ECN 110B, Spring 2005
World Economic History
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2. The British Industrial Revolution, 1760-1860

In the eighty years or so after 1780 the population of Britain nearly tripled, the towns of Liverpool and Manchester became gigantic cities, the average income of the population more than doubled, the share of farming fell from just under half to just under one-fifth of the nations output, and the making of textiles and iron moved into the steam-driven factories. So strange were these events that before they happened they were not anticipated, and while they were happening they were not comprehended.[1]

"The whole of nature is unceasingly studied, requested, worked upon, fecundated, husbanded," Marquis de Biencourt, writing of England in 1784.

Introduction

By 1850, at the apogee of its power, Britain had 1.8% of world population. The area of the British Isles is only about 0.16% of the world land mass. Yet Britain then produced two-thirds of world output of coal and one half of world production of cotton textiles and iron. Output per worker was higher in Britain than in any other country. It had enormous colonial possessions including much of India and Pakistan, Canada, Australia, New Zealand, and Ireland. Its navy was the largest in the world, and British defense doctrine called for it to be bigger than the next two largest navies combined. In 1842 it had humiliated the ancient Chinese empire and forced it to cede Hong Kong and to allow the British to ship opium into China. In 1860 the British and French captured Beijing and forced even more humiliating terms on the empire.[2] Britain was so confident of its manufacturing prowess that it pursued an armed policy of forcing free trade on other countries, confident that its manufactures would sweep away protected infant industries in other countries. Thus Britain used a show of force in Persia in 1841 to force it to concede most

[1] D. N. McCloskey, "The Industrial Revolution in Britain 1780-1860: A Survey," in Roderick Floud and Donald McCloskey, The Economic History of Britain since 1700.
[2] It is claimed that by 1855 Chinese tariff policy was firmly under British control, the only restraint on the British being the fear of toppling the current regime by pushing them too far.

favored nation status. It intervened in Egypt in 1841 out of displeasure with the protectionist Pasha.[3] With its colonial possessions such as India, Britain in the nineteenth century similarly imposed a policy of strict free trade, even though wages in India were less than one sixth those of Britain by the late nineteenth century.

The ascendance of this minor country on the northwest corner of Europe, which in 1700 had a population about one-third that of France (and about 4% that of both China and India) to the position of power it occupied is traditionally seen as being largely the result of the Industrial Revolution which occurred in Britain between 1770 and 1850.[4]

Even within Britain the Industrial Revolution changed the balance of power. Up until 1770 the center of population and political power was the south. London had a population of over 500,000 and was the center of Government. The next largest towns in 1760 were Bristol and Norwich, both in the south (see figures 1 and 2). Manchester, the center of the cotton industry had a population of only 17,000. But the Industrial Revolution was a phenomenon of the North of the country, and population, income and political power moved in favor of the north. By 1830 Manchester had a population of 180,000, and within 50 miles of Manchester lay most of the cotton textile mills. Thus by 1850 the Manchester area was producing about 40% of the world cotton textile production.[5] The centers of traditional woolen cloth production in the southwest and around Norwich were replaced by the factory industry in Yorkshire. These areas deindustrialized losing population to the north or to emigration abroad as wages stagnated and unemployment rose. Thus the town of Worcester in the southwest went from 13,000 in 1779

[3] The British and French in 1845 intervened in Uruguay in support of a liberal regime that favored freer trade.
[4] The dating of the Industrial Revolution is largely arbitrary, and the start has been variously given as 1760, 1770 and 1780, while again the end is sometimes given as 1860.
[5] Liverpool which was the port for Manchester and the cotton textile region similarly grew from 34,000 in 1773 to 78,000 by 1801.

down to 11,000 by 1801. And Norwich in the south grew by only 1,000 people from 1752 when it had 36,000 to 1801.

Three questions arise concerning the Industrial Revolution in Britain. The first is "What was it?" At the most basic level of description what happened in Britain in the period 1760 to 1860 that leads it to be regarded as a period of great historical significance? Here we shall see there is a conflict between the traditional views of the Industrial Revolution that emphasize the revolutionary nature of the period and modern views that have emphasized that the events of 1760 to 1860 were merely an evolution from what had come before. Remember at the time the Industrial Revolution was occurring no-one used that term to describe events: it was introduced by Toynbee in the late nineteenth century. In the same way we do not know yet the term that will be attached to these epoch in the history of the USA. The second question is what was the effect of the Industrial Revolution on output per worker? And what was the source of these effects in terms of our growth accounting model? The third question is why did this Revolution occur in Britain? Any why did it occur in 1760?

In the traditional view **four** revolutions with completely different natures and mechanisms occurred simultaneously in Britain in the years 1760 to 1860: the **Industrial Revolution**, the **(English) Demographic Revolution**, the **Agricultural Revolution**, and the **Transport Revolution**. We first lay out what the traditional view of what happened in each area is.

Figure 1: England in 1800

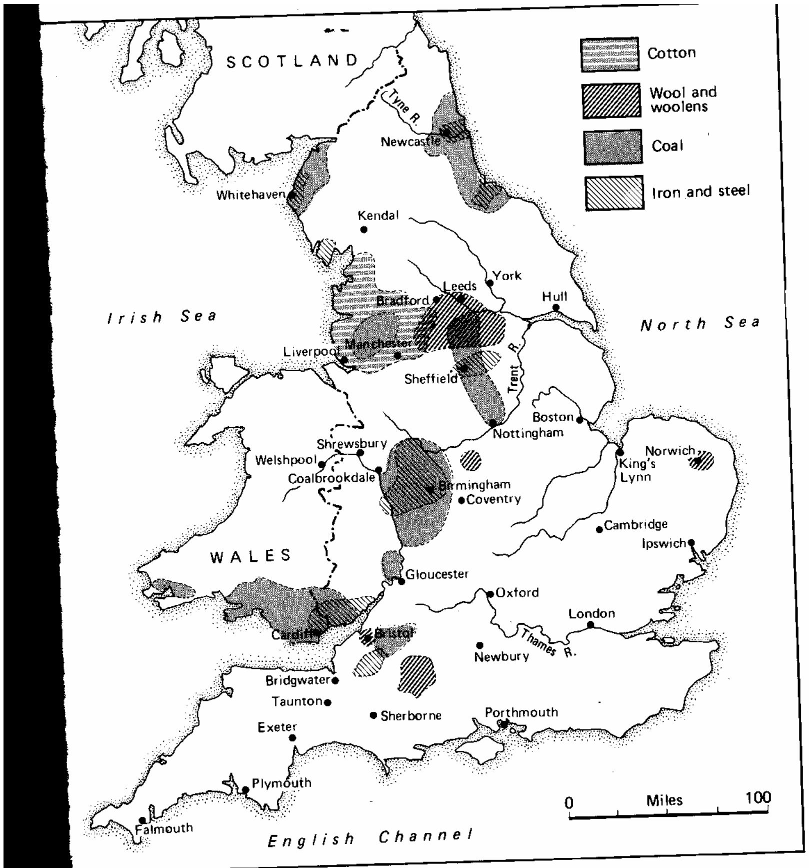


FIGURE 7–11. English industry in 1800.

The Industrial Revolution

In the traditional view this was an **unexpected** and **rapid** transformation of key industrial sectors by mechanical innovations. The key sectors transformed were the cotton textile industry, the power producing industry (with the steam engine and new energy sources in coal), the iron and steel industry, and eventually transportation with the introduction of railroads. The traditional account stresses that there were **a few key innovations** in each sector. These innovations led to the emergence of factory production and large scale modern industry. This new industrial economy in turn led to the imposition of factory discipline on workers and to their ultimate deskilling to the role of machine tenders. It also created social changes such as the proletarianization of much of the population, urbanization, and great accumulations of capital and hence great inequality in incomes.

We certainly see both dramatic technical innovations, as detailed below, and a huge growth in industrial output in Britain in this period. The output of a group of manufactured products whose quantities are measurable (textiles, metals, sugar, beer, hides, paper, tobacco, soap, candles) increased 6-fold over these years. The growth of this great industrial economy, it is argued, also led to the ascendance of the British empire by providing the resources and the technology for military conquest.

Cotton Textiles

The cotton industry was certainly rapidly transformed. The traditional textile industries in Europe prior to 1700 used linen and wool as raw materials. Sheets and undershirts were made of linen, outer garments of wool. Cotton was an exotic and expensive material that did not grow in western Europe. The cotton industry in Lancashire developed in the early eighteenth century as a result of trade with Egypt and India. It was still a minor industry in 1760, using only about 2.6

million pounds of cotton in 1760 (as compared to 90 million pounds of wool consumed in the woolen industry). Adam Smith in the Wealth of Nations published in 1776 hardly notices the industry, even though he was writing in Glasgow, an early center of the cotton industry. But raw cotton consumption rose dramatically by 1850, as Table 1 shows.

Table 1: Cotton Consumption 1760-1850

Year	Cotton Consumption (million lbs.)	Growth Rate
1760	2.6	-
1800	51.6	7.5%
1850	621.0	5.0%

By the 1830s cotton represented 20% of British imports, and cotton goods were 50% of British exports. The cotton industry rose from being about 0% of GNP in 1760 to about 8% of GNP by 1812. By 1860 65% of all the cotton goods produced in Britain were for export, as were 38% of woolen goods and 40% of linen goods. The reason cotton production rose so rapidly, and were so successful internationally, was the price of cotton goods fell dramatically, as figure 2, which gives costs in shillings per pound, shows.

Table 2: The Cost of Yarn

Year	Raw Cotton (s. per lb.)	Yarn (s. per lb.)	Manufacturing Cost (s. per lb.)
1784	2.0	11.0	9.0
1812	1.5	2.5	1.0
1832	0.6	1.0	0.4

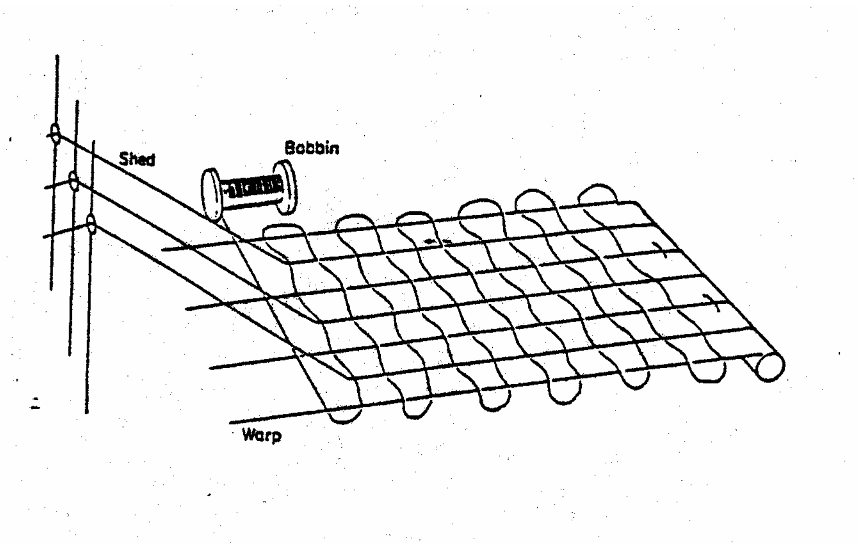
The cost of manufacturing 1 lb. of cotton yarn in 1784 was equivalent to 1 week's wage for an unskilled manual laborer. By 1832 it was equivalent to less than 3 hours wages. Cotton yard could be produced so cheaply in British factories that it displaced hand spun yard even in countries like India where the wages of workers were one sixth of those in Britain. By 1850 the only countries that had cotton spinning industries that survived were those like the USA which imposed protective tariffs against British imports. Otherwise Britain would have produced almost all of the cotton textiles in the world.

The reason that costs in the industry fell so dramatically were that there was a series of mechanical innovations in the cotton spinning and in the weaving industry which began as early as 1733. I will describe these in some detail since one interesting question we will ask is why these innovations occurred only in Britain in the early eighteenth century.

In 1700 the textile industry was almost entirely a domestic one. Women spun the yarn on the distaff or spinning wheel, then men wove it on looms in special rooms in weavers cottages or in loom sheds. Except for fulling woolen cloth the industry was all human powered and required enormous inputs of labor. Spinning was the most labor intensive part of the industry, since each spinner could only spin one thread at a time. It was mainly done in Europe using the spinning wheel (which was itself an earlier innovation in spinning.) To make cotton yarn a ball of cotton fibers has to be drawn out for fineness and at the same time twisted for strength. The spinner on the wheel would do this one thread at a time, using their fingers to pull out and twist the yarn. It thus took well over a week to spin a pound of yarn. That clearly imposes a strong limitation on the amount of clothing that any person is going to be able to consume.

