

3. Modern Interpretations of the Industrial Revolution

1. The Sources of Growth

Recent thinking about the Industrial Revolution has been dominated by the idea that the driving force in events in Britain after 1760 was an unprecedented set of technological advances, spread across a wide range of sectors in the economy. Cotton textiles, iron and steel production, mechanical power sources, shipping, railways and agriculture all saw significant advances and together these more than doubled the overall productivity of the economy.

Table 1 shows the recent estimates of output and inputs in Britain or England from 1700 to 1860 from Crafts (1985), and Crafts and Harley (1992) and the implications these have for output per worker, output per unit of capital, and total factor productivity. Though their estimates tend to more pessimistic than a previous generation of economic historians they still argue for a 5.7 fold increase in output between 1700 and 1860, and a near doubling of output per worker.

Though these changes may seem dramatic they actually imply very slow growth compared to the achievements of some modern economies. Table 2 shows the estimated growth rates of output, labor and capital for the years from 1760 to 1861, and what this implies about productivity growth. The overall productivity growth rate is only 0.58% per year, though the rate of productivity growth was gathering momentum over time. Crafts and Harley's data thus suggests that by the 1830s productivity growth rates were above 1% per year, and thus at "modern" levels.

Table 1: Conventional Estimate of Outputs and Inputs, 1700-1860

Period	1700	1760	1801	1831	1861
Population	100	119	160	240	367
GNP	100	143	210	361	764
Capital	(100)	143	210	351	640
Land	100	100	100	100	100
Output per person	100	120	131	150	208
Output per unit of capital ¹	(100)	100	100	103	119
Total Factor Productivity ²	100	116	128	150	209

Notes: ¹Capital per unit of output in 1700 is assumed the same as in 1760.

²Calculated assuming wages were 50% of output, capital 35% and land 15%.

Sources: Crafts (1985); Crafts and Harley (1992), Industry, GNP 1700-1831; Wrigley and Schofield (1997), population.

Table 2: Productivity Growth in the Industrial Revolution, Crafts

Period	Output per Person Q/L (%)	Capital per Person K/L (%)	Land per Person T/L (%)	Total Factor Productivity (%)
1700-1760	0.30	0.31	-0.29	0.24
1760-1801	0.21	0.22	-0.72	0.24
1801-1831	0.45	0.36	-1.35	0.53
1831-1861	1.09	0.59	-1.42	1.10
1760-1861	0.54	0.37	-1.12	0.58

Note: Productivity growth is calculated assuming that the share of capital in national income is 35%, and the share of land is 15%, so that the share of labor is 50%. Remember that $g_A = g_Q - \alpha \cdot g_K - \beta \cdot g_L - \gamma \cdot g_T$. Do the calculation yourself to check you understand the method!

Table 3 shows the performance of the British economy in this period compared to the post World War II interlude for Britain and Germany and for Japan. As can be seen British growth in the Industrial Revolution period is extremely anemic by the best modern standards. Everything happened extremely slowly. The rate of growth of output per person was very slow, the rate of increase of the capital stock per person was very slow, productivity growth was slow. Thus while output per person grew by 70% in Britain in the 100 years between 1760 and 1861, output per person in Japan grew 640% in the thirty years from 1950 to 1980. The only thing that was reasonably fast by modern standards was the growth of population. Further the period of the great innovations, 1769-1800 experienced the slowest productivity growth and rates of growth of income per person. Growth did have a modern character, however. It was based largely on efficiency growth with capital playing a much smaller part.

Table 3: Growth in the Industrial Revolution Compared to “Modern” Growth

Country	Output per Person Q/L (%)	Capital per Person K/L (%)	Land per Person T/L (%)	Total Factor Productivity y (%)
England, 1760-1861	0.54	0.37	-1.12	0.58
Britain, 1950-80	2.05	3.07	-0.33	1.30
Germany, 1950-80	5.35	5.24	-0.66	3.07
Japan, 1950-80	6.67	6.90	-1.10	5.00

Note: ^aCapital growth rate not known, set equal to output growth. The shares of capital, labor, and resources in income are assumed to be 0.25, 0.70, and 0.05 in 1950-80.

Why was there so little growth of capital per person in this period? Overall the capital stock per person rose by only 34% from 1760 to 1860. With all the investment in cotton mills and mines, with the building of over 5,000 miles of railway, 18,000 miles of turnpike roads, and over 2,000 miles of canals, why was the capital stock not significantly increased? The answer comes if we look at the composition of the British capital stock in 1860, measured in millions of £s. This was:

Agriculture: buildings, land improvements, etc.	£400
Dwellings	£600
Buildings, Public Works	£650
Railways	£270
Mines, gasworks, waterworks	£110
Industrial Machinery	£170
Other Machinery (ships, etc.)	£ 80
Inventories	£210
Total	£2,760

Buildings alone are over half of the capital stock. The new investments of the Industrial Revolution era, railways, mines, industrial machinery, are still in 1860 only 20% or so of the capital stock. The railroads, while they had large fixed capital costs, may have saved capital invested in inventory in that they made the distribution of goods in the economy faster and more reliable. If we look at the investments in textile mills alone in 1860 we find that the total value of the buildings and the machinery for cotton mills was only £46 million, less than 2% of the national capital stock. Most of the capital was housing and infrastructure that would be determined largely by the size of the population and the real income per person.

Thus right from the start of the Industrial Revolution the message about the Industrial Revolution has been the same one as for modern economies. If we want to understand what triggered the Industrial Revolution, and why it occurred when and where it did we need to understand why efficiency grew in the economy.

Investigation of the productivity growth rates of the “revolutionized” sectors, and their likely contribution to national productivity growth, suggest that all the productivity growth can be accounted for by the sectors listed in table 4 below. Aggregate productivity growth rates will be the sum of productivity growth rates in each sector, weighted by the share of output in that sector in GDP. Thus

$$g_A = \sum_i q_i g_{Ai}$$

where g_A is the overall productivity growth rate, q_i is the share of each industry in GDP, and g_{Ai} is the productivity growth rate of each industry. If we calculate sectoral productivity growth rates on a value added basis, then the weights q_i will be value added in each sector relative to GDP. If we calculate productivity growth rates treating intermediate inputs as factors of production in each industry, then the weights will be the ratio of gross output of each industry to GDP, and these weights will add to more than 1.

Using the estimates made by McCloskey of sectoral productivity growth rates from 1780 to 1860 using input and output prices we see in table 4 that six revolutionized sectors, plus agriculture, explain all the productivity advance in the economy. The great bulk of the economy, including manufacturing, apparently saw no productivity advance from 1780 to 1860. In terms of importance the revolution in textiles matters most, explaining about 48% of all the productivity growth in the economy from 1780 to 1860. But even without anything happening in textiles from 1780 to 1860 it would still have been a period of unusual productivity advance, with a productivity growth rate of 0.30% per year, above the rate in the years 1700-1760, and certainly above the 0% rate estimated for 1265-1700. Improvements in transport and in agriculture would have significantly expanded output without any textile revolution. Thus the Industrial Revolution is still a fairly broad based occurrence. It is unlikely to be explained by chance since there was little or no connection between the advances occurring in textiles, in metallurgy, in steam power, in shipping, and in agriculture.

