3. The Significance of the English Industrial Revolution

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

Introduction

The Industrial Revolution has been traditionally regarded as one of the most important discontinuities in world history - a sharp break between a world of technological stagnation and one of technological dynamism. Recent quantitative studies suggest that this discontinuity was less dramatic than earlier descriptions of the Industrial Revolution, such as that above, implied. A new factory civilization did not spring up overnight from the fields of England. Even such a distinguished economist as David Ricardo, writing in the 1810s, a generation after the Industrial Revolution had seemingly commenced, was totally unaware that there had been a profound shift in the way economies operated. He was unaware because the Industrial Revolution consisted mainly of a gradual drift upwards in the efficiency of techniques and a gradual spread of new mechanically powered processes. The transforming power of the Industrial Revolution came not from its suddenness, but from the steady accumulation of small improvements in technique year by year. We in our lives have all seen much more revolutionary change than those of the inhabitants of Industrial Revolution England.

But the importance of the Industrial Revolution is not in its speed and drama, it is in whether it truly was the beginning of a world transformed, one where we lost all limits on the

[1] McCloskey (1981), p. 103.

potential material living standards of the average person. And economic historians do find that around 1800 in England there was an epochal shift in the way economies operated. Thus figure 1 shows the estimated rates of productivity advance for the English economy, by 25 year period, from 1700-24 to 1975-99. By 1800 estimated efficiency growth rates were higher than those ever observed over sustained periods for any pre-industrial economy. And by 1830 efficiency growth rates were well within the modern range.

The prime candidate for the source of this efficiency advance has been a sudden and marked increase in the efforts devoted to the search for innovations in the 1760s. One measure we have of the search for new techniques is the number of patents taken out each year. Most of these patents had no economic value, and some were for quite fantastical fancies. But they are an indication of how much activity was being devoted to innovation. Figure 2 shows the annual numbers of patents in England from 1660 to 1851. The number awarded per year in the 1760s was more than twice that of the previous decade, and indeed more than twice that of any decade since the patent system was fixed in form in 1617. Thereafter the number of patents awarded grew rapidly. The upsurge in patenting even pre-dates the dramatic innovations in textiles in the late 1760s and 1770s, and the Watt steam engine of the late 1760s.

It has been natural to assume that the efficiency growth of the English economy was intimately linked with the ascendance of this minor country on the wet and windy northwest edge of Europe, which in 1700 had a population about one-third that of France, and about 4% that of both China and India, to the position of world dominance it occupied in 1850. In the Industrial Revolution the size of the English economy increased rapidly relative to its European competitors. Aided by its newfound economic output, Britain defeated France to emerge as the unchallenged European power by 1815, and in the process swept its rivals from the seas to erect the greatest Empire the world has seen. By 1850, at the apogee of its power, Britain still had a mere 1.8% of world population. The area of the British Isles is only about 0.16% of the world land mass. Yet Eric Hobsbawm claimed in his survey of the Industrial Revolution that Britain then produced two-thirds of world coal output, half of iron output, and one half of factory produced cotton textiles.[2] Output per worker was higher in Britain than in any other country. It had enormous colonial possessions including much of present day India and Pakistan, and the whole of what is now Canada, Australia, New Zealand, and Ireland. Its navy was the largest in the world, bigger than the next two largest navies combined. In 1842 it had humiliated the ancient Chinese empire and forced it to cede Hong Kong and to allow the British to ship opium into China. In 1860 the British and French captured Beijing and forced even more humiliating terms on the empire.[3] The transition to modern rates of efficiency growth nicely coincides with political events.

Britain by mid nineteenth century was so confident of its manufacturing prowess that it pursued an armed policy of forcing free trade on other countries, confident that its manufactures would sweep away protected infant industries in other countries. Thus Britain used a show of force in Persia in 1841 to force it to concede most favored nation status. It intervened in Egypt, nominally a province of the Ottoman Empire, in 1841 out of displeasure with the protectionist Pasha.[4] With its colonial possessions such as India, Britain in the nineteenth century similarly imposed a policy of strict free trade, even though wages in India were less than one sixth those of Britain by the late nineteenth century.