The first two major innovations were actually designed for the woolen industry since at that stage cotton was important. The first change occurred in weaving. Weaving is a simple process conceptually. A series of stronger threads, called the "warp" threads is drawn out parallel. They are attached by loops to a set of vertical threads called the "harness." One half of them are lifted to form the 'shed' through which the cross or 'weft' threads are passed. Then the other half if lifted, and the weft is passed back through. The weft is wound around a bobbin. Before 1733 this was thrown by hand from one side of the loom to the other (see figure 3). This meant that any cloth more than 3 feet wide required two people to weave it — one to throw and the other to catch the shuttle. It also meant that the insertion of the weft was necessarily a slow

Figure 3: The Basic Weaving Process



process. "The flying shuttle," that propelled the weft mechanically across the loom was invented by John Kay, a weaver and a mechanic in Yorkshire in 1733. In the 'flying shuttle' the bobbin is carried in a little vehicle called a 'shuttle,' which has wheels and is pointed at both ends. The shuttle is projected at speed from one side of the cloth to the other, and back again. Thus the name. The projection is done from a kind of launching box at each side of the loom, which propel the shuttle out to the box at the other side of the loom when the weaver jerks a cord. In this way the weaver can weave much more speedily, and can weave cloth of any desired width.

Kay did not have instant success with his device. He was persecuted by the weavers in Yorkshire who feared unemployment as a result of his improvement. After failing in a legal case to protect his patent he fled to France in 1753 to take up an offer of royal patronage there. But in spite of worker opposition the flying shuttle soon became an essential part of any loom in Britain. And despite the demonstration projects funded by the French crown in France the flying shuttle was very slow to catch on there.

The next major innovation came in spinning cotton. Cotton spinning in factories actually consists of a series of steps. The cotton is first "carded" which is a process by which the tangled fibers are aligned in the same direction in a loose rope called "roving." Then by progressive steps this roving is both stretched out (and so made thinner) while at the same time being twisted to give it strength. Mechanical silk spinning mills has existed for long before 1769. They were developed in Italy in the 16th century.[6] Silk is a material that is very easy to spin. The fibers are very long, and being sticky they hold together easily. Cotton and wool both have much shorter fibers, so the threads formed from them are thus much more fragile. Thus spinning them is more difficult. Before the eighteenth century these fibers had to be spun by hand. The 'spinster,' almost always a woman and hence the modern use of the word, would use her fingers to draw out the thread which was then given twist by the spindle of the spinning wheel.

In 1738 Lewis Paul, a small scale inventor in the garment industry combined with John Wyatt, originally a ship's carpenter, to develop a mechanically powered "spinning engine," to spin cotton and wool. Wyatt and Paul's machine was similar to silk throwing machinery, but their innovation was the idea of using rollers to draw out the loose rope of cotton or wool, called the 'roving.' The thread then went to a flyer that both twisted it and wound it onto a bobbin. The basic design is shown in figure 4. The twist was imparted to the yarn by the device of the flyer which was already in use in the Saxony spinning wheel. Paul also developed a carding machine which was patented in 1748. Though technically at least partially successful, the Lewis and Paul engine was a financial failure resulting in the bankruptcy of its promoters. Wyatt and Paul's machine does not appear to have worked well, though factories were set up using it in 1740, 1741, 1742 and 1744. The first factory was powered by two asses, and employed ten girls. The 1744 factory used water power, and had 250 spindles and 50 workers, and operated for some years.

Wyatt and Paul's idea was only successfully implemented thirty years later by Richard Arkwright in 1769. Arkwright had little or no education, and had been trained as a barber. Experiments in dyeing hair led him into the occupation of wig making, and he spent much time touring county fairs buying human hair. In his travels he met a clock-maker named Kay in 1767 who told him of making a model of a mechanical spinning machine for Thomas Highs, a local mechanic. Arkwright financed Kay to develop a new model of a spinning machine. In the process the services of a local blacksmith and watch-toolmaker were secured to make some of the parts. To get extra finance for the undertaking a local liquor-dealer was brought in. Though Arkwright was based in Preston in Lancashire, fear of rioting induced them to move to Nottingham which had no established cotton spinning industry. There Arkwright linked up with Need and Strutt, local machine makers for the knitting industry, who suggested a number of improvements. The machine was patented in 1769.

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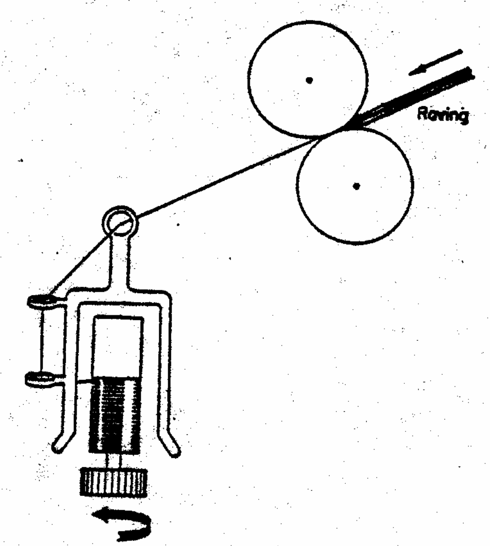
[6] The first mechanical silk mill was built in England in 1721 by Thomas Lombe, who succeeded in pirating the Italian design.

Figure 4: The Wyatt and Paul Spinning Method



The key discovery Arkwright made (or perhaps stole from Thomas Highs) was that to draw out the yarn successfully using a machine there had to be two sets of rollers moving at different speeds and spaced at a precise distance apart. By inserting a second roller he made Wyatt and Paul's idea of roller spinning work. The cotton was first cleaned and combed and made into the loose ropes of roving about a quarter of an inch thick. These rovings were wound onto a bobbin, from where they were fed through two pairs of rollers, the first rotating more slowly than the second. These rollers drew out the roving into a thread which was strengthened by being twisted by the revolving flyer as it was wound onto a spindle. The thread was guided onto the bobbin by notches on the flyer and had to be manually moved from position to position. The Arkwright machine is outlined in figure 5. The water-frame was improved significantly over the following years. Thus by 1775 the notches on the flyer were replaced by a guide rail which moved up the length of the bobbin automatically.

Arkwright's first 'water-frames' were driven by horses, and spun four threads at once. By 1771 a water powered mill was established. In 1774, after the expenditure of about £12,000, profits began to be made. Note that in this period the average carpenter would earn no more than £36 per year, so the capital sums invested were substantial. Arkwright and his associates also worked to develop new preparatory machines to produce the cotton roving for the spinning machine itself, and in 1775 Arkwright patented various such machines. So by then the spinning process was all effectively mechanized. By 1780 six mills had been set up using the water frame.

Without Arkwright's permission other manufacturers began to build and operate his machines, forcing Arkwright to sue nine of them for patent infringement in 1781. After a long period of litigation the courts in 1785 struck down his spinning and carding patents, partly on the grounds that he had stolen the spinning invention from Highs and the carding invention from another innovator, Hargreaves. Courts in the late eighteenth century were unsympathetic to patent holders, often striking down patents on minor technicalities. Whether or not Arkwright stole his key innovations, he was a vigorous promoter and developer of his machines. He received a knighthood and died worth £500,000, which measured in terms of the wage of the ordinary workman would be about the equivalent of $200 million now.[7]

[7] Assuming a worker then earned £50 per year, and now earns $20,000 per year.

Figure 5: The Arkwright Water-Frame

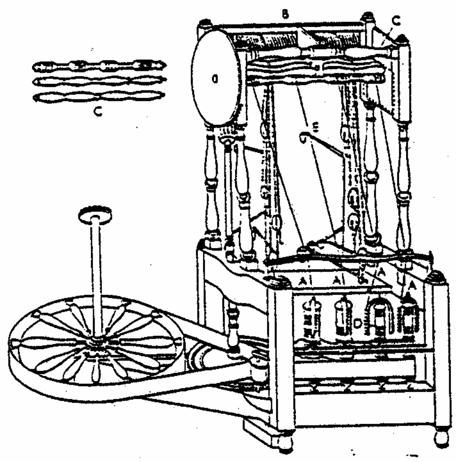


FIGURE 149—*Arkwright's original water-frame spinning-machine of 1769. The four threads* (A) *come from the roving bobbins* (B), *through the rollers* (C) *and on to the flyers* (D), *which are shown in different positions. The pairs of rollers* (*shown enlarged at the side*) *are pressed together by the weights* (E).

At the same time that Arkwright was inventing, or stealing, his machine, James Hargreaves developed a very different way of spinning by machine. He patented his **spinning jenny** in 1769, though it was devised in 1764. Here the rovings were wound on a row of bobbins from which they passed through a pair of parallel horizontal bars to a row of spindles. As the bars were pulled out the spindles rotated, twisting the threads. The bars were then clamped together, holding the threads. Then a horizontal wire, the 'faller wire,' pressed the threads down the spindle as they were wound onto these. As this was done the bars were moving back to their original position. This is shown in figure 6. The spinning jenny was still human powered spinning. But it allowed the operator to spin many threads at once. The first jennies had 16 spindles, but by 1800 jennies had 100 spindles each. Thus the productivity of workers in spinning yarn was enormously increased by this one innovation. The jenny, however, was still a cottage instrument which could be accommodated without large factories.

Hargreaves was never able to enforce the patent rights to his machine. Soon after the patent was granted he offered a reward to anyone supplying information about illegal use of the machine. He also met with the Manchester cotton manufacturers in 1770 to negotiate the sale of the rights to use the machine to them. Though they offered £3,000, Hargreaves held out for more. Since, however, he had sold jennies to them before the patent was granted, he was unable to sue them for infringing the patent under English law at that time. Thus he derived little benefit from his innovation.

For about 10 years the water frame was used for the stronger warp (lengthwise) yarns for cloth and the spinning jenny produced the weaker weft (crosswise) yarns. In 1774 Samuel Crompton, a jenny spinner, began experimenting on a machine that brought the two ideas together, roller spinning from Arkwright and alternate drawing and spinning from Hargreaves, and hence called the '**mule**.' He never patented this machine. It would have been hard to protect using the patent system since like the jenny it was still a hand powered machine that could be used in domestic industry. But the more likely reason is that since it used essential ideas from both the water frame and the spinning jenny it could not have been patented since it was regarded as derivative on the two other machines. The spindles were mounted on a carriage and as this was drawn out the spindles rotated imparting twist. The lengths of yarn were wound onto the spindles on the inward motion of the carriage. The mule could spin yards of any desired fineness. This allowed all cotton fabrics to be produced in Britain for the first

Figure 6: The Spinning Jenny

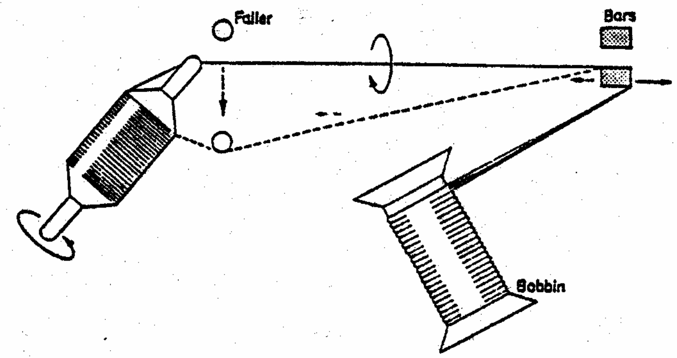


Figure 26. *The mechanism of the Hargrave's Jenny.*

time. The basic principles of the mule were the backbone of the British spinning industry for the next 150 years.

Like Hargreaves, Crompton derived little benefit from his machine. Impoverished he appealed to Parliament for a pension in 1812 in recognition of his contributions, and received £5,000. The early cotton mills, because they relied on water power were often in country districts which had rivers and streams available. It was the development of the steam engine that allowed them to move to urban concentrations. At first steam engines were used to pump water up into mill ponds to power machinery through water wheels since they were too uncontrolled to power machinery directly. But in 1785 the first directly powered factory was established. By 1910 at the maximum extent of the British cotton industry there were 56 million spindles in operation, most of them mule spindles. Most of them were located within 30 miles of Manchester.

Thus within 11 years the spinning industry was revolutionized, though all these machines were continually refined and improved after their first introduction. Thus while the early mules relied on the operator to push a long carriage in manually, later the self acting mule took over this task, and the operators merely supervised the machine, pieced together the broken threads, and put on and took of the yarn. The development of the 'self-acting' mule, as it was called, took over 40 years of experimentation, starting as early as 1790. Success came only in 1830. Roberts, the inventor, was sponsored in the final stages of his work by a firm of machine builders, since the last steps in its development cost £12,000. The number of spindles each spinner could tend rose continually in the early nineteenth century as continuous refinements were made in the spinning machines.

The dramatic advances in spinning cotton lead to a great increase in demand for cotton goods and hence a great increase in the demand for weavers. Wages accordingly rose. The scarcity of weavers led the Reverend Edmund Cartwright, the vicar of Goadby Marwood in Lancashire who had received a university training in theology and the classics, to wonder if it might be possible to invent a powered loom. He allegedly got these ideas before he had any detailed knowledge of the weaving process. With the aid of a local carpenter and blacksmith he devised a powered loom in 1785. Cartwright built a small factory for his machines in 1787, but it was not commercially successful.[8] A larger factory designed for 400 looms was erected in Manchester in 1791 but was not commercially successful, and was destroyed in a fire allegedly set by a mob of weavers angry at the prospect of unemployment. Cartwright's machine had a number of imperfections that may have rendered it uneconomic, but there were many attempts to improve it over the next 30 years. The key improvements were made by Horrocks in a machine patented in 1813, but he failed financially before he could profit from the machine. By 1820 there were over 12,000 power looms in operation, and by 1833 85,000. By the 1840s they had displaced almost all the hand powered looms.