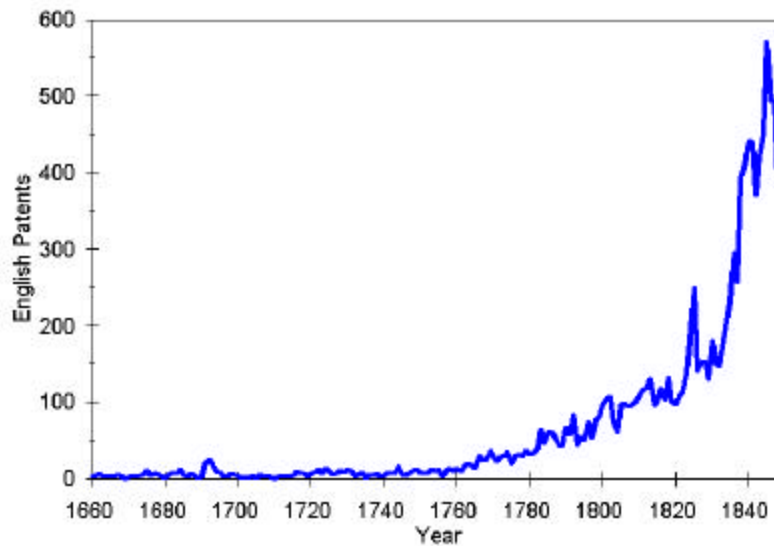
Table 4: McCloskey on the Sources of Productivity Growth in the Industrial Revolution, 1780-1860

Sector	Productivity Growth Rate, 1780-1860 (%)	Average Share of Output Value/GDP	Contribution to Productivity Growth Rate (%)
Revolutionized Industry		0.29	0.52
1. Cotton	2.6	0.070	0.182
2. Worsted	1.8	0.035	0.063
3. Woolens	0.9	0.035	0.032
4. Iron and Steel	0.9	0.020	0.018
5. Canals and Railways	1.3	0.070	0.091
6. Coastal and Foreign Shipping	2.3	0.060	0.138
Agriculture	0.45	0.27	0.12
Rest of the Economy	0.02	0.85	-0.06
All		1.36	0.58

Source: The sectoral productivity growth rates are from McCloskey (1981). Overall productivity growth rate calculated from table 3.

Broad based technological advance as an explanation of the Industrial Revolution is seemingly also supported by the patent statistics of the era. Figure 1 shows patents taken out per year in England from 1600 on. Note that on this picture of what happened in the Industrial Revolution output per person grew by 73% from 1760 to 1860. But Feinstein's recent estimates suggest real wages per person grew by only about 44% between 1770 and 1860. Thus the share of income claimed by capital and land owners seemingly increased during the Industrial Revolution.

Figure 1: Patents per Year, 1660-1851



2. The Cause of the Industrial Revolution

We have seen that the Industrial Revolution was much more limited than previously thought, being confined mainly to advances in a few industries. But it is widely accepted that it still represented the beginnings of modern economic growth founded on technological advance. It thus seems to be the major turning point in history. But why did this change occur in England as opposed to in Ancient Rome, or in the Netherlands in the seventeenth century? And why did it occur around 1770?

There have been two major schools of thought on these questions, the "evolutionists" and the "revolutionists."

Evolutionists: These people believe that the Industrial Revolution was the inevitable result of the creation of the necessary preconditions in Britain. The Industrial Revolution did not represent a radical and unexpected break from the past, but was a consequence of changes that the British economy had undergone in the years before 1770. The Industrial Revolution was inevitable or at worst highly likely given the conditions reached in Britain by 1760. It was merely the continuation of previous developments. We saw in the first section of the class notes that already by the first half of the eighteenth century the economy was showing signs of progress in that population and wages were both rising.

To make this explanation convincing we should thus be able to specify what were the necessary pre-conditions for the Industrial Revolution, and show why they were not present before 1760. We should thus be able to show why Ancient Greece, or Ancient Rome, or China in the fifteenth century could not have experienced the Industrial Revolution.

Revolutionists: The Industrial Revolution was a chance event. It could have happened elsewhere, it could have happened at another time. There is no reason to believe that Britain in 1760 was any more likely to experience an Industrial Revolution than France, Belgium, the Netherlands, Germany, or Switzerland. There was no reason that an Industrial Revolution need not have happened in Ancient Rome or Greece, or in China in 1700. Small changes in circumstance could have caused a very different outcome for the world economy. Had one person such as Arkwright been living in France instead, then I might well be standing here explaining (in French) why the Industrial Revolution was bound to occur in France in 1770, why the preconditions were set and the mechanism was assured. Had Arkwright stuck to dealing in hair then the world might have waited another hundred or two hundred years for

the breakthrough of the Industrial Revolution. This view implies that the details of history matter. Accidents are important in telling the history of the world. From the same initial conditions in 1700 there were numerous possible outcomes, none overwhelming probable.

THE INDUSTRIAL REVOLUTION AS AN EVOLUTION

The core of this argument is that there was something different about British society in 1760, compared to the societies that had come before, that made rapid innovation highly likely.

The argument in part is the negative argument that the Industrial Revolution was too complex an event to be ascribed to chance or accident, and thus must stem from some systematic feature of Britain in 1760. For a start it was not a randomly chosen country in the world that experienced the Industrial Revolution. Already by historical standards England was an advanced economy as early as 1700. We saw, for example, that the productivity of British agriculture was very high already in 1700. It is estimated that by then England was the economy in Europe with the highest income per capita. It had an income level equal to that of The Netherlands, and perhaps 20% ahead of France. London was the largest city in Europe, and was twice the size of Paris. There was already a large share of the population employed in industrial activity. If the Industrial Revolution was a chance occurrence, why did it occur in the world's then most advanced economy?

Further there was no single, crucial innovation which created the Industrial Revolution. It is true the textile innovations were very important, but even within textiles there were many innovations and improvements of innovations that generated the rapid productivity growth. Outside textiles there were improvements in steam engines, and iron and steel, and the introduction of steam railroads. The chances that this was all luck were extremely small. The British must have been searching much more actively or more successful for advances in technique than did previous economies. The idea that there was a big upturn in the degree of energy people put into searching for innovations in the late eighteenth century is supported by the fact that the number of patents taken out rose sharply for both industrial and agricultural innovations, even though the mechanisms of innovation were very different in agriculture. Also the number of books on topics such as agriculture expanded sharply in the late eighteenth century, as did the number of societies devoted to agricultural improvement.

The famous innovations of the Industrial Revolution were mainly relatively simple, and had little connection to scientific discoveries. They were made, by and large, by practical tinkers who had knowledge of some industry. These discoveries would have been made long before if there had been an appropriate set of incentives. Had the Greeks, the Romans, or the Italians of the Renaissance been looking for better textile technologies they were quite capable of finding them.

Finally if the advance of the British economy was the result of happy accidents, then we would expect that the other countries would quickly learn of these discoveries, and exploit them as effectively as the British. The British government did have prohibitions on the emigration of skilled workmen until 1825, and on the export of machinery until 1842. But these prohibitions seem to have been largely ineffective. Many thousands of skilled British artisans emigrated to the Continent and to the USA in the period between 1770 and 1825 lured by promises of high wages in return for carrying knowledge of new techniques with them. Boulton of the firm of Boulton and Watt, for example, was invited to Sweden by the Swedish crown in the late eighteenth century. The Paris-Rouen railway line built in 1841-43 was promoted by a British diplomat and one third of the capital raised was from Britain. All the early locomotive engineers were British, and its locomotives were built by a British firm.

