steel between rotating metal blocks to make thinner sheets, giving a wider range of applications. In 1804 the Dillingen mill became one of the first in continental Europe to use rolling on a commercial scale, for instance to make metal plates for shipbuilding. By the early twenty-first century Dillingen was part of Germany – following multiple changes of jurisdiction as this corner of Europe was swapped between Germany and France. The works were now run by Dillinger Hütte,[2] a company in which Arcelor had a 51 per cent stake, with smaller shareholdings owned by German investors. Building on its technological strengths of the previous 300 years, Dillinger Hütte was one of the biggest companies in the world making heavy steel plate for oil and gas pipelines, earth-moving equipment and bridges. One of its key strengths was its sophisticated rolling technology, used to make plate to tolerances of less than a millimetre.

When Lakshmi Mittal acquired Arcelor in 2006, his new business became, almost by accident, the majority owner of Dillinger Hütte. In the excitement of the bid battle, the steel magnate had given the Dillingen-based company little thought. But as Mittal got on with the job of making the merger work, he paid Dillinger Hütte more attention. If he could integrate it properly into ArcelorMittal, the Indian billionaire would have access to Dillinger Hütte's strengths in plate-making technology that could be useful in other parts of his business. The expertise would help to counter JFE and Nippon Steel – two large Japanese steel-makers which are also leaders in steel plate and strong competitors in new markets in Asia.

But there was a snag. To exert maximum influence over Dillinger Hütte, Mittal had to boost ArcelorMittal's stake to above 70 per cent. This followed from an obscure part of its constitution stipulating that a shareholder could take management control only if its stake reached this level. During 2007 and early 2008, Mittal held secret talks with the other large shareholder in Dillinger to see if it would sell some of its stake. The investor was a private trust with strong links to the federal state of Saarland where Dillinger Hütte is based. The Saarland politicians and business people who controlled the trust were extremely cool. Outright acquisition by ArcelorMittal would leave Dillinger playing a peripheral role in a sprawling global empire, its best technology used elsewhere. Mittal indicated he would pay at least $1 billion for the shares he needed. 'Of course ArcelorMittal would gain from this, but so would your company – it would become part of a much bigger business, providing a solid platform for growth,' he told the trust.[3]

But on this occasion Mittal's persuasive manner – and the promise of a lot of money – failed to carry the day. Late in 2008, Mittal abandoned the effort to take control of the company. As one of Mittal's aides commented: 'This was a battle that was not just about money.' The fight over Dillinger Hütte had essentially been about the control of technology. The outcome denied Mittal access to a prized stock of practical knowledge, and damaged his reputation for deal-making. In a wider sense, the affair illustrated the power of technology to influence manufacturing. Dillinger Hütte's history also underlines the idea that technology – in whatever product area – rarely stands still. While individual technologies are improved, they also combine with others to make existing products more useful, and to make new ones possible. In the new industrial revolution, there is more technology available, and the possibilities for using it are increasing.

A switch in time

If you ask Eddie Davies how he became wealthy, he will hand you some small, circular pieces of metal, each the size of a Polo mint. Like the mint, they are roughly 1 centimetre in diameter, and have a hole in the middle. Where they differ is that they have a small 'tongue' protruding into the hole from the solid rim. In 2005, Davies made $160 million from the sale of the company that produces these metal objects.[4] Davies shares with Mittal a strong interest in football. While Davies owns Bolton Wanderers, a club with an illustrious pedigree that is one of the oldest members of the UK's premier league, Mittal is a large minority shareholder in Queens Park Rangers, a London club that won promotion to the premiership in 2011. Both men are also fascinated by metals technology. In the Englishman's case, the interest is reflected in his collection of Japanese cloisonné, a delicate form of enamelware. Less obviously attractive than Davies's prized enamel, the Polo-like metal pieces on which he has based his career each weigh only half a gram. Known as 'blades', they are vital parts of electric kettles. They act as 'fail-safe' devices to ensure kettles can be used without boiling dry and catching fire. Every day, an estimated 1 billion people use a kettle that contains one of Davies's blades. Strix, the company that makes them, is based on the Isle of Man, off the north-west coast of England.

In the 1970s, kettles were used predominantly for tea-making. But now someone is just as likely to buy a kettle – perhaps in China or Russia – to boil water to make soup or coffee as for a cup of tea. Two of every three of the 80 million kettles made in 2009 incorporated at least one control device made by Strix. Kettles are produced mainly from plastic rather than steel (the material favoured in the 1990s), which has made them more attractive, and cheaper. Helping further to reduce prices was the migration between the mid-1980s and 2010 of 85 per cent of the world's kettle production to China.

The blades in Strix's kettle controls are produced from layers of different metal alloys, built up in a 'sandwich' structure by being rolled together using versions of the machines operated by Dillinger Hütte. Strix goes to some lengths to protect its technical secrets. The alloys contain a range of metals, among them iron, copper, nickel and chromium. But the precise identity of the ingredients in the strips, and the combination in which they are formulated, are not disclosed in any of the 500 patents Strix has published on kettle controls. Neither are these details divulged to anyone other than trusted partners in its manufacturing processes. In 2009, Strix needed about 200 tonnes of strip, supplied by Kanthal, a Swedish company, and others around Europe. The strip is shipped to a small Strix factory in Ramsey, on the Isle of Man. Here, the metal is converted into blades using special stamping machines. The blades are then sent to other Strix factories – the main one being in China – where they are assembled into control units that form part of kettles.

Strix has based its business not just on knowledge of materials. Control of movement plays a big part, as does management of energy. As different materials heat up, they expand at different rates. A layered arrangement of two metals is known as a 'bi-metallic' strip, while one with three layers is a 'tri-metallic' strip. In such a product, the interplay between the constituents in the sandwich will determine what happens to the piece of metal as a whole. By choosing specific types of metal that change their shape in particular ways when heated or cooled, Strix's engineers have devised a series of bi-metallic (and also tri-metallic) switches that behave as electrical switches.

In the manufacturing process, the blades are made slightly curved, so they are bulging outwards. But when the water in the kettle reaches boiling point at close to 100 degrees centigrade, the blade changes shape, so the curve faces inwards. This sudden 'snapping' action takes place in a matter of microseconds. The movement of about 2.5 millimetres pushes a small rod out of contact with the source of electrical power, breaking the supply and preventing the possibility of overheating. If the same energy