This was one of the first great instances of technological unemployment. While spinning had displaced hand spinners, these had been mainly women who were not the main income source for their families. But hand weavers were mainly men (in part because hand weaving required strength). In the 1780s and 1790s the rise in earning had attracted into the industry many workers who had lived comfortably and had been able to acquire their own cottages with loom sheds attached. They led an independent life, which workers seem to have greatly valued. The rapid displacement of hand looms by power looms which could be worked by unskilled workers in the factories led to a rapid decline in the incomes of the hand weavers from 1815 on. It is estimated that there were 240,000 hand weavers in 1830, but only 43,000 by 1850 and 10,000 by 1860. There were calls for government action to remedy the situation by controlling the new technology, but the government chose instead not to intervene.

By 1850 cotton mills constituted a half of all factories in Britain with more than 100 employees. Indeed as late as 1870, of a total steam power in employment in Britain of 2 million horsepower, 0.6 million was in cotton mills.

There was one important development which took place in weaving in this period, but which occurred in France, not England. This was the development of what has come to be known as the Jacquard loom, after its most famous inventor. This was the culmination of long search to produce a loom that would weave patterned cloth. Patterned cloth can be produced in two ways: by printing a pattern on them after weaving, or by weaving in different colored warp and weft threads. To do this the warp threads had to be lifted in different sequences. This was a difficult and laborious task, requiring two people to a loom. In the eighteenth century a number of

[8] He allegedly powered his first loom using a cow!

French innovations came up with the idea of using essentially what are punch cards to select the threads to be lifted to produce the pattern. The first such machine was produced in 1725, but it was not until 1803 that Jacquard built a practical working loom on this principle. The Jacquard solution was to have a role of punched cards which had holes corresponding to the desired pattern. Where a warp thread was to be lifted there was a hole, where it was not to be lifted no hole. Against the current card rests a set of steel rods. Where the rod encounters a hole it pushes in, allowing the line attached to the warp thread to be pulled up by a bar. This was a very important technical advance (which of course presages the use of punch cards in early electronic computers), but it was still a hand powered loom.

There were also important developments in the U.S.A. that enhanced the growth of the cotton industry. While the cost of manufacturing cotton yarn fell sharply in the Industrial Revolution period, so did the cost of raw cotton itself, which was a third of its price in 1830 compared to 1780. Part of the reason for this was the invention in the US South of the cotton gin by Eli Whitney in 1793. The cotton boll picked in the field has to have the seeds removed before the cotton can be spun. Before the invention of the cotton gin this was a laborious hand task, which greatly drove up cotton prices. The cotton gin mechanized this process.

The experience of the cotton industry in the Industrial Revolution raises a number of interesting problems that we will return to after we complete our survey of the events of this period. The first is that since the innovations that so radically transformed the cotton textile industry were often relatively simple, why did they not occur until the eighteenth century? The second is why did they occur in Britain, and indeed mainly in the north of England when other countries such as France had much larger textile industries in the eighteenth century?

The innovations in textiles led directly, so it seemed to a new kind of industrial organization. Before the hand workers, as we shall discuss further below, had a great deal of liberty and independence, often working in their homes in small villages or towns with their children as helpers. Children often learned their trade from their own parents. Workers could vary the monotony of work by tending a garden or keeping a cow. They were free to observe the local holidays and to vary the intensity of work from week to week. The new powered factories demanded, it seemed, a new discipline from workers. The expensive capital equipment could not be idle while workers took leisure. Visitors to Manchester in the early nineteenth century thus marveled at the 6 am cacophony created by the factories all sounding their whistles to summon the workers to work, followed soon after by the sound of thousands of workers hurrying through the dark streets to get to the factory gates before they were locked out for unpunctuality. A new occupation, the "knocker upper" was created whose job it was to wake up the workers in the morning.

The new factories it seemed also widened the gap between employer and worker. Before workers could hope to ascent the occupational ladder by subcontracting work to other workers and becoming a "small master" in their own right. Now the requirement for becoming an independent cotton spinner was a very substantial capital.

Finally the new textile innovations seemed to set in process a constant search for means by which to reduce the skill content of labor. The early mules required highly skilled workers who formed a kind of "labor aristocracy." But the constant search was for machines that demanded less and less training and skill from workers. In cotton spinning the development of the "ring" seemed to achieve this aim of a totally deskilled labor force by the late nineteenth century.

Power

The second area to be radically changed in the Industrial Revolution period was the generation of power. Pre-industrial society was starved of power. The only sources were animals, water-wheels, and wind-mills. All these power sources were improved considerably in the years before 1700, at least in Europe. But they represent an inherent limitation on the expansion of the economy. It took two acres, for example, to feed one horse for a year. Thus even if 20% of the land in Britain had been devoted to horse feed only about 3.5 million horses could have been supported. Many of these, as many as 1 million, were needed just to plow and cart in agriculture. Water wheels could develop considerable horsepower, but again they were inherently limited by the lack of good sites on rivers and streams. Windmills were less limited in terms of location but produced much less power. The pre-industrial economy just could not generate much power.

To illustrate how tight this energy limitation was note that the average reported annual yield of coppiced wood (woodland cut back to the stumps ever 10-15 years) of different species in recent years in England is 1.27 tons per acre of dried wood, or 92.5 cubic feet of wood.[9] This is equivalent to 0.91 tons of coal per acre per year. That implies that had ALL the land in pre-industrial England been devoted to growing wood for energy it would have produced only about 20 million tons of coal per year. Given that most land had to be devoted to producing food to feed people the actual energy production in the form of wood for fuel and animal feed was probably well below the equivalent of 4 million tons of coal. By the 1860s England was consuming about 80 million tons of coal per year. Thus energy consumption had risen about 20

[9] See Begley and Coates (1961), Evans (1984), Rollinson and Evans (1987). Hammersley (1973), pp. 604-5, notes that woodland can produce "up to 100 cubic feet per year."

fold by the end of the Industrial Revolution, as a result of the greater use of coal as an energy source.

There has been debate about whether this great expansion of coal output represented a technological breakthrough, or just an expansion of output at relatively constant cost in response to increased demands in England created by other developments in the Industrial Revolution era. For an earlier generations of economic historians—T. S. Ashton, Ferdinand Braudel, Rondo Cameron, J. H. Clapham, Roy Church, Phyllis Deane, Michael Flinn—coal was at the heart of the Industrial Revolution.[10] Roy Church notes in his history of the coal industry, for example, "It is difficult to exaggerate the importance of coal to the British economy between 1830 and 1913" (Church (1986), p. 758). This picture has persisted also in the popular imagination — the Industrial Revolution IS coal, steam iron, factories, and railways.

But more recent writers have — those of Deirdre McCloskey, Nick Crafts, Knick Harley, and Joel Mokyr, for example—make coal only a bit actor.[11] Despite enormous increases in output the coal industry is credited with little of the national productivity advance either directly, or indirectly through linkages to steam power, metallurgy, or railroads. McCloskey (1981) does not even list it among the revolutionized sectors of the Industrial Revolution. The dramatic expansion of mine output accompanying the Industrial Revolution is attributed to an expansion of the industry at constant cost in response to new demands, or an expansion driven by transport improvements and changes in taxation, not an expansion driven by productivity gains within the mining sector. Coal experienced a mere 'shift along the supply curve, rather than outward movement of the curve'; that is, output soared because of increased input utilization and not due

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[10] See Ashton (1948), Braudel (1981), Cameron (1989), Church (1986), p. 758, Deane (1965), and Wrigley (1988).

[11] McCloskey (1981), Crafts (1985), Crafts and Harley (1992), Mokyr (1990).

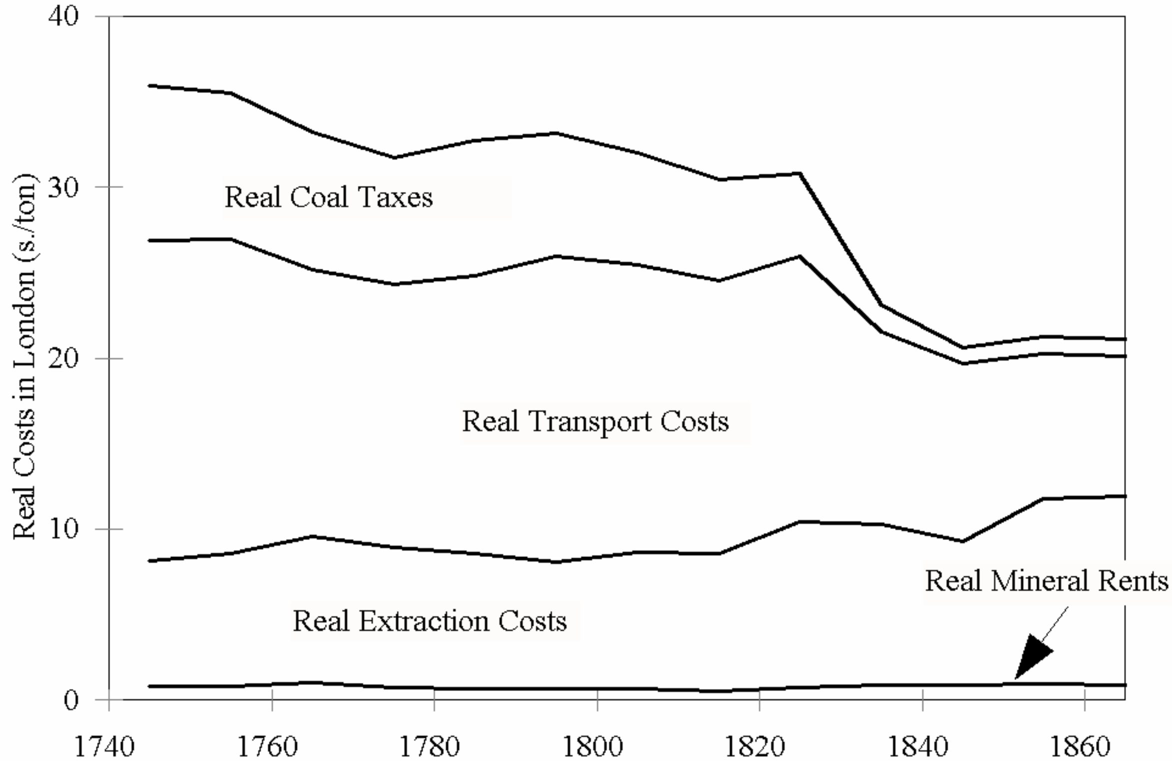
to the development of ‘new techniques allowing existing resources to produce cheaper or better’ (Mokyr, 1990, 110).

Certainly coal was mined in England from at least the medieval period. In the northeast coalfield, the major coalfield in England before the nineteenth century, the coal seams run to the surface. Thus the early mines were just tunnels driven down into the earth at an angle. Also some of the seams were exposed under the North Sea. Thus then, and to this day, coal washed up continually on the beaches of the north east where scavengers collect it for use. Also there were no really revolutionary changes in mining technique between 1760 and 1869. Mines were dug to greater and greater depths as the surface seams were exhausted. But mining remained largely a manual task, with the coal being dug out by pick and shovel at the coal face, then hauled to the mine shaft by hand or by poney. Only winding the coal to the surface was mechanized, but this was a relatively small element of costs.

Coal use before 1760 was limited before 1760 by several factors: it was very expensive to transport to consumers who were not right at the mines, and iron smelting, a major user of energy, iron making, could only employ charcoal as a fuel for reason of the impurities in coal, and for traction and driving machinery only horses could be used.

Figure 7, for example, shows real coal costs (coal costs measured relative to the prices of goods in general) in London from the 1740s to the 1860s. In the 1740s the extraction costs, the costs of actually mining the coal, for coal in the northeast coalfields were only about a quarter of the price to consumers in London. Transport costs and government taxes were nearly three quarters of the costs.