Yet despite the porous nature of international borders, Britain established a very large lead in industrial output per capita by the mid-nineteenth century. If industrial output per capita in the United Kingdom (Britain and Ireland) in 1860 was 100 units per head, then the level of output in the closest competitors was:

Belgium	44
Switzerland	41
France	31
Germany	23
Italy	16

Thus the output of industrial products per capita was more than twice as great in the United Kingdom than in Belgium and Switzerland, and more than three times as great as in France.¹

The argument that there was some predictability to the Industrial Revolution runs into difficulty, however, when we try to

¹ Ireland was largely rural in 1860, so that the comparison between Britain alone and these other countries would show an even larger advantage for Britain.

specify just what was different about Britain in 1760. The principal ideas for what lay behind the Industrial Revolution are:

- 1. Incentive Structure of British Economy by 1760**
- 2. Advance in the General Level of Education**
- 3. Accretion of Knowledge**

Incentives in Britain

Since Britain was a relatively laissez-faire economy with a very stable political system in the eighteenth century historians have sometimes argued that the breakthrough of the Industrial Revolution was the result of a very favorable economic environment for innovation. The problem with securing technical progress in any economy is that innovators such as Hargreaves and Crompton produce a strange good, which is “knowledge.” Unlike wheat or cloth, where if I sell you a unit of the good, it does little to change the price of any other units I produce, it is very hard to make any profit from producing knowledge unless there are social institutions in place to protect the property rights of the innovator.

Suppose that in 1300 in Britain I introduced a simple hand operated spinning machine such as Hargreaves later introduced. The 1300 economy had no effective mechanism to protect property in knowledge. I could have worked the machine myself and profited by being able to produce much more yarn per hour than other spinners. In that case the return from innovation would be very modest, and there would be little incentive for anyone to innovate. But suppose I try to increase my rewards by hiring others to work the machine. If it is relatively simple then when others see how it works they will be able to describe that the machine sufficiently well to other craftsmen so that they will be able to produce a replica. Once that happens the machine will spread to all my competitors and my profits will be exhausted. As Richard Roberts, the inventor of the power loom noted, “no trade can be kept secret long; a quart of ale will do wonders in that way.” Similarly Arkwright noted “We may swear [the hands] as we pleased, but if any body would give them a penny more, they would divulge it.” (Houghton, p. 111). Thus there will be little financial inducement for people to pursue easily copied innovations if there is no effective patent system in place in a society.

Were incentives in Britain after 1760 unusually favorable for innovation? Britain initiated a patent system in the reign of Elizabeth I (1568-1603). A patent cost £100, which was a

considerable sum for a small innovator, for a 14 year monopoly on the device. The system was originally designed to promote the immigration of Continental craftsmen to England, and was actively supervised by government ministers seeking to introduce better techniques. In the seventeenth century the system was subject to abuse by the impecunious Stuart Kings who sought the revenue the patent fee generated. They would grant spurious monopolies as a way of inducing people to pay for patents. After the Glorious Revolution of 1688-9 the new regime sought to escape the taint of scandal associated with the system by devolving the supervision of patents to the courts. Generally the courts would allow any patent to be registered as long as no other party objected. No major European country had a formal patent system as in England before 1791.

There is a long lag, however, between the introduction of the patent system in England and the increase in innovative activity after 1760. Also while countries such as France did not have a formal patent system, they did reward innovations deemed in the public interest. The King was able to award *privilèges* to innovators, giving them exclusive rights to exploit an innovation, from the sixteenth century on. In 1762 this old system was codified in the form that the privilege was to last 15 years, and had to be employed within one year of the grant. The King would also reward worthy innovators through either lump sum grants or life pensions, ennoblement and hence exemption from taxes, or setting them up in royal manufactories. The drawback of the French system was that a worthy innovation might fail to be granted privileges if the government officials were not impressed or were hostile to the innovator. And innovators with political connections could secure spurious monopoly rights. When John Kay failed to enforce his English patent in the courts he went to France in 1749 and received large cash grants for instructing weavers on how to use the flying shuttle. The English Parliament refused to grant him any monetary reward when he applied to them.

Further most of the innovators in the early Industrial Revolution period either did not try to protect their innovations with patents, or were unsuccessful when they tried to do so. Kay patented the flying shuttle but was financially ruined by litigation costs in trying to defend the patent. Later Hargreaves, Crompton, and Cartwright all derived no benefit from patent protection (Crompton and Cartwright were awarded modest pensions by the government later in compensation). The only early cotton textile innovator able to derive profits from patent protection was Arkwright. But Arkwright made most of his money from setting

up factories of his own or in partnership after his patents were invalidated in 1785. Thus it is hard to know exactly how much of the fortune Arkwright made in the textile industry came from the patent rights he took out.

The Swiss inventor Aimé Argand took out a patent for a new type of oil lamp in England in 1784, licensing the production to Matthew Boulton, Watt's partner. The ease with which the lamp could be made encouraged a host of infringements, and legal action had to be taken against them. But the legal case failed in 1785, and the patent was declared invalid. In contrast in France Argand was granted a royal subsidy of £1,000 to set up a factory to produce his lamps, and his business flourished until the Revolution.

The uncertainties of legal protection for patents are illustrated in the case of John Heathcoat, who patented a lace making machine in 1808. In 1813 when he tried to prosecute an infringer of his patent, he had to abandon the case when it was discovered that a copyist had omitted a single line from the patent specification. In 1816 his patent was secured in a different court case. But at this point there were said to be 156 unlicensed makers and owners of his machines. After the successful legal case Heathcoat agreed to issue licenses for 700 outstanding machines, licenses which produced an income of £10,000 per year. But many unlicensed machines continued in operation, reducing the price of lace, and hence the profit derived from the patent.

Thus the record of the British patent system was a very mixed one. Some innovators were able to secure their rights, but equally some fared very poorly in the courts. From 1750 to 1799 of 18 patent infringement cases brought to court where the verdict is known, only 7 were concluded in favor of the patent owner.² Only in the 1830s did the courts become much more favorable to the plaintiffs. And the risk and cost of litigation induced many innovators to compromise with infringers for modest sums, or to tolerate infringement of their patents. There is no clear evidence that the British system was superior to earlier systems of royal patronage and rewards such as the French system before 1789.

There is also good evidence that a lot of the innovation in the textile industry was quickly leaking from the innovators to other producers with no rewards to the innovators. Knick Harley has reconstructed the profit rates being made by some of the more successful cotton spinning and weaving firms in the early

² Dutton, p. 78.

Industrial Revolution period. The cotton spinners *Samuel Greg and partners* earned an average profit from 1796 to 1819 of 11.7% per year, where the safe return on capital would be 5%. This is just a very normal commercial return for a risky venture such as manufacturing. Given the rapid improvements in cotton spinning productivity going on in the industry in these years it suggests that whatever innovations were being introduced were spreading from one firm to another very quickly. Otherwise leading firms such as *Samuel Greg* would have made large profits compared to their competitors. Similarly the firm of *William Grey and partners* made less than 2% per year from 1801 to 1810, which is a negative economic profit rate. The innovations in the cotton spinning industry seem to have mainly caused prices to fall, leaving little excess profits for the firms that were innovating.