All these considerations seem, like clues in a well structured detective novel, to indicate some sudden and decisive change in the operation of the British economy in the 1760s. There

[2] Hobsbawm (1969), p. 134.

[3] It is claimed that by 1855 Chinese tariff policy was firmly under British control, the only restraint on the British being the fear of toppling the current regime by pushing them too far.

has thus been a long search for a key institutional or other change in the late eighteenth century, or earlier, that would explain the Industrial Revolution. The suddenness of the productivity gains attributed to the Industrial Revolution, in terms of the long sweep of history, arbitrates strongly against endogenous explanations of the Industrial Revolution. As we saw above in looking at the work of Kremer linking population and efficiency advance, it is hard to think of endogenous processes that will produce such a step like change in efficiency growth rates. Such an abrupt break seems to require an institutional innovation, or a sudden switch between equilibria. This search, however, has been quite fruitless. Those who favor an institutional explanation are confronted with the remarkable fact of the incredible institutional stability of eighteenth century England. The last institutional innovation of any consequence before the Industrial Revolution was the Glorious Revolution of 1688-9, 80 years before the onset of the Industrial Revolution. Thus generation after generation of economic historians have thrown themselves fruitlessly at the problem of the Industrial Revolution. Like the infantry in World War I, platoon after platoon has emerged from the trenches and advanced past the lifeless bodies of their fallen colleagues only to see themselves also cut down by the impossibility of the problem.

What I will argue in this chapter, though, is that dazzled by the sound and light show of the Industrial Revolution - the swelling of output, the steam engines, the blast furnaces, the factories, the canals and railroads, the imperial conquests – we have systematically tended to overestimate the discontinuity that the Industrial Revolution represents, and the effects technological advance alone had on Britain's position in the world. The progress of the English economy in 1760 to 1860 was much less dramatic than has been popularly believed. Further

[4] The British and French in 1845 intervened in Uruguay in support of a liberal regime that favored freer trade.

England had achieved a position of primacy in Europe in terms of the efficiency of its economy, and its levels of income per person, long before 1760. Efficiency growth in 1760-1860 was less, and more episodic, than figure 1 suggests. The huge gains of the British economy relative to its rivals around 1800 owed a lot more to unusual British demography than to the efficiency gains of the Industrial Revolution.

Further I will also show that there is a very loose connection between the underlying rate of technological dynamism in economies and the rate of growth of measured efficiency. Technological dynamism is greater for modern economies than for Malthusian economies, but the transition between the two types of economy was slower and more extended than has been perceived. England in 1650 was more unlike the typical pre-industrial economy than England in 1850 was unlike England of 1650. Indeed, given our inability to quantify the rate of flow of innovation, as opposed to the resulting gains in national efficiency from this innovation, it may never be possible to quantify when exactly the switch between the old economy and the new economy took place.

Part of the reason for the traditional overestimation of the efficiency gains of the Industrial Revolution was that much of the simultaneous growth of population and living standards in the years 1770-1860, the breaking of the old Malthusian constraints, was created by events outside England. Most of the ability of the economy to sustain both income gains and population growth after 1800 was created by events outside England: specifically lower population growth in England's trading partners, declining transport costs, the addition to the world economy of the new land of the Americas, and the growing efficiency of the American economy.

There was a transition between the low efficiency growth economy of the Malthusian era and the fast efficiency growth modern world, but the precise timing of that transition will never be determined, because it occurred over centuries, and in a way much influenced by chance and accident. The Industrial Revolution was the culmination of changes that occurred hundreds of years before.

When was the Industrial Revolution?

On November 15, 1688 William of Orange landed his army on the south coast of England, so sparking the Glorious Revolution that displaced James II and initiated the modern constitutional democracy in Britain. On April 19, 1775 British troops engaged Colonial irregulars at the Battle of Lexington, provoking the American Revolution. On July 14, 1789 a mob stormed the Bastille in Paris, launching the French Revolution, the political regime shift that helped give the Industrial Revolution its name. Revolutions we expect to have a beginning, a place, and an end. What then was the date the Industrial Revolution began on? And exactly where did it take place?   Was it in Bolton in Lancashire in 1768 when the hairdresser, wig maker and pub owner, the future Sir Richard Arkwright, took out a patent for a mechanized cotton spinning machine? Was it in Glasgow in 1769 when James Watt invented the separate condenser for steam engines?