Figure 7: The Elements of the Real Cost of Coal in London, 1740-1869



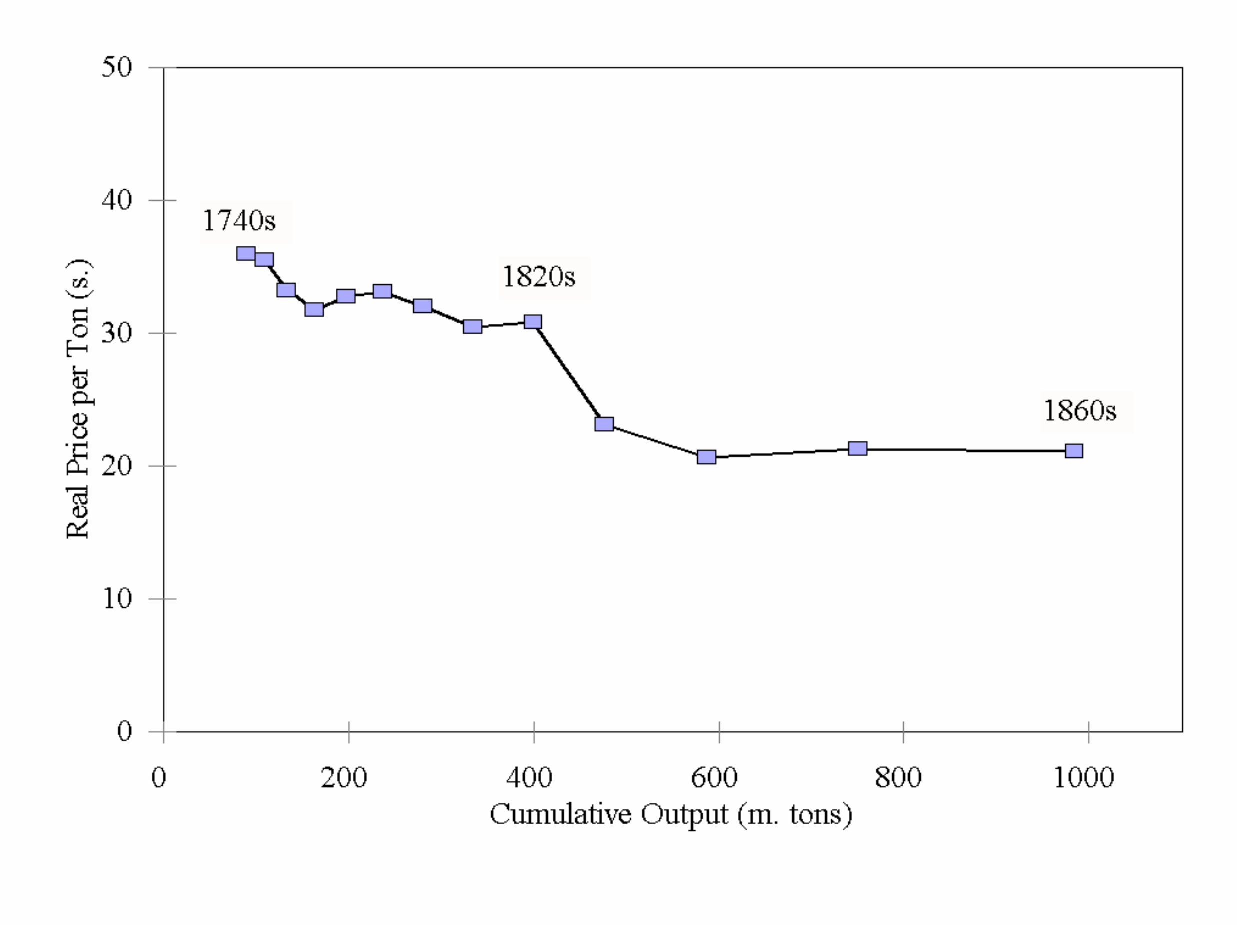
Certainly the output and price statistics suggest something unusual was happening. Figure 8, for example, shows estimated cumulative output in millions of tons from the north east coalfields compared with the estimated real price of coal in London, supplied by the north east, measured in the prices of the 1860s.[12] In real terms the price of coal to consumers in London nearly halved over the course of the Industrial Revolution, at a time when annual output from

[12] Thus the price in the 1740s was 23/- in nominal terms, greater than the 1860s nominal price of about 21/-. But between the 1740s and 1860s all prices rose by 57%, so in real terms the 1740s price is much higher at 36/- per ton.

coalfields expanded 12-fold. Was this not a revolutionary change in the economy? There is a puzzle, however,

Below we shall consider how important coal really was in launching the modern world.

Figure 8: Real prices in London and cumulative output from the north east coalfields, 1740s-1860s



Note: The price is standardized to that of Wallsend coal. The cumulative output in 1730 from the north east is assumed rather arbitrarily to be 81 million tons. It would not affect the picture shown here if it were made higher or lower. Prices are deflated by a cost of living index for manual workers derived in Clark (2004).

Sources: Outputs, Flinn (1984), p. 26, Church (1986), p. 3. London Prices, see appendix. General price level, Clark (2004).

The initial use of coal for steam power owes to the scientific discovery in the seventeenth century that the surface of the earth is at the bottom of an ocean of air that exerts the tremendous pressure of 15 lbs per square inch on all objects. In a famous experiment in 1672 Otto von Guericke showed that if the air was pumped out of two hemispheres put together to form a sphere, then 16 strong horses could not pull them apart. This was the discovery that led to the invention of the steam engine or 'atmospheric engine' as early steam engines are sometimes called. In 1691 a French scientist Denis Papin suggested the essential principle of the early steam engine, creating a vacuum under a piston using steam.[13]

The first full scale engine was built by Thomas Savery, who was originally an army engineer, in England in 1699, and was designed to pump water out of a mine. It consisted of a chamber in which water was heated to produce steam. The steam was released into a second chamber through a valve. Then the chamber is cooled, creating a vacuum that draws up the water. The water is forced out of the chamber into a tank higher up by the steam valve being released again. The engine was thus a simple pump with a double action.

The limitations of this device were many, and we do not know if it operated effectively. The need to cool the pumping chamber on each cycle would lead to it being very inefficient in translating heat into useful work. Also since boilers and pipes of the period could not withstand pressures of more than a few atmospheres the height to which it could pump water would be very limited. The vacuum part of the lift would draw up the water only 32'. If the steam was at two atmospheres pressure it could push the water up a further 64', so the entire lift would be less than 100'.

Thomas Newcomen (1663-1727) was the first to develop a practical steam engine, in 1705. Newcomen was an ironmonger with connections to the Cornish mining industry. Newcomen

[13] Several continental scientists had suggested creating the vacuum by exploding gunpowder to drive out the air, but this proved

was an ironmonger with connections to the Cornish mining industry. He was also a member of a Calvinist religious sect. The principles of the Newcomen Engine are easy to understand. It consists of a large cylinder containing a piston connected to a heavy beam that is pivoted in the middle and has the other end attached to pumping gear. Steam is drawn into the cylinder by the upward movement of piston. Then cold water is sprayed in a jet. This condenses the steam leaving a vacuum. Atmospheric pressure then pushes the piston down. The engine is thus powered using vacuums and atmospheric pressure.[14] This is shown in figure 9.

Though the concept is relatively simple there are a number of difficult engineering problems that Newcomen had to resolve. To make the engine automatic values had to be devised fitted to the beam that would operate the flows of steam and condensing water. Also since water contains dissolved air, the steam entering the cylinder is accompanied by air, which after a few strokes will 'air log' the cylinder so that the engine stops. This air has to be removed from the cylinder using the incoming steam and a one-way valve.

The Newcomen engine spread rapidly within Britain and to other European countries. By 1729 Newcomen engines were found in six other countries in Europe. It was used to drain the coal mines of northeast England and the tin mines of Cornwall. It was possible to increase the power of the engine simply by increasing the size of the piston and the steam boiler. Thus by 1760 a Newcomen engine had been built that developed 75 horsepower, and had a cylinder 6' in diameter and 9' long.

James Watt (1738-1819) began as an instrument maker at Glasgow University in Scotland. He was friendly with both Adam Smith and James Black, the famous professor of Chemistry. He became acquainted with the problems of the Newcomen Engine because of a scale model the

infeasible in practice.

[14] Which is why it is sometimes called the atmospheric engine.

university possessed. His great achievement was not as is sometimes supposed in inventing the steam engine, but in improving the efficiency of the engine. The Newcomen engine was very inefficient because the piston cylinder had to be repeated on each stroke of the engine. It is estimated that the Newcomen engine of 1718 converted the energy of the coal into mechanical power with 0.5% efficiency. This limited the economical working of the engine to areas such as coal mines where coal was extremely cheap, or to places where there was very strong demand for power.

Watt's first improvement to the Newcomen was thus to develop ways of keeping the piston hot all the time. He did this by condensing the steam in a separate chamber. The second improvement was that he realized that if the piston is driven down with cold air then the piston walls cool down on each stroke. It was thus more efficient to push the piston down using steam. This steam on the upstroke was pushed below the piston, there to be condensed.

Figure 9: The Newcomen Engine

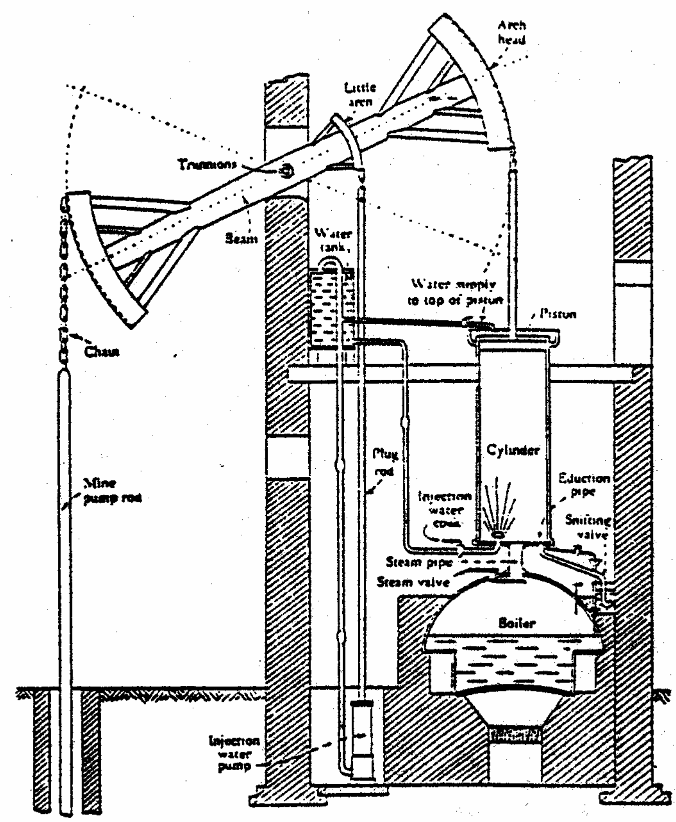


FIGURE 104—*Diagram of Newcomen's atmospheric engine, 1712.*

Watt's engine was much more complex than the Newcomen engine. It was, however, much more efficient. The original Newcomen engine had been increased to about 1.4% efficiency by 1774 through the efforts of John Smeaton (1724-1792), who did considerable work improving both steam engines and water wheels in the eighteenth century. Watt's first engine improved that to about 2.7% efficiency. By 1792 the Watt engine operated with 4.5% efficiency, a 9-fold improvement over the original Newcomen.

Interestingly at the same time the steam engine was being improved Smeaton, originally like Watt and instrument maker, was experimenting to improve the water wheel. He demonstrated in 1759, despite theory that established the opposite, that the overshot wheel was more efficient. This led to the replacement of most undershot wheels where practical with overshot wheels. He worked also on the most economical design of the wheel and found that the slower the overshot wheel moved the more efficient it was. Smeaton's experiments roughly doubled the efficiency of the water wheel. By the late eighteenth century water wheels capable of delivering several hundred horsepower were developed. A water wheel was installed in London Bridge in 1768 which was 32' in diameter and 15' wide. Efficiency improvements continued in the nineteenth century, especially in France which had few coal resources and relied much more on water power.

Watt entered into a partnership with Matthew Boulton to produce the Watt engine. Boulton and Watt depended heavily on the patent system to protect their monopoly on the Watt engine. They vigorously pursued anyone who tried to infringe their patent. Unfortunately Watt decided that it was impracticable to build a high pressure steam engine, given the machining tolerances of the day. Since the development of such an engine involved use of some of Watt's patented ideas, this delayed what was to be the next big step in the development of the steam engine until the patent monopoly ended in 1800.

The Watt engine used steam condensation to create a vacuum and hence produce power. The high pressure engine used steam at pressure as the major source of power. The high pressure engine was first proposed by Jacob Leupold of Leipzig in 1725. The idea was thus not new, it was the implementation that was the key. The high pressure engine was developed independently by Richard Trevithick (1771-1833) in England and Oliver Evans (1775-1819) in the USA.

By using steam at pressure the piston could be smaller to deliver a given amount of power. The problem was that the boiler, piston, and valves had to be able to withstand much higher pressures. Also since the steam pressure drove the engine the condenser could be dispensed with for little loss of efficiency. Finally the high pressure engine was also the key to achieving greater fuel economy. But a high pressure engine would be small enough that it could power a ship or a steam carriage. Trevithick built his first high pressure engine in 1800, and his first steam carriage in 1801. By 1802 he had built an engine that worked at 9 atmospheres pressure. The boiler had to have cast iron walls 1½" thick. By 1811 a steam locomotive was being used to draw coal trucks on the six mile Leeds-Middleton railway line. This was still a very primitive railway system. The driver walked alongside the locomotive and the trucks were linked together by simple chains.

A whole series of further improvements were made to steam engines over the next 100 years. By 1828 it was possible to build steam engines of 12% efficiency. By 1834 if was 17%, and by 1884 the Parson turbine achieved 25% efficiency. One thing that may have aided the development of more efficient steam engines is that the Cornish mine owners began to publish regular reports on the performance of their steam engines from 1811 on, to encourage competition to produce better results and to give information to mine owners on what was possible. The rapid increase in efficiency in the early nineteenth century is seen in these reports, as is shown in table 3.

Table 3: The Efficiency of Cornish Steam Engines

Year	Number of engines	Average efficiency (%)
1811	12	1.5%
1816	35	2.0
1826	51	2.6
1844	-	5.9

Cornwall was an area where fuel efficiency was important since, unlike the steam engines of the coal fields or Lancashire, coal was much more expensive in Cornwall since it had to be imported from other areas.