The firm of *Richard Hornby and partners* in the years 1777 to 1809 was in a sector of the industry, hand loom weaving, which had not yet been transformed by any technological advance. Yet its average profit rate was 11.4%, as high as *Samuel Greg* in the innovating part of the industry. The conclusion is that the host of innovations in cotton textiles do not seem to have particularly rewarded the innovators. Only a few such as Arkwright and the Peels became noticeably wealthy.

The deficiencies in the patent system led some innovators to prefer secrecy as a way of trying to earn profits from their innovations. A famous example of this is Henry Bessemer's machine for producing gilt powder. Until 1843 gilt powder for decorating was made from little sheets of bronze which were hammered by hand between skins to form bronze leaf which was then pulverized. This hand industry was so time consuming that the resulting powder cost as much as gold. The world gilt industry was concentrated in Nuremberg in Germany.

When Bessemer discovered a set of simple machines which would make gilt powder at far lower cost he decided against patenting his discovery since a patent required describing the machine well enough so that someone else could copy it, and patents only protected the invention in England, not in other countries. To keep his discovery secret he had the machine parts made by different metal forming firms. He and his two brothers-in-law then assembled the parts in an inner room of a factory which had a double set of doors. The inner door was only opened once the outer door had been locked. The factory operated for many years without others discovering the secret producing gilt for about 5% of the cost in Germany and earning Bessemer huge

profits. The German industry allegedly sent agents to England to try to bribe workmen to reveal the nature of the machinery, but without success.

At best we can say that the rewards to innovators do not look any better than they would be in the Netherlands in the seventeenth century, or in France or Italy at the same time. At worst it is not clear if the rewards to innovators were any better than in the middle ages or the classical world.

Some have argued that what made the rewards for innovation particularly high in Britain was the social structure. In eighteenth century Britain wealth led quickly to social prestige and political power. Thus Arkwright who had completely humble origins was knighted, and became the sheriff of Derby County, a high local position. Robert Peel senior, another early cotton magnate, became a member of Parliament, and saw his son go on to become Britain's youngest prime minister. But it was the case in most continental countries that wealth also led to easy access to the nobility. Thus in seventeenth and eighteenth century France the Kings ennobled large numbers of people in return for cash as a way of raising revenue. Louis XIV is said to have ennobled 500 people in one year alone.³

An alternative argument that the incentives for innovation were uniquely favorable in Britain in the eighteenth century is that the government was strong and stable, and so blocked all attempts to obstruct innovation by those who would lose. Any innovation generally creates both winners and losers in a society. It is an efficient innovation if the monetary value of the gains of the winners exceeds the monetary value of the losses of the losers. But as we saw even the spectacular gains in cotton textiles created both winners and losers. The losing groups will often try and block innovations by legal or extra-legal measures. In England of the eighteenth century the government repealed laws that mandated obsolete ways of producing goods, and vigorously moved to squash labor organizations (called "combinations" then) that in part opposed new techniques. Local magistrates called out the militia to defend the new factories when they were attacked by mobs, and when the rioting got beyond local control, as with the Luddite riots, the central government sent in soldiers.

While the argument above may be correct it is not clear if Britain in the eighteenth century was unusually well placed to

³ In France before the revolution nobles were exempt from taxes, so that a title was also a valuable thing to possess economically.

allow innovation. In the medieval period, for example, governments were much more likely to support those who wanted to impede innovation. But offsetting this in the medieval period government control was much weaker. If a new loom was introduced in one town and ran into opposition, manufacturers could switch production to another town where there were less vested interests. Nor is there any clear indication that authorities in other economies such as the Netherlands in the seventeenth century or the Northern Italian towns in the fifteenth century were any less inclined towards promoting innovation.

Literacy and Numeracy

We saw in chapters three and four that the Industrial Revolution seemed to depend crucially on the creation of new knowledge, and this creation was done mainly by relatively low level artisans, not by governments or universities. Thus one appealing argument is that the Industrial Revolution depended on the evolution of a society where a large stock of people had some degree of education, and thought about the physical world in a flexible, experimental way. Perhaps formal education transformed peoples' ways of thinking about the world so as to make them much more capable of finding improved techniques.

People in earlier societies do seem to have lacked the ability to represent the world very clearly in their written communications. They were either largely innumerate or used numbers in ways that seem just nonsensical to us. Table 5, for example, shows the ages declared by Aurelius Isidorus, a wealthy landowner in Roman Egypt in the time of Diocletian, in various documents preserved in his family archive. No two reported ages, even over relatively short time intervals are consistent. Other evidence from the archive suggests that Isidorus was illiterate, as were apparently a large proportion of the propertied classes in Roman Egypt.

TABLE 5: AGE-REPORTING BY AURELIUS ISIDORUS

Date	Declared Age	Implied Birth Year
April 297	35	262
April 308	37	271
August 308	40	268
pre-June 309	45	264
June 309	40	269

Source: Richard Duncan-Jones, Structure and Scale in the Roman Economy (1990), p. 80.

Literacy levels in the past can be estimated by looking at the number of people able to sign their names in documents such as marriage registers or wills. Since marriage registers only exist for England and France for the years from 1540 on, we cannot use this as a source to go back before then. But from 1540 we get some idea of the literacy rates of the whole population. Study of a national sample of 274 parishes in England in the 1770s suggests that 60% of men and 40% of women were able to sign their names, and were thus literate (Schofield (1973)). This may not seem a very impressive performance, but in 1901 in India it is estimated that only 10% of males, and 1% of women were literate. Indeed as late as 1981 still less than half of males in India were literate. The literacy rate in England was also higher than the rate estimated for France in 1770-79 using the same method. In France only 45% of men were literate, and only 23% of women.

The registers also show some improvement in literacy in England from 1540 to 1770. Thus in the diocese of Norwich in England there was a improvement in the literacy levels of tradesmen from only 39% in the 1580s to 66% by the 1700s. Farm workers saw little improvement, however. They went from about 7% literacy in the 1580s to 13% literacy in the 1700s. They also suggest literacy rates were higher in the north of England and in

Scotland, the areas which were most transformed in the Industrial Revolution. The reason for this was in part the religious tradition of Scotland and the north of England, where a more fundamentalist Protestantism prevailed. This Protestantism emphasized that good Christians had to be able to read the Bible themselves, and that hence educating even the poor was an important religious duty.

