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Econ 110B
Spring 1999

6. WHAT CAUSED THE INDUSTRIAL REVOLUTION?

6.1 INTRODUCTION

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 still represented the beginnings of modern economic growth founded on technological advance. 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 are 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.

6.2 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 which 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 tinkerers 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 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

[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.

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 a 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.

[2] Dutton, p. 78.

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 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 allow innovation. In the medieval period, for example,

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

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 6.1, 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 6.1: AGE-REPORTING BY AURELIUS ISIDORUS

Date	Declared Age	Implied Birth Year (AD)
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.

Note that four of the five declared ages are divisible by five. This phenomena, called "age heaping," is very characteristic in censuses of poor countries even now. Figure 6.1, for example, shows the population of Turkey in 1945 by gender and age. As can be seen while ages ending in 0 or 5 should be only one fifth of the population, the numbers so reported are much greater. This happens because many people either did not know their exact age, or attached no significance to it, and so gave the census taker only an estimate. Notice that the degree of "age heaping" is greater for women than for men, reflecting the inequalities in education between men and women found in most poor societies.

We can use the degree of age heaping as an index of the degree of numeracy of a society. The more age heaping we find the less literate and numerate a society is, at least in the modern world. If X is the percentage of ages in a sample which are divisible by 5, a standardized measure of the degree of age heaping is Z, where

$$Z = (X-20)\times 1.25$$

Z will range from 0 (no age heaping) to 100 (all ages given as multiples of 5). This can be loosely interpreted as the percentage of people who do not know their exact age. Thus in Egypt in 1947 the Z is 75 for men aged 23-62, and 80 for women. It is estimated that at that time 68% of men in Egypt were illiterate, and 91% of women. Thus the two measures accord reasonably well.

The age at death recorded on tombstones in Ancient Rome shows very strong heaping, as is illustrated in figure 6.2. Table 6.2 shows the degree of age heaping according to this measure for persons aged 23-62 in the Roman world. Since these figures are calculated from ages recorded on tombstones, it limits the sample to the economically select strata of society whose members could afford tombstones. As can be seen even in the upper classes of Roman society a large number of people's exact age was unknown when they died, implying that there was a high degree of illiteracy even in this select group.

As a comparison the table shows the degree of age heaping in some communities in western Europe from 1540 to 1833. The recorded age at death is shown for the towns of Geneva (Switzerland), Liege (Belgium) and Paris. Since these are the records for all deaths they will include poorer members of the society, which would not appear in the Roman records. These death records clearly show that by 1700 western Europe far exceeded the ancient world in the degree of numeracy, and hence likely also in literacy. Also shown is the degree of age heaping found in some records of some living population groups in England in the early nineteenth century. As can be seen, even though these are relatively poor groups, those in a poor house, and in cotton textile factories, there is very little sign of age heaping. Apparently by the early nineteenth century most people in England knew what age they were, and were able to keep track of that as the years passed. The detailed numbers from England are given in the appendix so that you can calculate the degree of age heaping for yourself. Do this as an exercise to make sure you understand the procedure.

FIGURE 6.1: AGE HEAPING IN TURKEY, 1945

FIGURE 6.2: AGE HEAPING IN ANCIENT ROME

TABLE 6.2: AGE-HEAPING, ROME VERSUS LATER EUROPE

Place	Index of Rounding, Z		
	All	Male	Female
Imperial Rome			
Rome	48.6	47.0	50.2
Italy outside Rome	42.2	42.6	41.8
Gaul	43.6	44.1	43.1
Africa and Numidia	51.8	51.4	52.2
Spain	57.5	56.6	58.4
Germany	39.0	57.3	20.7
Modern Europe, death records			
Geneva, 1560-1600	54.5	-	-
Geneva, 1601-1700	44.5	-	-
Geneva, 1701-1800	23.4	-	-
Liege, 1740	26.2	-	-
Paris, c. 1750	15.3	-	-
England, Poor House, 1816	23.1	-	-
England, Cotton Factory Workers, 1833	5.5	6.4	4.2

Source: Richard Duncan-Jones, Structure and Scale in the Roman Economy (1990), p. 84, 90.

Another indirect source on people's facility with numbers comes from looking at the sale prices of pieces of land. In England in the middle ages land of varying sizes transacted at a surprisingly small number of different prices. Prices tended to be quoted in very simple units, using very rounded numbers. The modern equivalent would be if all houses in Davis sold only in units of $50,000. That is houses would sell for $50,000, $100,000 or $150,000 but at no price in between. Table 6.3 shows for a set of samples of land sales the number of transactions and the number of separate prices recorded. Thus in 72 land sales before 1376 there were only 12 separate prices quoted. In contrast by the nineteenth century we would expect to see 45 separate prices quoted in 72 land transactions. People later used much finer gradations of monetary value. But the switch to a more sophisticated use of numbers seems to have been largely complete by the sixteenth century.

TABLE 6.3: LAND PRICE VARIATIONS

Period	Transactions	Prices	Transactions/ Price
pre 1376	72	12	6.0
1556-58	27	14	1.9
1600-49	320	157	2.0
1650-99	600	265	2.3
1700-49	1,056	427	2.5
1750-99	466	254	1.8
1800-49	451	301	1.5
1850-1912	801	470	1.7

Source:

Literacy levels in the past can be also 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:

	France	*England*
	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

6.3 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 Exports***
1578	360,000 lbs
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 form 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

[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.

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 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 lead 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.

6.4 CONCLUSION

My interpretation of this debate is that we can say for sure 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 and 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: AN EXERCISE

We saw how we can use age heaping to examine the degree of numeracy in different societies. The following table gives the age distributions of a group of factory workers in 1833 in England, and of a group of poor house inmates in 1816 in England, who would be the poorest and least well educated workers. Calculate the implied Z score for each group and compare it to the Z score of Ancient Rome. Was there any apparent difference in numeracy between men and women factory workers?

REPORTED AGE	POOR HOUSE INMATES, 1816	COTTON FACTORY WORKERS, 1839 MALE	COTTON FACTORY WORKERS, 1839 FEMALE
23	1	104	138
24	0	83	100
25	0	100	99
26	0	73	72
27	0	79	67
28	0	75	54
29	0	52	45
30	3	76	57
31	1	31	21
32	1	51	24
33	1	46	20
34	1	41	10
35	1	46	25
36	0	45	22
37	0	21	13
38	0	38	21
39	1	26	10
40	2	38	15
41	1	17	11
42	0	34	12
43	2	12	6
44	0	18	4
45	2	17	5

REPORTED AGE	POOR HOUSE INMATES, 1816	COTTON FACTORY WORKERS, 1839 MALE	COTTON FACTORY WORKERS, 1839 FEMALE
46	1	13	10
47	0	18	3
48	0	21	4
49	0	9	4
50	1	27	2
51	0	6	0
52	3	7	1
53	0	6	0
54	2	12	1
55	0	10	2
56	0	5	0
57	0	3	1
58	0	3	1
59	0	8	0
60	1	9	1
61	0	1	0
62	1	3	0
all (23-62)	26	1,284	881

Sources: British Parliamentary Papers, Factories Inquiry Commission, Second Report. 1833. Dr. Mitchell's Report, p. 21. British Parliamentary Papers, Children's Employment Commission.

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