Interestingly while the steam engine is an interesting technical development in this period, and while we tend to think of it as almost defining the Industrial Revolution, it had much less impact on output per person in the British economy that did the innovations in textiles, especially in the period before 1800. It is estimated that by 1800 there was still only 29,000 horse powers worth of steam engines employed in the whole economy.[15] Indeed Nicholas von Tunzelman has gone so far as to try to calculate what the drop in income per capita would be in 1800 in Britain if James Watt had never existed. The reason this calculation is possible is that since Boulton and Watt vigorously defended their patent rights, which expired only in 1800, we have a record of all the Watt engines in use in 1800. Von Tunzelman finds that then there was only 12,500 horsepower in Watt engines. If all of these engines had been replaced by the less fuel efficient Newcomen engine, then the fuel cost per year would have been a tiny fraction of GNP. The final conclusion is that in 1800 if James Watt had never existed the drop in income per capita in Britain would be less than 1%.

Iron and Steel

The iron and steel industry was another sector which saw dramatic growth in the Industrial Revolution era. Iron production in Britain in 1750 was a mere 28,000 tons. By 1805 this had increased to 250,000 tons, nearly 10 times the level of 50 years before, and an increase of 4% per year. The growth of the industry was again the result of a series of technical change. To understand these we need to understand that iron can be produced in 3 major forms:

wrought iron	100% iron, malleable
steel	1–1.5% carbon
cast iron	> 2% carbon, brittle

Cast iron has few final uses because it is too brittle, while wrought iron is not very strong.

The pre Industrial Revolution furnaces operated at a low heat, so that the iron never became liquid. Instead it was produced as a red-hot lump. The material on the outside of the lump was steel, that on the inside pure iron. Different parts of the lump were used for different purposes. The fuel for these furnaces was charcoal, which was produced from wood. This required large supplies of wood: it is estimated that 10 acres of coppice wood were required for each ton of iron produced.

[15] A one horse power steam engine is capable of doing much more work than one horse, however, since the work day of a horse is limited and the steam power can be applied continuously.

Britain in the seventeenth century was very poorly endowed with woodland. Population pressure on the land had led to the destruction of most of the original forest. Thus wood was relatively expensive compared to Eastern Europe where the population per acre was much smaller, and large amounts of woodland remained. Thus in the seventeenth and early eighteenth centuries much of the iron used in Britain was imported from Sweden and Russia. Since there were only about 1 m acres of woodland in Britain, if there ever was to be a significant domestic iron industry it would either have to use imported wood (which was very expensive because of transportation costs) or else use another fuel source.

The earliest attempts to use coal as a fuel in smelting in Britain took place as early as 1619. They were unsuccessful commercially in part because they produced cast iron as a final product. The first successful smelting using coal as a fuel was achieved by Abraham Darby in 1735. Darby's furnace used a Newcomen Engine to pump water up to a reservoir to be used to produce the blast of air into the furnace that was required to get the temperature high enough. The Darby furnace, as in the earlier attempt at coal smelting produced cast iron, iron with a high carbon content. The blowing apparatus was perfected by Smeaton in 1760. But it took a lot longer to devise a way of removing the excess carbon from the iron produced. Finally in 1783 Onions, and in 1785 Cort, independently developed "puddling," the method by which the molten iron is stirred to remove the excess carbon. As a result of these innovations the British were able to produce low cost iron using their own coal resources. This is what stimulated the great increase in iron output.

At the same time in the 1780s the rolling mill was perfected by which the smelted iron was squeezed by huge rollers into sheets of iron. These iron sheets made the construction of much stronger iron boilers possible. By 1787 they had also been used to produce the first iron vessel, a canal boat.[16]

Railways

In 1824 there were no steam powered railways in Britain. In 1850, 26 years later there were 6,000 miles of track. The modern railway was really an amalgam of an old technology – freight tramlines powered by horses – to a new power source, the steam engine. The horse powered tramline existed long before the development of the Watt steam engine. Thus the mines in Newcastle in the northeast of England as early as 1676 were employing such tram lines to pull coal carts from the pitheads down to the wharves where the coal was loaded onto ships for carriage to London and other markets. By 1820 the coalfields in Glamorgen in the south of Wales had 250 miles of such horse powered "rail lines" while the Newcastle district had 400 miles.

The Watt steam engine had no immediate effect on the development of modern railways because the Watt engine was too heavy per unit of power delivered to be used to power trains. The steam engine used for the railroad had to be much more powerful at the same size. Thus the railroad waited on the development of the high pressure steam engine, which could only be produced if boilers could be made stronger and cylinders bored more finely.

The first high pressure locomotive was developed by Trevithick in 1801. Trevithick's idea was that this would run on the public highways. By 1804 he had built a model that hauled 5 wagons containing 10 tons of iron and 70 men at 5 mph. Over the next 20 years there were

[16] Iron took over from wood as a material for boat building because it produced lighter boats! To get the same structural strength from wood as from iron required a greater weight in wood than in iron.

persistent attempts to replace horse drawn stage coaches with steam carriages. One was built in 1827 that could do 20-30 mph over short distances. It operated on the roads near London for two years. Steam coaches also operated for some time between Stratford and London, and between Cheltenham and Gloucester. As late as 1831 a report by Parliament assumed that future transportation would be based on steam coaches. The steam carriage was doomed, however, by the fact that the gradients on the public roads were too variable. The steam carriage could not develop enough power to get up the steeper hills.[17]

Steam railroads developed in the coal fields of the North East independently of these experiments with steam coaches in the south of the country. The coal mine owners applied steam power to their tramlines in a variety of ways: stationary steam engines pulling coal carts using cables, moving steam engines with ratcheted wheels, and finally modern steam locomotives on smooth rails. George Stephenson, the head engineer at Killingworth Colliery, conducted a series of experiments in 1818 that convinced him that steam locomotives could be employed to haul carriages as long as the gradient was kept very low, below 1%. On a level grade wagons presented a resistance of 8 lbs. per ton, but that resistance increased by 20 lbs. per ton for each 1% of grade. Thus Stephenson appreciated that steam coaches on roads would not work because of the highly variable grades of public roads. Steam could be used effectively for haulage only on specially constructed railways with low gradients.

When the coal mine owners in the area planned a tramway from Stockton to Darlington in 1821, Stephenson convinced them to use steam locomotives. The line opened in 1825. But while it used steam locomotives the majority of the traffic was horse drawn for a number of years. This initial railway was curious in many ways. It was a single line with sidings every

[17] Effective steam cars were developed in the late nineteenth century, and cars such as the "Stanley Steamer" were serious competitors to the gas powered automobile in the early twentieth century. While the gas engine had to work within a limited

quarter of a mile. There were no signals, so that there were complex conventions about who had to back up when the two trains met. Private trains and wagons operated over the line as well as the company trains. Indeed passengers were carried by stage coaches drawn by horses.

Thus the first modern railway line was not built until 1830 when the 40 mile long Liverpool-Manchester line in the rapidly growing cotton district opened. Stephenson was hired as engineer, and convinced the promoters to invest the extra money needed to made the grade low, and thus run the whole line with steam locomotives. A competition was held for proposed providers of the locomotive, where the winner was required to go at least 12 miles an hour. Stephenson and some partners entered their own design, “the Rocket,” an easily won, their engine achieving 29 miles an hour in the trials.[18] Soon the Liverpool Manchester line was carrying 1,200 passengers per day, and the railway age had arrived.

Railway development again spread rapidly across Europe. Indeed in 1835 Belgium opened a railway line which carried more passengers than all the lines operating in Britain at that date.

The Industrial Revolution was thus characterized by an increase in the amount of innovation in the economy. This is shown in figure 10, which shows the patents per year from 1660 to 1780. There is a sharp upturn around 1760.

The descriptions given above of the technical changes that occurred in the Industrial Revolution show that there were both technical and demand connections between the developments in different sectors. The development of the steam engine aided the development of the cotton textile industry, the coal mining industry, the railway, and the iron and steel industry. The developments in Iron and Steel aided both the development of the steam engine

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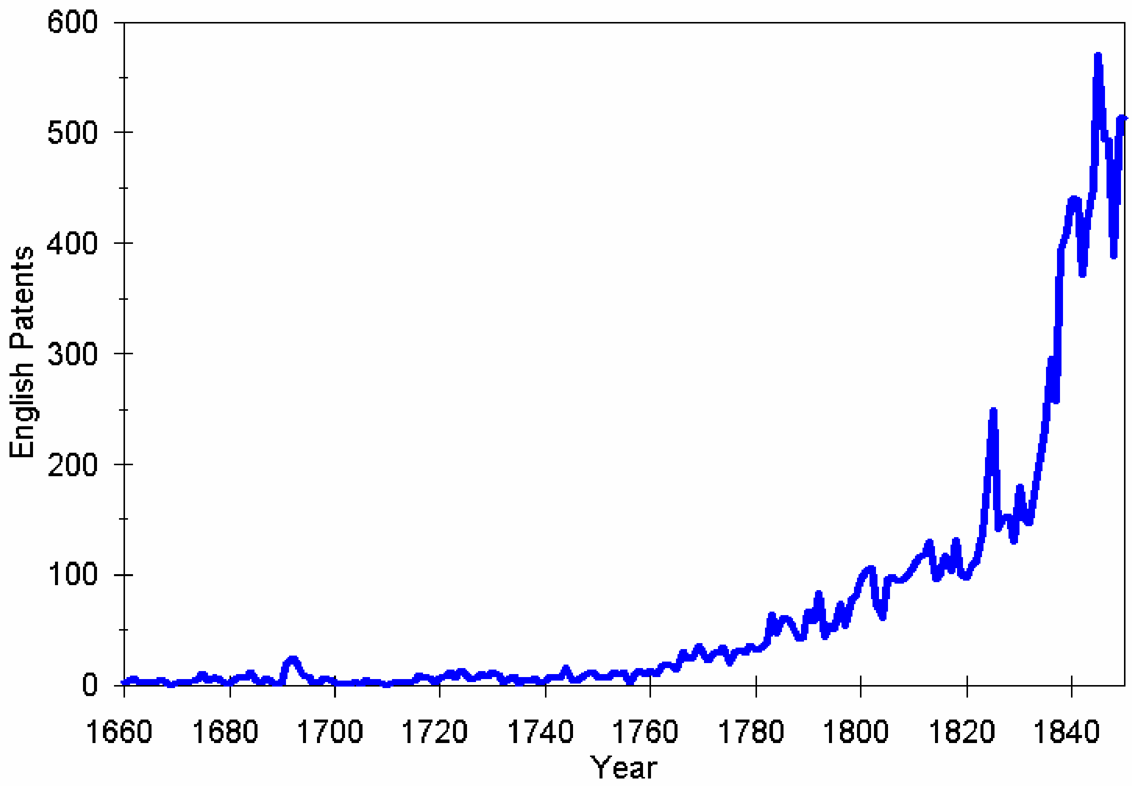
range of revolutions per minute, so that a clutch was required, the steam engine could run at an speed so that the power could be transmitted directly to the wheels. Thus the Stanley Steamer had only 26 moving parts.

[18] Several years later this same engine achieved 54 miles per hour in a trial.

(through developing sheet steel that could make stronger boilers, and through providing more accurately bored cylinders), and the development of the railway (by providing cheaper iron for rails). Similarly developments in coal mining provided the fuel for the iron and steel industry and for the steam engines and railway system. But coal mining also provided a demand for steam engines to pump water out of mines, and a demand for new methods of transportation to get the coal to the customers.

Figure 10: Patents per Year, 1660-1851



The English Demographic Revolution

At just the same time as the Industrial Revolution the British population, which was probably smaller in 1700 than it had been in 1300, began to grow rapidly. Population tripled between 1761 and 1861. Thus the estimated total population of Britain was:

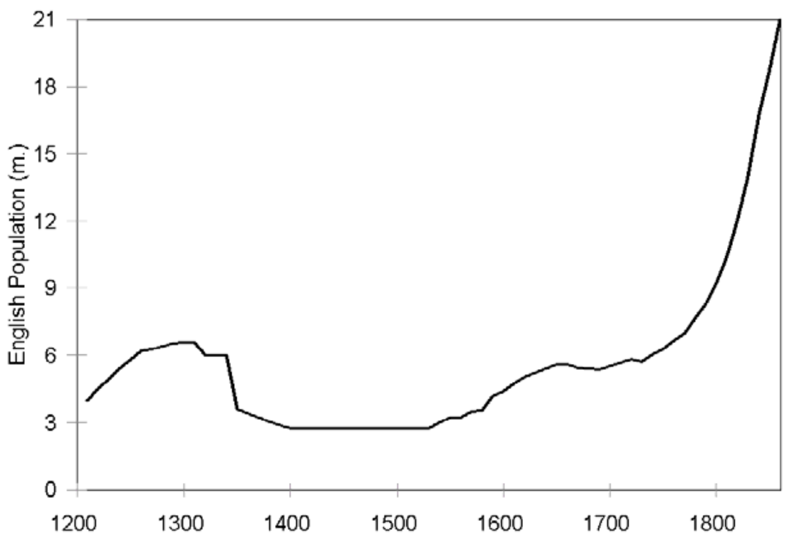
1701	6.5 m.
1761	7.8 m
1861	23.1 m

Figure 11 shows the estimated population of England from 1215 to 1865. Britain thus moved from having about one third of the population of France in 1700 to being nearly equal in population by 1861.