The problem with the argument that the spread of numeracy and literacy was key to the increase in the rate of technical progress starting with the Industrial Revolution is that while Scotland and England were relatively literate, they were not the most literate societies in the world in 1770. The areas which first achieved very high levels of literacy were instead those of Scandinavia (Sweden, Norway, Denmark, and Iceland), the Netherlands, Germany, and the New England region in America. Yet the Scandinavian countries remained relatively poor and under-developed until the late nineteenth century. That is why there was still substantial emigration from Scandinavia to the northern plains of the U.S. in the late nineteenth century. Literacy levels in the Netherlands in the seventeenth century, one hundred years before the Industrial Revolution, would be just as high as in Britain in 1770. And even though France was less literate as a whole than England, there were regions in the north east of France, such as Alsace and Lorraine where literacy rates were much higher than in England. Thus in the north east in the 1770s 80% of men were literate at time of marriage

Further the spread of literacy may just be a symptom of the economic development of countries as opposed to the cause. The reason most people were illiterate in the middle ages may well have been that literacy was of little value. Before the invention of the printing press with movable type by Gutenberg in 1453 books had to be copied by hand, and were thus extremely costly and available to very few people. It is estimated that within 50 years of the introduction of movable type more books were produced using it than had been written in the previous thousand years. As the cost of books fell the advantages of literacy increased accordingly. By 1731, for example, a literate person living in London could subscribe to the Gentleman's Magazine, a monthly publication that was a cross between the New Yorker and the Economist.

If literacy and numeracy rose mainly because technological advance had greatly increased the usefulness of literacy, can we conclude that literacy implied an enhanced capacity of people to analyze the material world? How do we test whether literacy really made any difference?

The Stock of Knowledge

Rather than focus on literacy and numeracy as the key, a broader argument focuses on the stock of practical knowledge in a society. In terms of living standards in 1760 England may not have been so different from ancient Rome or Greece, or from China in 1400. But perhaps English society was in fact in a very different condition. It was different because of the much greater stock of practical knowledge that had accumulated by trial and error over the course of the centuries. Hargreaves in 1765 trying to mechanize hand spinning had access to a much greater stock of practical information about mechanics and woodworking than would have been available to a similar mechanic in Ancient Rome. Arkwright similarly was able to call on watchmakers, clockmakers, and knitting machine makers to help him in his endeavor. People could have had ideas about mechanizing spinning before 1760, and probably did, but they would not have been able to implement them.

Why was Britain in 1760 in so much better a position? If we go back to medieval England we see many differences. The urban sector was much smaller, because a lower efficiency in agriculture in the medieval period meant that most of the population had to labor in agriculture just to feed the society. This meant that a worker in any town in the textile industry desiring to innovate would come in contact with many fewer possible partners and collaborators. There was just a much smaller and more scattered community of mechanics and artisans. Similarly the lack of a printing press meant that information about new techniques and developments spread slowly and imperfectly. When Bessemer, for example, set about mechanizing the production of gilt, he discovered how the German workers made gilt by hand by doing research in the British Library in London. In 1300 he would have had no such source. The idea here is thus that there are big economies of scale in innovation. Innovators who are part of a rich community of craftsmen and mechanics, with easy access to help and ideas, are much more likely to prosper. Similarly the presence of a community of merchants and investors who had access to capital, and a willingness to gamble, was also important in the early Industrial Revolution. Had Arkwright not found financial backers, his machine might never have been developed sufficiently to be practical.

In the modern world communities of innovators often cluster together. Thus Silicon Valley persists as a center of software and

hardware development in the computer industry, despite extremely high real estate prices, because of the gains to new firms from the rich collection of talents available there, and easy access to venture capital. Similarly the film industry clusters in the Los Angeles area, again despite very high real estate prices, for very similar reasons.

While this argument has some plausibility it fails to explain why Britain as opposed to France or the Netherlands would experience the Industrial Revolution, since they also would have accumulated a similar stock of knowledge, and had developed sophisticated urban societies. While output per capita in France in 1780, for example, was below Britain, total output in all key sectors was higher because of the much larger French population. Thus as Table 3 shows in terms of stocks of knowledge France looks as prepared.

Table 3: Comparison of France Versus Britain, 1780

	France	Britain
Total population	25.6 m	9.0 m
Cotton consumption	11 m lbs.	7.4 m lbs.
Iron production	135,000 tons	60,000 tons

THE INDUSTRIAL REVOLUTION AS A REVOLUTION

In this view the Industrial Revolution was a chance and accidental event, which might have happened elsewhere, and might not have happened till hundreds of years later. One way of telling the story as an accident would be as follows. Technical innovation had been occurring periodically in Europe since at least Roman times, but the innovations to date had all had relatively small impacts on the productivity of the economy. The key event in the

Industrial Revolution was the innovations in the cotton textile industry, which spread from there to the other textile industries such as wool, linen and silk. Of all the technical innovations in Britain between 1770 and 1860, those in textiles account for almost all of the productivity advance, and for most of the productivity advance in the economy as a whole. It turns out that of all the fibers used for clothing, cotton is peculiarly suitable for mechanized spinning and weaving. It was only once innovators showed the way with cotton that people were gradually able to extend the techniques to the other fibers.

But cotton spinning and weaving did not exist in Europe before the fifteenth century, and even after then for many years very small amounts of raw cotton were imported into Venice from Syria. Cotton does not grow well in the European climate. Imports of cotton cloth increased once the Portuguese developed the sea route to India around Africa circa 1500, and as seafaring technology improved and prices fell the amounts of Indian cloth imported increased greatly. By the eighteenth century a fashion developed for very fine printed cotton fabrics called “calicos.” This led to attempts to produce such cloths within Europe, which was initially only profitable with the coarser grades of cloth. Thus only in the eighteenth century did a significant cotton industry emerge in countries like England, France and the Netherlands.

Hargreaves and Arkwright’s discoveries of 1769 sparked an enthusiasm for innovation in the textile industries that generated a rush of new attempts at innovation. The productivity advances in textiles were so spectacular that they created an expectation that with sufficient attention other areas of production could be revolutionized in the same way.

In many ways the argument that the Industrial Revolution was a surprising and chance event stems from showing that it is hard to show any sense of inevitability about an Industrial Revolution in Britain in 1760. The fact that Britain was the most advanced economy in 1760 implies no prediction that it would continue in this position. Economic history shows that the position of leading economy and technical innovator is constantly shifting from one economy to another and from one area to another. Northern Italy was the advanced economy in the period 1400-1550. This is the period of the famous Italian painters, and of a vigorous intellectual life. But a rapid decline in the economic fortunes of Northern Italy set in the late sixteenth century, for reasons that no-one understands. Thus the textile industry was the major industrial sector before the Industrial Revolution, and a good measure of the

fortunes of industry in various economies. Textile production declined rapidly in Northern Italy from a high point in the late sixteenth century. Thus the number of woolen cloths produced in Florence fell sharply from 1572 to 1650. Thus:

Year	Cloths Produced
1572	33,000
1602	14,000
1650	6,000

Milan and Venice show the same pattern. In the same period the silk spinning industry went into decline. The numbers of pounds of silk exported from Genoa were:

Year	Silk (lbs)	Exports
1578		360,000
1621		135,000
1700		49,000

The reason the cloth industry was declining in Northern Italy was that it was being undercut by the more efficient industry developing in the Netherlands. Thus cloth production in Leyden increased from 30,000 pieces in 1585 to 140,000 in 1665. The Netherlands economy took over the position of the leading economy of Europe from 1609 until perhaps 1700. But then it mysteriously stagnated while England gained the lead in the eighteenth century.

Even within Britain the Industrial Revolution did not occur in the area of highest income and of the concentration of industry in 1700. For this was, as noted above, the south of the country. The Industrial Revolution was largely a phenomenon of the north, and

left the south mainly untouched. Real incomes did rise in the south, but mostly because textiles imported from the north were now cheaper, as was coal imported from the north for heating.