The mechanism of this population boom was relatively subtle and is still debated. There is not much sign of any great decline in mortality rates. Thus figure 12 shows estimates of life expectancy at birth for England from 1600 to 1850 from two sources. The first is life expectancy for a sample of 26 parishes where the entire demographic history of the population has been reconstituted. The second is a calculation from national population levels after 1801, and from births and deaths in a large sample of parishes before then. These measures suggest little or no gains in life expectancy between 1600 and 1850. The population boom must thus largely have been created by increased fertility.

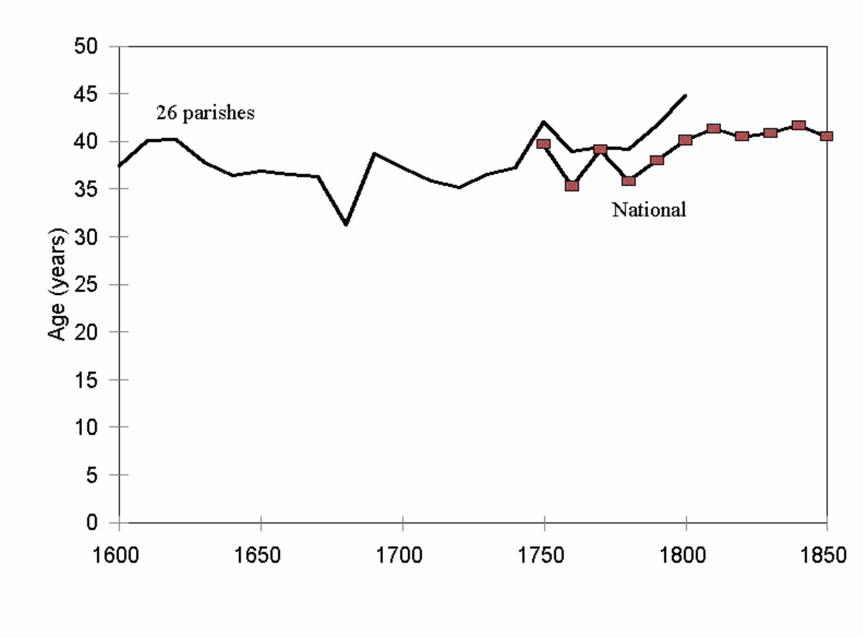
As an interesting reflection on the nature of the life in the pre-industrial world table 4 shows over these years the chances that a women would from complications from a pregnancy over these years. In the seventeenth century almost 1.5% of pregnancies ended with the death of the mother. That meant that a women marrying at 25, who would give birth to the average of 5.6 children for such marriages, would have about a 9% chance of dying as a result of the complications of pregnancy in the seventeenth century. But the early nineteenth century these chances had dropped to about a third of their earlier level (in contrast the chance of dying as a result of the complications of pregnancy in England in 1988 were 0.006% per birth). Here there are very clear signs of declining mortality in the late eighteenth century.

Figure 11: English Population, 1215 to 1865



Source: Post 1540 - Wrigley, Davies, Oeppen, Schofield (1997), p. 614.

Figure 12: Life Expectancy at Birth



Source: Wrigley, Davies, Oeppen, Schofield (1997), pp. 295, 532.

Table 4: Deaths in Pregnancy

Period	% pregnancies resulting in death of mother	Changes of death by pregnancy in course of average marriage (%)
1600-49	1.55	9.3
1650-99	1.45	8.7
1700-49	1.28	7.7
1750-99	0.92	5.5
1800-37	0.55	3.3

Source: Wrigley, Davies, Oeppen, Schofield (1997), p. 313.

As noted in ECN 110A population levels in pre-industrial Western Europe were mainly restrained by the European Marriage Pattern. In this pattern the average women married for the first time in their mid-twenties, as many as a quarter of each cohort of women never married, and there were very few illegitimate births. Even though fertility was unrestricted within marriage, this marriage pattern at its extreme around 1650 avoided about half of all possible conceptions.

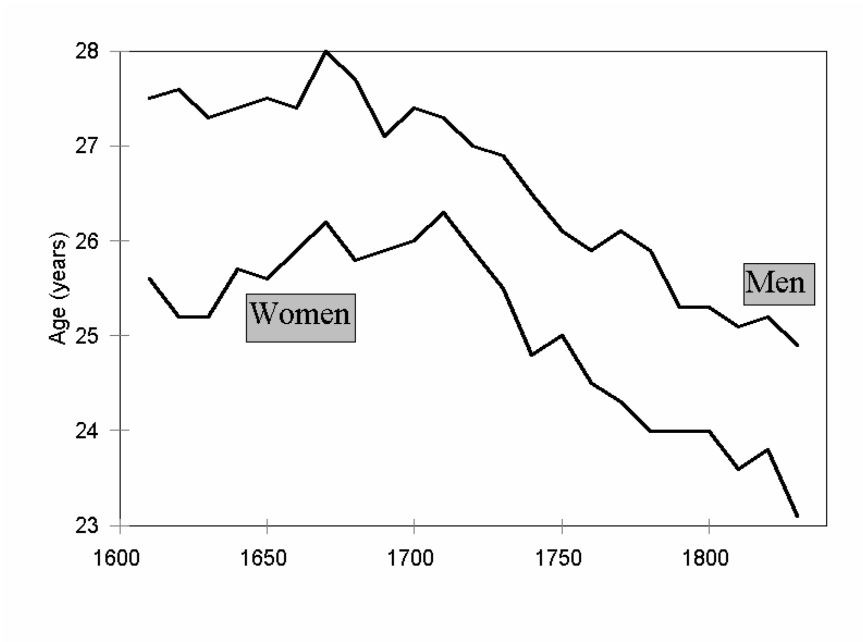
For unknown reasons, in the early eighteenth century the age of first marriage of women began to decline. Table 5 shows these calculated ages for a sample of 26 representative parishes for both men and women. For reasons connected with the form of the data source the age can be calculated only for marriages where this is the first marriage of both the husband and the wife (women who married men who had already been married typically were 3-4 years older). From the late seventeenth to the early nineteenth centuries there is a drop of almost 2 years in the average age of marriage for women. Figure 13, which shows the information by decade reveals that this drop began in the 1720s. This decline in age of first marriage was enough on its own to raise the birth rate by 20%.

Table 5: Mean Age of Marriage – Batchelor/Spinster Marriages

Period	Mean age of marriage, Men	Mean age of marriage, Women
1610-49	27.4	25.5
1650-99	27.6	25.9
1700-49	27.0	25.7
1750-99	25.8	24.3
1800-37	25.1	23.6

<u>Source</u>: Wrigley, Davies, Oeppen, Schofield (1997), p. 149.

Figure 13: Age of First Marriage by Decade



<u>Source</u>: Wrigley, Davies, Oeppen, Schofield (1997), p. 149.

At the same time as women began to marry at younger ages more of them were getting married. It is estimated that circa 1650 about 20% of women never married. By the early eighteenth century this was down to 10%, and the rate remained at this lower level through the Industrial Revolution. This added another 12% to the increase in fertility. Finally illegitimate births increased. By the end of the 18th century about a quarter of all first births were illegitimate. Another quarter of first births were within marriage but conceived before the marriage took place. Increased illegitimacy added about another 5% to the rate of fertility. Multiplying these factors together we get an increase in fertility between 1650 and 1800 of about 40%. Thus while in 1650 there were only about 1.93 children per women who survived into adulthood, by 1800 there were 2.68 surviving children per woman.

The sources of these changes in nuptiality do not seem to be economic. They occurred in both the north and the south of England even though the north was much more transformed by the Industrial Revolution than was the south. And it occurred in parishes where employment was mainly in agriculture as well as in parishes mainly engaged in trade, handicrafts and manufacturing, as table 6 shows.

Table 6: Women's Average Age of First Marriage by Parish Type

Period	Agricultural Parishes (8)	Retail and Handicraft Parishes (5)	Manufacturing Parishes (3)	Mixed Parishes (10)
1700-49	25.2	26.5	26.6	26.3
1750-99	24.3	24.8	24.6	24.7
1800-37	23.7	24.0	23.4	23.7

Source: Wrigley, Davies, Oeppen, Schofield (1997), p. 187.

The Agricultural Revolution

The much larger population of Britain in the 1860s had to be fed. With the seeming rise of incomes from improvements in industrial techniques it also seemingly had to be fed better.

The idea that an **agricultural revolution** accompanied the Industrial Revolution, and indeed contributed more to the overall productivity growth of the British economy in the years 1700 to 1850 than did the revolutionary changes in cotton textiles, still dominates thinking about the Industrial Revolution period.[19] Table 7 shows, for example, some recent estimates of productivity growth in English agriculture between 1700 and 1860. The authors vary in where exactly they place the productivity growth, but all find productivity more than doubled between 1700 and 1850, just at the time of the Industrial Revolution.

It is important to understand that none of these estimates of productivity growth in agriculture are derived from direct estimates of outputs and inputs. Such figures do not exist for the years before 1860. Instead scholars believe in an agricultural revolution mainly because of three things that happened in the economy as a whole: growing population, rising incomes, and urbanization. The population of Britain increased from 6.5 m. in 1700 to almost 21 m. by 1851. Since domestic agriculture still fed four out of five Britons in 1850, the population it fed increased 150% from 1700 to 1851. Since both output per person and real wages are widely believed to have increased in Britain after 1800, that should have boosted food consumption even more since at higher incomes people consume more food. In studies of the value of food consumed compared to income for groups of workers at particular times in the late eighteenth and nineteenth centuries it has been found that consumption per capita, c, is well predicted by a function of the form, $c = a.(w/p)^{\varepsilon}$, where w/p is real income, and ε is the elasticity of demand for

[19] Knick Harley, for example, attributes to agriculture more than one third of all the productivity growth in the Industrial Revolution. See Harley (1983).

food, which seems to be about 0.65. In intuitive terms this implies that each 1% rise in real wages is associated with a 0.65% increase in real food consumption.

Table 7: Estimated Productivity Levels, 1700-1860

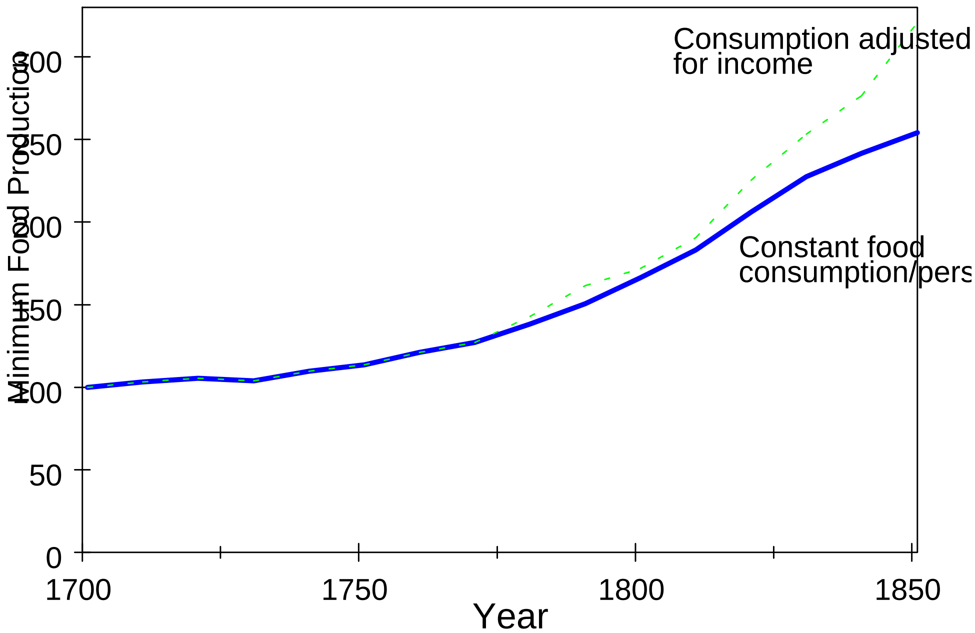
Period	1700	1760	1800	1850	1860
Crafts	100	135	146	234	259
Allen	100	-	182	234	-
Overton	100	-	142	208	-

Sources: Crafts (1985), pp. 41-4, 84; Deane and Cole (1967), p 166; Allen (1994), p. 111; Overton (1996), p. 86.

Since even relatively pessimistic estimates such as the recent ones of Charles Feinstein suggest a 43% gain in real incomes between 1770 and 1850, total agricultural output would thus have increase by 220% between 1700 and 1850.[20] The cultivated area seemingly increased little between 1700 to 1850 so yields per acre should have tripled. Implied food output is shown in figure 14.

[20] Feinstein (1997). Assuming real incomes in 1780 were the same as in 1700.

Figure 12: Predicted Agricultural Output in Britain, 1700-1850



Notes: The solid line shows the food output required in Britain to keep consumption per capita constant. The dotted line shows the output required given evidence on real wages in Feinstein (1997b).

There has been equivalent optimism about increases in output per worker. The census of population gives estimates of the share of the work force in agriculture from 1801 onwards. These suggest that the share of the adult male labor force in agriculture was 25% or less in 1851, and 36% in 1801. Before 1801 there are no census figures, so the labor in agriculture must be deduced from other considerations. E. A. Wrigley uses urbanization rates as a guide and concludes that 55% of the labor force was in agriculture in 1700. Crafts uses information on occupations gathered from probate inventories by Lindert to get a similar figure of 56% of workers in agriculture in England in 1700.[21] These considerations imply an adult male labor force in agriculture of about 0.9 million in 1700, and 1.0 million in 1861. Thus the swelling food production was largely achieved without greater labor inputs, so that output per worker grew as much as 170% between 1700 and 1860. Once these large increases in output per acre and output per worker are concluded, it follows that overall productivity in agriculture increased in the way shown in table 7.

The existence of the agricultural revolution has profound implications for our thinking about the rate of overall economic growth in the Industrial Revolution, the level of industrialization in England before the Industrial Revolution, and about the cause of the Industrial Revolution. Yet it remains a maddeningly elusive event. It is only observed indirectly, through the shadows it casts on other actors. When we get down to the level of what was happening in the fields and the barns during the Industrial revolution period we see little sign of any major changes. It also has no discernable connection with events in industry. Mechanization was minimal in English agriculture by 1850, the only task substantially affected being grain threshing. And even threshing was still mainly a hand task in much of the south of the country as late as 1850.

[21] Wrigley (1985). Lindert (1980). Crafts (1985), p. 15.

Similarly there are no heroes of agricultural innovation - no Hargreaves, Arkwrights or Cromptons - just an amorphous collection of anonymous sons of the soil somehow bringing home more bacon. The early stories of the revolution emphasized “Great Men” – Jethro Tull, “Turnip” Townsend, Arthur Young and the like - who pioneered new techniques. But the great men have been shown to be self-publicizing midgets, and all subsequent accounts have been of incremental changes, carried out by a broad swath of farmers across a broad sweep of time. Jethro Tull, for example, in his famous six volume work, “Horse Hoed Husbandry” advocated the completely erroneous theory that plants grow only using air and water, and that getting air to the roots is the key to high yields.[22] “Turnip” Townsend got his nickname from his supposed role in introducing the turnip into the arable rotation. But it turns out turnips were being grown on his family estate long before he took over management, and modern science suggests that the turnip played little significant role in raising yields.

Such a diffuse agricultural revolution has powerful implications for the likely cause of the Industrial Revolution. A diffuse revolution occurring precisely at the time of the Industrial Revolution implies that the gains of the Industrial Revolution period most likely stemmed from some economy wide social or institutional change – changed attitudes on the part of all producers as in Jan de Vries’ Industrious Revolution, or improved incentives for all economic actors as in North and Weingast’s analysis of the Glorious Revolution of 1688, or superior incentives to move labor out of agriculture as argued by O’Brien (1996).[23]

However, despite the popularization of the concept of the agricultural revolution by Toynbee and Lord Ernle as long ago as the 1880s, agrarian historians have been singularly unsuccessful in pinning down the details of what allowed this revolutionary improvement in land

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[22] This work was the first English work on agriculture translated into French, and was much discussed in the Salons of eighteenth century France.
[23] See de Vries (1994), North and Weingast (1989), O’Brien (1996).

and labor productivity. Enclosure of common lands, the elimination of peasant agriculture, and new crops such as turnips and clover, have all been placed center stage in the drama of the agricultural revolution. None of these actors, as we shall see, has proved up to playing the lead role in a dramatic agricultural revolution.

Even more puzzling, agricultural historians have been singularly unsuccessful in showing directly that output per acre and per worker did indeed triple as expected.   In discussing the agricultural revolution we are at the most basic terms discussing what happened to four simple aggregates: agricultural output, and the inputs of labor, land and capital. The trouble is that for both output and capital we have **no** direct information for the period 1700 to 1850. For labor we have no firm information for any years before 1801. The land area available for agriculture did not change much, but other than that we know little directly. The last major attempt to estimate the volume of agricultural output between 1750 and 1850 by B. A. Holderness, for example, concluded with the warning to the reader that,

> The section on production and productivity is so replete with expressions of doubt, uncertainty, and disbelief that it reads like a litany for skeptics.[24]

Holderness's caveats are not false modesty, for his firmest estimates of output, for grains, are still based on pure speculation on the level of grain yields in 1750-70, and in the case of meat and dairy products the speculation is heavily guided by the need to ensure that the resulting figures do not imply too big a decline in consumption per person.

The best we can say of the direct estimates of outputs and inputs in the eighteenth century is that there is evidence of some gains in grain yields per acre between 1700 and 1850, but no firm evidence on pasture yields, which was about half the farm sector, or on labor or capital inputs. The agricultural revolution accepted by such writers on the Industrial Revolution as Crafts

[24] Holderness (1989, p. 174).

(1985), Harley (1993), Allen (1994), O'Brien (1996), and Overton (1996) is one that is derived mainly from population, income, and urbanization.

It is true, nonetheless, that by 1850 British agriculture had achieved levels of land and labor productivity which were far in advance of most European countries. Table 8 shows output per acre and per worker for different European countries circa 1850. Though the comparison here is crude because of the nature of the sources, as can be seen output per acre in Britain in 1850 was triple that of Russia, and output per worker was triple or greater. Output per acre in Britain in 1850 was at least twice as high as in 1300, and output per worker may have increased by as much. Britain's productivity advantage in 1850 lay particularly in high levels of output per worker. The cross-country differences in 1850 do seem to imply that some time between 1300 and 1850 Britain seemingly experienced an agricultural revolution, which made it not only the most efficient producer of industrial goods in 1850, but also one of the countries with the highest output per acre and per worker in agriculture. Indeed as we move from the west to the east of Europe in 1850-70 we seemingly move back in time, with Russian agriculture in the late nineteenth century apparently the equivalent of English agriculture in 1300.

Table 8: Agricultural Performance, circa 1850

Location	Year	Output/Acre (England 1851=100)	Output/Worker (England 1851 = 100)	Total Factor Productivity (England 1851 = 100)
Britain	1851	100	100	100
Netherlands	1850	94	54	76
Belgium	1850	122	37	73
Ireland	1851	78	47	67
France	1850	82	44	66
Germany	1850	56	42	56
Romania	1870	51	40	53
Austria	1854	54	32	50
Sweden	1850	45	37	49
Hungary	1854	36	30	41
Russia	1870	24	29	34

Note: I assume that the shares of capital, labor and land in costs are .2, .4 and .4 respectively, and that output per unit of capital (which is unobservable) is constant across countries and time. Output per acre in Britain in 1851 is estimated at the equivalent of 12.6 bushels of wheat, and output per worker at the equivalent of 272 bushels of wheat.

Source: Clark (1991, p. 213).

The Transport Revolution

The last of the four apparent revolutions in this period was in the traditional transport sector or roads and canals. This experienced substantial reductions in cost in the Industrial Revolution period without any obvious technological changes.

Up to almost 1750 the pack horse was the main means of land transport in Britain. Thus as early as 1637 there were over 200 carrier services from London to regional towns, but they mainly used pack horses. Indeed up until the mid eighteenth century many towns in the north of Britain did not have wheeled transportation links to London. Coach service from Manchester to London, for example, was only introduced in 1754. Many "roads" in the north were in fact just walkways for pack horses. The wheel allows greater economy in transporting goods over land. A pack horse can carry 220-330 lbs, while a horse can pull a wagon carrying 1100 lbs (or a canal boat carrying 5500 lbs).

From 1700 to 1850 the frequency, variety and speed of road transportation in Britain improved greatly. The average speed of regular coach service, inferred from surviving advertisements of coach service was 5.5 mph in 1750. By 1818-1840 the average speed had increased to 8.7 mph. The average travel speeds of coaches in 1660 were less than a quarter the speeds in 1840, or less than walking speeds. Despite the improvements in comfort and speed real costs for passenger travel stayed roughly constant. Those for freight fell markedly to about half their level.   Thus nominal and real costs costs per mile were as is shown in table 9.

Table 9: Nominal and Real Road Transport Costs per Mile

Years	Coach Nominal Costs d./mile	Coach Real Costs (1750-70 =100)	Wagon Nominal Costs d./cwt/mile	Wagon Real Costs (1750-70 =100)
1750-70	2.54	100	0.58	100
1818-40	4.02	103	0.47	53

Note: The real costs are calculated by deflating by an index of the cost of living of workers.

The reason for these gains in the cost and quality of service were organization and investment as opposed to technical changes. Up until the 1690s the road system was maintained by making each parish repair any roads that passed through this parish. The parish would in turn require all the households to contribute a certain amount of labor to maintaining the roads: the statute of 1563 required all parishioners to contribute 4 days of labor per year to the roads. There were two problems with this system. The first was that often parishes had little incentive to repair and maintain highways that they were responsible for, since most of the traffic on the road was not local. The second was that even where they had an incentive there was often a mismatch between the resources of the parish (which could over only a few hundred people) and the requirements of road repair. A rural parish with a heavily used main road running through, for example, would face very large costs for road maintenance. When the road got in bad repair coaches and wagons would often veer off into the fields on either side, creating new roads and damaging the farmland and crops. Thus the roads outside the environment of cities often consisted of little more than a right of way across the fields. A cartoon of the mid eighteenth century shows a sailor with a wooden leg being offered a lift in a stage coach, to which he replies "No. I'm in a hurry!"

The organizational innovation of the later seventeenth century was the Turnpike Trust. This allowed local merchants and promoters to set up trusts to build and maintain roads, charging a toll to travelers. Local magistrates set the toll rate that could be charged. Tollhouses were built every few miles along the road. The actual collecting of the tolls were often auctioned off to "toll farmers" for a fixed sum. They made their profit by collecting the toll efficiently. The toll rates were in part established with reference to how much damage each type of vehicle did to the road. Thus wagons with very wide wheels were encouraged.

The Turnpike Roads were mainly built using long established construction methods up until the end of the eighteenth century, which were little improved on those known to the Romans. The land would be leveled, drains installed, and a bed of stones laid with larger stones below and closely packed stones above. After the 1690s the miles of road built by turnpike expanded rapidly, as table 10 shows. Figure 15 shows the complex network of roads that had been turnpiked by 1770.

Table 10: Miles of Road Turnpiked, 1663-1836

Year	Number of Trusts	Miles of road
1663	0	0
1750	143	3,386
1770	519	14,965
1836	942	21,991

Figure 15: The Turnpike System in 1770

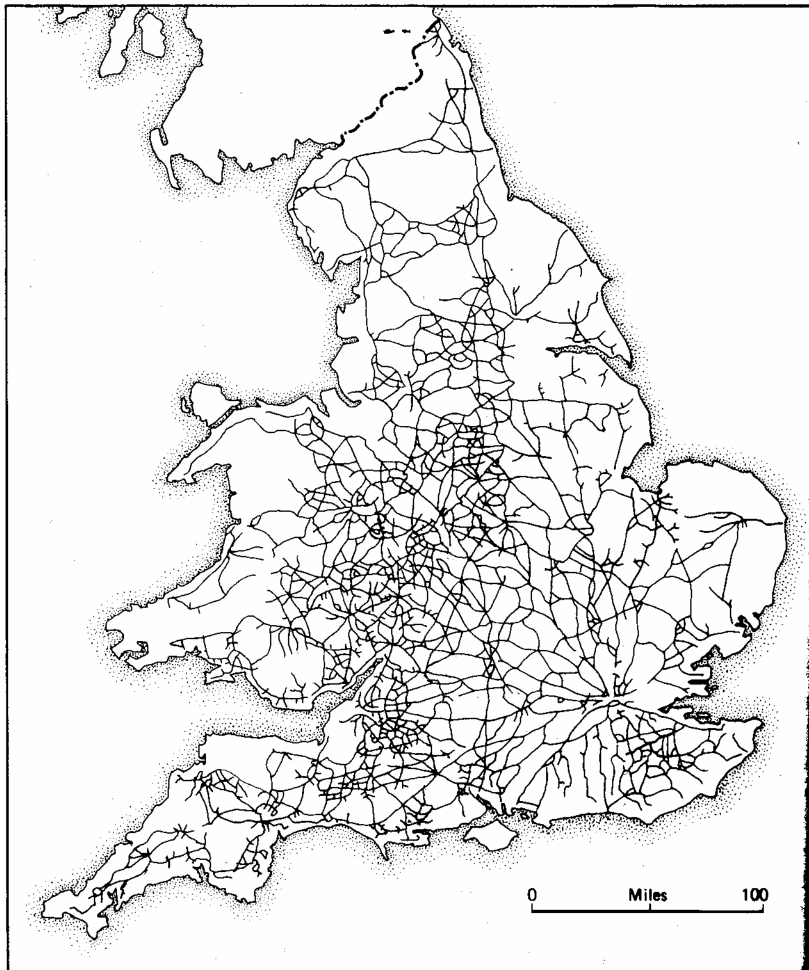

FIGURE 7–6. Turnpikes in 1770.