The Evolutionists argue that Britain must have achieved a new social, political and economic system that resulted in the Industrial Revolution. Yet it is impossible to identify any crucial change in the society before 1760, nor is it possible to discern any key difference between the north and south of Britain. Thus essentially the same political system of limited Parliamentary democracy covered England, Scotland and Ireland from 1688 on. Why is there such a discontinuity in results after 1760?

Also this system was associated with rapid economic growth only in the north of England and Scotland. In Ireland there was little development from 1760 on, and indeed signs of de-industrialization in the period 1770-1850 under competition from the more efficient industries of the north of Britain.⁴ In the South of England most of the growth in incomes per capita from 1770 to 1850 came from the lower cost of textile goods, iron, and coal all of which were imported from the North of the country. Had Britain been divided into two countries, "North Britain" consisting of Scotland and the North of England, and "South Britain" consisting of the rest, then the history texts would have lumped in the south with countries such as France and The Netherlands in this period, and concentrated on "North Britain" as achieving the Industrial Revolution. Thus a stable political framework may be necessary for economic growth, but it is certainly not sufficient.

Similarly interest rates fell from 1600 to 1750 on the eve of the Industrial Revolution, when they were as low as 4%. But there is no sign that the abundance of capital on the eve of the Industrial Revolution played any role in the events that followed. And the Netherlands achieved interest rates as low as 2.5% in the seventeenth century without sparking an Industrial Revolution.

The new industrialists of the north were often religious dissenters – people who held a brand of Protestantism that placed them outside the established Church of England. Such dissenting Protestants had values that were conducive to economic progress. They emphasized literacy, hard work, and frugal living. Also in

⁴ More dramatically, after 1858 the British imposed direct rule on India, setting up a very secure and stable system of property rights. Yet India remained mired in poverty from 1858 to 1947 when it regained independence. Indeed in this period its income per capita relative to Britain was falling.

Britain in this time such individuals were barred from seeking careers in the government or at the universities. Business was the only activity available to them. Could it have been the creation of this group of driven, literate, and talented outsiders that sparked rapid economic growth? Such dissenters were concentrated geographically in the north of Britain, precisely the area which industrialized after 1770. There were, however, large communities of people who held the same Protestant views all across northern Europe in the eighteenth century, yet only Britain experienced the Industrial Revolution. Also Belgium, the country which followed Britain most closely in this era, was a largely Catholic country.

One way that accident could matter would be if there are some areas of activity which are ripe for innovation in a given epoch, others which are unpromising. No one knows in advance which is which. But innovations tend to be made in areas where industrial activity is already concentrated, or where prices encourage exploration. If you are interested in innovating but have no idea what area will be most likely to yield technical advances, then it is best to innovate in the areas with the largest output, and in the processes which have the largest share of costs. Thus countries where wages are high will tend to look for innovations in the form of labor saving devices, countries where materials are very expensive will look for resource saving innovations, and countries where power is expensive will look for energy saving innovations.

Thus the accident of location of activity can have a big effect on the prospects for technical changes in a given period. The Netherlands, for example, was a very advanced society in the seventeenth century, and probably was the richest country in Europe then. Why didn't an Industrial Revolution occur in this society in the seventeenth century? One answer could be that the Dutch economy was concentrated in unpromising activities because of the location and topography of the Netherlands. Sea trade and fishing were both very important activities, but neither may have been ripe for rapid technical advance as was cotton textiles. The Dutch made important strides in developing windmills, and had built over 3,000 by 1650, but no matter how efficient a windmill was made it was inherently a limited and inflexible power source. The Dutch also greatly improved the sailing ship, but again that was a limited line of technological advance. Also improvements in building wooden sailing ships had little technological spillover into other areas of production. Finally the Dutch also were great clock makers, but again the benefits from making more accurate clocks were inherently limited.

Wrigley argues the British were focused on a fruitful path of development by the chance scarcities of the British economy as early as the seventeenth century. Britain was relatively heavily populated, so that power was scarce. Power in other societies came from mainly from wood, wind or water. But the dense population of Britain drove up the price of wood as a fuel. This led to a search for alternative fuel sources. Coal was substituted increasingly for wood in heating homes. Thus the amount of coal shipped from Newcastle to London increased by 400% from 1600 to 1700. There were also attempts to use coal for smelting iron. The exploitation of coal led to a variety of technical problems. As mines got deeper water had to be pumped out from greater depths. This led to the development of the steam engine, which because of its great inefficiency early on was particularly suited to areas where coal was cheap such as coal mines. Coal also needed to be shipped to the cities. It was bulky, so this need led to the development of the early rail tramways and canals. We saw that the development of steam railroads was intimately connected with the coal fields of the North East. Without the stimulus of the well developed system of tramways innovators might have continued to try to develop steam vehicles for public roads with little success. Thus the chance scarcity of fuel sources such as wood combined with the chance availability of coal led to a unique path of technological development. While this argument connects coal, iron smelting, steam engines and railways, it turns out that collectively these innovations explain little of the productivity growth in Britain in the Industrial Revolution period. What matters most is textiles, which seemingly could have developed without any coal industry.

CONCLUSION

My interpretation of this debate is that we can say for sure if the conventional estimates of the sources of productivity growth are correct that the Industrial Revolution was not a random, chance occurrence. It had too many components that were relatively independent to be plausibly explained by good luck. Thus there must indeed have been something special, something different about the British economy and society in 1760 compared with all the societies that had come before. There was some crucial factor "Z" which was present in Britain, but not elsewhere ("Z" might also be a combination of other factors). But the problem is that no one has been able to give a plausible account of what factor "Z" was. Dutch society in the seventeenth century looks very similar to the British in the eighteenth century. Indeed in much the same

way that countries now look to the USA as a model of how to succeed economically, British writers in the seventeenth and eighteenth century often advocated emulating some aspect of the Dutch economy.

One possible factor Z would be the following. Suppose that in any pre-industrial society there are very weak economic incentives for people to invest in new techniques, because the knowledge generated is often not appropriable. Once news leaks out others can use the new techniques, because they are still relatively simple at this stage of technical progress. Even if they are patented the small scale nature of the new machinery makes detection and prosecution of patent violators impossible. Also the inevitable opposition that new techniques generate from workers who are displaced implies that innovators often have their equipment destroyed by irate workers, or are unable to employ their devices. If a pre-industrial society is composed of self interested rational actors, then there will be little technical progress in this case.

But suppose also that people sometimes get interested in the idea of new techniques. They form a romantic view of technological progress. They fall in love with gadgets and devices. They begin to celebrate those who make industrial innovations, and regard them as heroes to be praised and emulated. In this case, despite the weak economic incentives, talented and energetic people will turn their attention to improving production techniques. They will do so in large part not because they expect monetary gain, but because of the hope for fame. Some societies celebrate the arts and literature (in current Russia, for example, poets are accorded great respect), while others give adulation to outstanding athletes. The choice about who to admire and praise is to some degree arbitrary. Thus the Industrial Revolution in Britain may be the result of no more than a cultural fad, a fashion for industrial innovation, that is as inexplicable as other fads. But once people saw the fruits of these innovations, they began to be pursued on a much more systematic way, oriented towards profit alone.

While this makes the Industrial revolution predictable once we get to the British economy in 1760, in some ways it just pushes the randomness back to an earlier period. Why did Britain evolve to be an economy of people who loved innovation and celebrated it in 1760? No one knows.

APPENDIX: A CHALLENGE TO PESSIMISM

The conventional estimates imply that the Industrial Revolution only touched a few of the industrial sectors of the economy, textiles and iron and steel, which employed less than 15% of the labor force by 1850. Large sections of the economy, and indeed large areas of southern England, witnessed no productivity gain in this period. As Peter Temin notes in a recent article “This new school of thought sees the Industrial Revolution as a much narrower phenomenon, as the result of technical change in a few industries. The new industries, obviously, were cotton and iron. All others were mired in pre-modern backwardness.”

Temin has disputed the assertion that productivity growth in the rest of industry was non-existent on the basis of British trade statistics. If we just look at British trade overall we see the pattern shown in table 6.

**TABLE 6: BRITISH EXPORT SHARES, BY DECLARED
VALUE, 1794-1856 (%)**

	1794- 96	1814-16	1834-36	1854- 56
Manufacturing/Total	86	82	91	81
Cotton and Wool/Manufacturing	45	70	70	57
Iron/Manufacturing	11	2	2	7
Other/Manufacturing	44	28	28	36

Sources: Davis, The Industrial Revolution and British Overseas Trade, pp. 95-101.

Manufactures other than cotton or wool textiles and iron continued to be a very large share of manufactured exports. Indeed the share of the advanced sectors of textiles and iron in total exports showed no significant gain between 1794 and 1854. There were large volumes of other manufactures still being exported in

the 1850s. Table 7 shows what individual goods were the most important exports of Britain after cotton, wool, linen, and iron and steel. They are listed by the value of the exports. What is impressive is the wide range of other manufactures that are still being exported in 1850. Prominent among these are hardware and cutlery, pottery, clothing, hats and umbrellas, beer, arms, stationary and books, soap and candles, and furniture.

If we look at imports as in table 8 what we find in contrast is that all the significant imports were of food or raw materials (manufactured imports are shown in bold type). Thus in the table of total imports (aside from textiles and iron products) of £93.2 m. per year, food and raw materials were £88.4 m., and manufactures only £4.8 m. But manufactures include £0.93 m. for wines, which could not be easily produced in Britain, and £0.90 m. for “spirits” which again may be produced abroad as a way of sharply reducing the transport costs of the raw materials. In contrast exports of manufactures other than textiles and iron totalled a much more impressive £14.0 m.

Thus, though Britain had a huge markets for boots and shoes in 1850, with 30 million people to be shod, the total imports of boots and shoes were a mere £94,779, which is dwarfed by imports of sugar at £10,762,045, and even by imports of currents at £559,919. Similarly there were no significant pottery imports, despite exports of £975,855 of earthenware goods. Hats were exported, but not imported. Similarly though £2,366,502 of hides, skins, and furs were imported to be manufactured into leather products, very few manufactured leather products such as leather gloves (£81,441) were imported.

Temin argues that the failure of Britain and Ireland to import any significant quantities of manufactured goods reveals there must have been widespread technological improvement in other manufacturing in Britain. For suppose that Britain had technical advances only in textiles. Then the cost of production in textiles should be less than for other areas of manufacturing in Britain than in the rest of the world. Britain should thus start exporting textile products. But exports and imports don't depend on the absolute costs in one country relative to another, they depend on comparative costs. In particular suppose that Britain produced two manufactured products, textiles and pottery, both of which used only labor. Suppose that each required in Britain one unit of labor per unit of output. Suppose also that in other countries the labor requirements were respectively 10 units and 1 unit of labor. I.e.

TABLE 7: EXPORTS OF MANUFACTURES OTHER THAN YARN, CLOTH OR IRON GOODS BY VALUE, 1850-2

Product	(£)
Hardwares and Cutlery	2,556,441
Brass and Copper Manufactures	1,830,793
Haberdashery and Millinery	1,463,191
Earthenware	975,855
Machinery and Mill-work	970,077
Tin and Pewter Wares and Tin Plates	904,275
Apparel, Slops and Negro Clothing	892,105
Beer and Ale	513,044
Arms and Ammunition	505,096
Stationary	373,987
Apothecary Wares	354,962
Lead and Shot	339,773
Glass	296,331
Plate, Plated Ware, Jewellery and Watches	286,738
Soap and Candles	275,200
Painters' Colours and Materials	237,880
Books	234,190
Cabinet and Upholstery Wares	155,407
Cordage	155,127
Hats	141,084
Leather Saddlery and Harness	121,401
Musical Instruments	85,006
Umbrellas and Parasols	72,928
Carriages of all sorts	57,018
Spirits	52,843
Fishing Tackles	41,607
Mathematical and Optical Instruments	34,289
Spelter, Wrought and Unwrought	22,097
Bread and Biscuit	15,529
Tobacco (Manufactured) and Snuff	14,762

Notes: These figures are for Britain and Ireland together.

Source: Parliamentary Papers, 1852 (196) XXVIII.1, quoted in Temin (1997).

TABLE 8: IMPORTS OTHER THAN TEXTILE AND IRON PRODUCTS BY VALUE, 1850-2 (£)

Product	Value of Imports
Raw Cotton	23,670,472
Sugar	10,762,045
Tea and Coffee	9,276,680
Corn, Meal and Flour	9,167,600
Silk	5,163,865
Flax and Hemp	4,114,264
Hides, Skins, and Furs	2,366,502
Wool	2,049,348
Cochineal	1,909,848
Oil	1,793,320
Madder, Madder Root, and Garancine	1,687,568
Tallow and Lard	1,592,679
Guano	1,476,940
Indigo	1,191,495
Wood and Timber	1,153,477
Dye and Hardwoods	1,104,308
Butter and Cheese	1,003,779
Spelter (zinc)	957,540
Wines	927,721
Spirits	902,351
Pork, Bacon and Hams	892,841
Currants and Raisins	730,362
Seeds	719,017
Rice	668,585
Potatoes	562,595
Copper, Unwrought and part Wrought	477,778
Spices: Cinnamon etc	474,697
Brimstone (Sulphur)	383,691
Tobacco	367,685
Saltpetre and Cubic Nitre	355,564
Gum	298,147
Oil Seed Cakes	296,993
Glass	270,110
Bark and Cork	266,904
Ashes, Pearl and Pot	238,077
Turpentine	213,561
Bones of Animals and Fish	209,326

Quicksilver (Mercury)	201,669
Tin	200,801
Sago	178,329
Watches and Clocks	169,589
Lead, Pig and Sheet	169,024
Borax	164,565
Terra Japonica and Cutch	150,035
Hair or Goats' Wool, Manufactures of	148,473
Cocoa, etc, and Chocolate	145,973
Tar	142,819
Animals, living	138,607
Beef	122,855
Embroidery and Needlework	114,999
Copper Ore and Regulus	113,166
Safflower	94,911
Boots, Shoes and Calashes, and Boot Fronts	94,779
Lace, Thread, and Cushion or Pillow Lace	82,816
Leather Gloves	81,441
Shumac	80,320
Oranges and Lemons	74,845
Rhubarb	70,912
Valonia	66,799
Horse hair	63,159
Fish, of British taking	60,405
Almonds of all sorts	59,705
Pimento	57,222
Liquorice	54,153
Senna	53,452
Rags, &c. for Paper	49,140
Bees' Wax	46,160
Teeth, Elephants'	44,661
Bristles	44,048
Cassia Lignea	43,735
Books	33,865
Annatto	25,468
Isinglass	24,685
Figs	22,812
Barilla and Alkali	2,122

Notes: The numbers in bold type are those for imports of manufactured products.