Britain had about 1,000 miles of river that had been improved for navigation by 1750. But much of the country was far from navigable water. The development of coal as an important fuel source gave impetus to canal building since coal was heavy and its cost rapidly increased the further it had to be carried over land. The modern canal system began to be built in 1757, but the principles of canal building had been well established before 1700, including the use of locks to adjust for differences in the level of the canal. The first well known canal was the Bridge water Canal built to carry coal into Manchester in 1761. The main periods of construction were in the 1770s and in the canal 'mania' of the 1790s. By 1830 there were 2,000 miles of canal in Britain. Rivers were improved also so that by 1850 there were 4,250 miles of navigable water in Britain.

The development of canals again seems to have largely resulted from organizational rather than technical changes in the economy. Already by the mid sixteenth century the Netherlands had a very sophisticated canal system linking all the major towns. These canals were called **Trekschuit**. By 1700 there were over 400 miles of such canals. They operated passenger service much like modern shuttle services on airlines between, for example, New York and Washington. There were regularly scheduled departures, standby barges in case of overloads, and first and second class accommodation. On the Amsterdam–Haarlem route a barge left very hour. Thus it was possible to go by canal all the way from Flanders to Amsterdam. The boats had a speed of about 4 miles per hour which was as fast or faster than coaches in the eighteenth century, but the ride was much smoother.

Interconnections

The traditional story of the Industrial Revolution with these four different revolutionary changes seems to demand that their must be some link between the various revolutions. It seems that after the economy was largely static for 500 years it would be too much of a coincidence for these momentous changes to have occurred together simply by accident. Thus historians have sought for ways to link these changes.

Marx, for example, thought that the basis for all these changes in Britain lay in much earlier political events which took place as early as the sixteenth century. By then in England local lords ceased to exercise power through the numbers of armed supporters they could call upon. Since tenants were no longer a source of political power lords began to look upon agriculture solely as a source of income. To this end they sought to remove small tenants from the land, and to turn agriculture into an efficient capitalist system. Their profit driven reform of agriculture created a class of landless rural laborers who were eventually driven to the towns in search of work. These workers formed the urban proletariat which allowed the rapid expansion of industry.

Other writers have focussed on the important political developments that preceded the Industrial Revolution. The political landscape in Britain throughout the Industrial Revolution period was largely set by the Glorious Revolution of 1688-9. The seventeenth century in England had been a period of great political instability. The Stuart Kings who ruled from 1603 to 1649, and 1660 to 1688 were in constant conflict with the English Parliament. Charles I had been deposed and executed in 1649. The Stuart Kings asserted their right to rule unchallenged by Parliament, but to get the revenue to do so they had to get the Parliament to grant taxes which it consistently refused to do. A political stalemate resulted with mistrust and recrimination on either side. The problem was exacerbated in the 1680s by the fact that the last Stuart King, James II, was a Catholic in a largely Protestant country. The Revolution of 1688 deposed James in favor of his Protestant daughter Mary and her husband William of Orange. But it also ceded a lot of the power of the Crown to the Parliament. From then on the king could only rule in consultation with Parliament. The settlement also excluded from the monarchy, the Parliament, or government service, anyone who was not a member of the Church of England.[25] This resulted in a very stable government from then on, with few serious challenges to the authority or legitimacy of the Parliament and Crown.[26]

The Parliament in power from 1689 to 1832 was elected by a very limited franchise. In the eighteenth century only about one in six adult males had a vote. The propertyless were excluded. The Members of Parliament were largely wealthy landowners. It was also possible to quite literally buy your way into Parliament since a number of parliamentary seats were assigned to what were called "rotten boroughs:" districts with no population or a very small one where the chief landowner effectively controlled the Parliamentary seat. Other growing towns, such as Manchester, had no representation in Parliament.[27]

The general policy of the government from 1689 on was one of very limited intervention in the economy. Almost all government expenditure was devoted to military purposes. Thus while the British government from 1688 to 1815 spent on average somewhere in the range of 8 to 12% of GNP on military expenditures, its total expenditures on economic development through infrastructure investments, promotion of industries, and spending on education and training were

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[25] Thus both Catholics and Protestant Dissenters were excluded from public offices.
[26] There were rebellions in Scotland in 1707 and 1745 when James II and his son "Bonnie Prince Charlie" tried to return to power, but these were easily suppressed.
[27] This situation was partially remedied by the Reform Bill of 1832.

minuscule – well below 0.5% of GNP.[28] Almost all the road, canal, and railroad building of the eighteenth and early 19th century was done with private capital. Similarly the form of land holding in large areas of the countryside were reorganized again through private initiatives.

The government did intervene to some degree in the economy. It imposed significant import tariffs, though these were largely motivated by revenue considerations. It supported British agricultural interests through the Corn Laws which limited grain imports. It also imposed the Navigation Acts which required goods to be transported on British ships, and required colonial trade to flow through Britain. This was justified partly on the military need to maintain a large cadre of skilled sailors. There were also on the books a whole series of measures requiring local magistrates to impose limitations on wages, and requiring artisans to serve apprenticeships. But the enforcement of these by local magistrates seems to have been singularly unenthusiastic, even in the seventeenth century. The same wages were passed year after year as the statutory maxima, but no-one was prosecuted and the wages bore no relation to actual market wages.

The government did also maintain a patent system which gave exclusive rights over innovations to their inventors for a limited number of years. This was established in 1624 under the Statute of Monopolies, which had swept away many monopolistic privileges. The importance of the patent system in stimulating the wave of innovation that swept through Britain in the late eighteenth century is unclear. It gave security to some innovators. But it was sometimes ineffective. And in other cases innovators used it to slow down the pace of innovation. James Watt, for example, used his control of key patents to the steam engine to block the development of new types of steam engines by other engineers, even under license

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[28] The amount of military expenditure over a period of 120 years is extraordinary by modern standards. Now the British government, which has proportionately one of the heaviest military expenditures in Western Europe, devotes less than 3% of GNP to defense. Even at the height of the Cold War the US spent only about 6% of GNP on defense.

from himself. Many manufacturers opposed the patent law and encouraged piracy – through they often had local reasons for doing so. The Society for the Encouragement of the Arts, Manufactures and Commerce, founded in 1753, offered lump sum prizes to innovators who were willing to allow free use of their inventions.

Britain on the eve of the Industrial Revolution was thus not the Smithian ideal of limited government and unfettered free markets. But it was an economy where the government played a minuscule role in directing economic activity.

The reasons for the non-interventionist policy were partly ideological and partly practical. The practical reason was that from 1688 on, Britain was engaged in a long struggle with France for military supremacy, sometimes called the Second Hundred Years War. From 1688 to 1815, when Napoleon was finally defeated at Waterloo, Britain declared war 8 times, and was engaged in fighting for one out of every two years. The wars placed enormous strains on the ability of the government to raise revenues, and severely limited its spending in other areas. For the government relied for revenue largely on excise taxes and custom duties.[29] These taxes probably fell disproportionately on the poor, as do consumption taxes generally since the poor consume a larger share of their incomes. Attempts to increase these taxes resulted in the problems of rioting, and of widespread evasion.[30] The ideological reasons for non-intervention were a long tradition in English Common Law which opposed monopolies and exclusive franchises, and strongly respected private property, as well as a general sentiment in favor of independent business activity.

[29] Under the pressure of the Napoleonic Wars an income tax was levied in 1799, but was repealed when peace came in 1816, and not reimposed until the 1840s. The other major tax in the 18th century was the Land Tax, which was imposed in 1692 on rental incomes. But since this became fixed in nominal terms the inflation of the late eighteenth century combined with the growing size of the economy steadily reduced its importance.

[30] Once the excise or customs tax got too high the incentive to smuggle or evade would rise correspondingly.

Some economists such as Douglass North and Mancur Olson have argued that it was the creation of a laissez-faire state which mainly served to provide public order and secure property rights which liberated the economic energies of people in Britain. That is why there were changes occurring in many sectors of the economy at once.

Since the changes in industry, agricultural and transport also required huge capital investments in many cases other historians have focused on changes in the capital market in the period leading up to the Industrial Revolution. The traditional account of the Industrial Revolution sees it as a period of great capital accumulation. After all there were built in this period 6,000 miles of railroad, and 2,000 miles of canals, as well as more than 18,000 miles of turnpike road. In addition we had great urban growth with all the associated housing stock and infrastructure. Also there was the expansion of the textile industries, iron and steel, and the coal mines.

Some writers of the traditional account, such as Ashton in the Industrial Revolution, seem to give almost a causal role to an increase in capital accumulation as causing the Industrial Revolution. Ashton notes that

> the importance of the lowering of the rate of interest in the half century before the industrial revolution has never been properly stressed by historians. If we seek – it would be wrong to do so – for a single reason why the pace of economic development quickened about the middle of the eighteenth century, it is to this we must look. The deep mines, solidly built factories, well-constructed canals, and substantial houses of the industrial revolution were the products of relatively cheap capital (Ashton, p. 11).

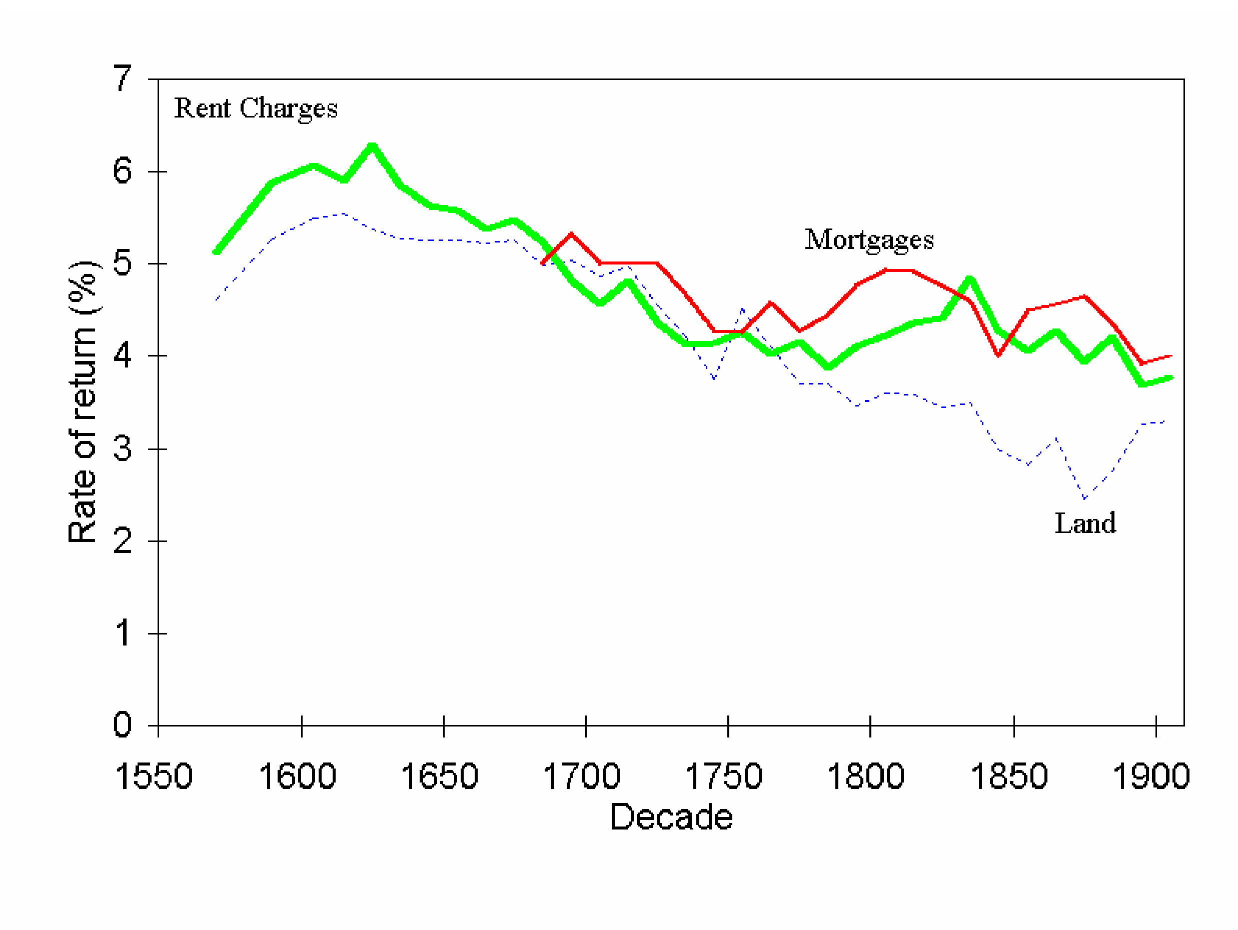
Ashton's argument is that as real incomes rose in the early eighteenth century, so did savings. Also the new political regime created by the settlement of 1688, which established William and Mary on the English throne, reduced the uncertainties associated with investment. This increased propensity to invest was reflected in lower rates of return earned on different types of capital asset in the economy. Figure 14 shows the rates of return on land, mortgages, and rent charges from 1600 onward in Britain by 10 year periods. As can be seen the rate of return on some types of assets fell quite significantly, though mainly in the seventeenth century.

As early as 1668, notes Ashton, Josiah Child, an early mercantilist writer on economics, had noted that,

> all countries are at this day richer or poorer in an exact proportion to what they pay, and have usually paid, for the Interest of Money. (Ashton, p. 10)

Thus the traditional account of the Industrial Revolution often stresses the importance of large scale investments in creating the changes of this period.

Figure 16: The Rate of Return on Capital, 1600-1912



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