Source: Parliamentary Papers, 1852 (196) XXVIII.1, as quoted in Temin (1997).

Table 9: Labor Requirements per Unit of Output

	Britain	Other Countries
Textiles	1	10
Pottery	1	1

Ricardo showed that in this case what will happen with free trade is that Britain will both export textiles, and import pottery. For trade depends not on absolute advantage, but on comparative advantage. Thus if the Industrial Revolution improved only the textile sector in Britain, then it would imply not just exports of textiles, but corresponding imports of other manufactured goods. This trade would continue until the relative price of textiles and pottery was the same in the rest of the world as in Britain. No textiles would be produced elsewhere, and no pottery in Britain.

We can generalize this result to the case where there are many different goods which experience different amounts of technical advance in Britain as follows. Suppose these are N manufactured goods. The technology of each country can be described by the labor needed to produce each of the N goods. Let the labor requirement to produce the i th good in Britain be a_i , where a_i is the number of hours of British labor needed to produce a single unit of the i th good. In this case $1/a_i$ is the output per worker hour in industry i , which is the efficiency in Britain of industry i .

Let a^*i correspondingly represent the hours of labor needed to produce the n th good in the rest of the world. A low number a^*i means a higher level of efficiency in producing the good abroad, since $(1/a^*i)$ is the output per worker hour in industry i abroad, which is the efficiency abroad of industry i .

The ratio of the labor needed to produce good I in other countries and in Britain is a^*i/a_i , which measures British efficiency relative to efficiency abroad. The goods can be re-ordered by this ratio, starting with the good for which the relative quantity of foreign labor needed for production is the highest (so the ratio, a^*N/a_N , is the lowest).

$$a^*1/a_1 > a^*2/a_2 > \dots > a^*N/a_N$$

1 is thus the industry in which Britain had the highest relative efficiency. The pattern of trade is determined by the relative costs of producing goods in the Britain versus other countries. Let w be the British wage; w^* , the wage in the rest of the world. Then the cost of producing good i in Britain is $w a_i$, while the cost abroad is $w^* a^*i$. Any good for which $w^* a^*i > w a_i$ will be produced in Britain because its production costs are cheaper in Britain. This implies that any good for which

$$a^*i/a_i > w/w^*,$$

or in effect

$$\frac{\text{BritishEfficiency}}{\text{ForeignEfficiency}} > \frac{\text{BritishWages}}{\text{ForeignWages}}$$

will be produced in Britain. All other goods get produced abroad.

Where the cutoff comes between exports and imports depends on the level of wages in Britain relative to the rest of the world. The higher are British wages, the higher the relative efficiency of a British industry has to be to allow exports of goods. Since British wages in 1850 were higher than those of all competitors this implies that any manufactured good that was produced at the same efficiency in Britain as abroad would be imported.

Consider now the effect of technical change in Britain in the Industrial Revolution. Suppose at the same time there was no technical change outside of Britain, that is, no change in labor productivity in the other countries. The improvements in productivity in textiles would increase British wages relative to those of the rest of the world. Textiles would now be exported, but some industrial products in those industries that experienced no technical change would start to be imported, as British wages rose. If other manufacturing goods saw no gain in productivity in the industrial revolution period, then since British wages in this period increased by at least 80% we should expect them to begin to face severe competition from abroad.

Since tables 7 and 8 suggest that still in 1850 almost all British manufactures were exported rather than imported Temin concludes that there must have been substantial productivity advance in the rest of the manufacturing sector also. In one of those few cases where we see manufactured imports exceeding exports, such as for watches and clocks, it had already been noticed by historians that

there had been a failure in this case by the British industry to make advances. Since productivity stagnated in the British industry it had become an import industry by mid-century. Since other manufacturing areas remained exporters, they must have seen productivity advance. It follows therefore that other British manufactures were not inefficient and stagnant, or at least, they were not all so backward. The spirit that motivated cotton manufactures extended also to activities as varied as hardware and haberdashery, arms and apparel.

Temin concludes that there must have been more technical progress outside the famous revolutionized industries to produce the results shown here. A corollary of Temin's article is that overall productivity growth in Britain in 1770 to 1850 was much faster than the aggregate figures suggest, so that the Industrial Revolution must have been more impressive than recent calculations suggests.

Is Temin's conclusion correct? Temin's argument makes three basic assumptions:

1. Labor is the only input.
2. There is free trade in all goods.
3. Technical progress in Britain does not diffuse quickly to the rest of the world.

The conclusions Temin wishes to draw follow nicely from his assumptions, so the crucial issue is the assumptions. Let us consider each of them.

LABOR IS THE ONLY INPUT. For manufacturing I do not think this is a particularly restrictive assumption, given the widespread international trade in the raw materials required for manufacturing, many of which were imported into Britain. But for agricultural the use of land in production means that we cannot say anything about productivity growth from trade flows without considering that constraint. Suppose, for example, the agricultural area of Britain had been 1 acre and not 29 million acres. Then we could have had productivity growth in agriculture at 10% per year and still have observed food imports. So this first assumption requires that we can only discuss the relative productivity growth of "footloose" manufactures. Given that Britain was constrained to import large amounts of food by 1850, the question is now why it did not pay for these only with exports of the revolutionized sectors - textiles and iron and steel?

TRADE BARRIERS. Suppose that either (a) barriers to exports of textiles exist or (b) Britain completely saturates the market for machine-made textiles in other countries by 1850. Then it might be forced to pay for food imports by exporting other manufactured products, even though they had witnessed no technological advance given the dense population of Britain and Ireland. The only constraint that would then arise would be that the wages of British labor could not rise relative to foreign competitors. Otherwise the non-revolutionized British products would cost more than the international competitors. This would say that the gains from technical progress in Britain in the Industrial Revolution could mainly accrue to workers in other countries in the form of cheaper textiles exported from Britain without much gain going to British workers.

In practice there were many trade barriers in the textile market in the 1850s. Markets in countries such as France, Germany, Russia and the USA were heavily protected by tariffs against British goods.

KNOWLEDGE DIFFUSION. Suppose that while the efficiency advances in British industry were confined mainly to textiles, the efficiency gains which were based on knowledge spread quickly to the rest of the world. There were textile mills in many other countries by 1850 including France, Belgium, the Netherlands, Switzerland, Germany and the US. Thus Britain did gain some comparative advantage in textiles, but not anything like the advantage Craft's figures for productivity growth in Britain alone would imply. In this case any gains Britain made in income per capita relative to other countries in the Industrial Revolution period were achieved by better X-efficiency rather than by better technical knowledge. Suppose Britain was in 1770 a relatively efficient producer of a whole range of traditional products, including textiles. It could be that in 1850 it had the same relative advantage across the board, based on some national level of manufacturing competence.