While there is no doubt that a revolutionary change took place at some point between pre-industrial society with its approximately 0% growth rate of measured productivity (TFP) and modern society with growth rates of measured productivity often exceeding 1% per year, I show below that the precise date of that transition is not easy to identify, and may be forever indeterminate.

It is no easy task to measure output and productivity in England before 1842 when official tax records begin, but the unique stability of England from at least 1200 onwards meant that records of wages, prices, population, rents and returns of capital can be constructed throughout these years, allowing us to estimate the total output of the English economy. Figure 3 shows this output for the 1200s to the 1860s, with 1860-9 set at 100. Clearly a huge upturn in the output of the English economy occurred sometime after 1600, with material output in the 1860s being about 12 times greater than in 1600 (the English economy now produces 180 times as much output per year as in 1600). Output in 1600, however, is estimated to be no greater than in 1200. If we look at the growth rate of output, as in figure 4, two breaks are evident, however. The first around 1600 when the growth rate of output goes from 0% to 0.6% per year for about the next 200 years, the second around 1800 is when the growth rate increases again to about 2.0% per year from then on. The growth of total output is composed of two things though: growth of population and growth of output per head. Since I have stressed that the crucial difference between modern and pre-industrial society is the TFP growth found in modern society, perhaps we will get a clearer of when the break occurred by calculating the level of TFP in England from 1200 to 2000 and look for where it starts to increase from pre-industrial levels.

A convenient property of economic efficiency is that it can be measured at the both the industry or the national level as

$$A = \prod_{i,j} \frac{\omega_j^{\theta_j}}{p_i^{\alpha_i}}$$

where A is an index of measured efficiency, p_i is the price of output i, and α is the share of output i in the value of output, ω_j is the wage paid to input j, and θ_j is the share of input j in the total payments to inputs. This formula just says that productivity can be measured as a weighted average of each input cost relative to an index of output prices. Productivity is thus a weighted average of the "real" costs of the inputs. If the shares of the inputs in costs change over time then productivity movements can be measured by chaining productivity indices that use different cost weights for shorter periods. After considerable labor I now have assembled the price and input cost indices that allow us to make this calculation all the way back to 1200 for England (though the earlier the data the more tentative the measure. Figure 5 shows the resulting measure of the efficiency (TFP) of the English economy from 1200 to 2000 by decades, with the 1860s set at 100. Figure 6 shows the details in close up for the crucial decades 1600-9 to 1860-9. Calculated TFP in the pre-industrial period before 1800 shows surprisingly little trend. The calculated efficiency of the economy circa 1800 is no higher than circa 1200. As an illustration of the stasis of the earlier economy consider the record of wheat yields per acre, measured as grains produced per seed sown, from 1211 to 1453, as is shown in figure 7. There is no sign of any gain over this period of nearly 250 years and if anything signs of slight deterioration. In the pre-industrial era there are some surprising long up and down swings of TFP. In that sense 1800 looks promising as the break between the old and the new worlds. But if we focus on the years after 1600 we see instead that from 1600 to 1800 TFP grew steadily at about 0.2% per year, which is much faster already than societies averaged before 1800. Was the revolution of 1800 then just the culmination of a process that began in 1600, or was it an unexpected deviation from a pre-industrial pattern? Just the aggregate data on output growth rates and efficiency levels do not decide this issue.

The Sources of Industrial Revolution Productivity Growth

Perhaps we can get more insight into whether 1800 represented the great divide between old world and new by looking at the sources of the more rapid productivity growth that appears after 1800. Donald McCloskey pointed out we can relatively easily decompose productivity growth at the national level into the shares contributed by various industries (McCloskey, 1981).

A nice property of the aggregate productivity growth rate is that it is just the sum of productivity growth rates in each sector, weighted by the share of output in that sector in GDP. Thus

where g_A is the overall productivity growth rate, θ_i is the share of each industry in GDP, and g_{Ai} is the productivity growth rate of each industry.[5] Where did the aggregate productivity growth rate of 0.51% per year in 1770-1869 derive from?

The flagship industry of the Industrial Revolution was of course textiles. The estimated efficiency in converting raw cotton into cloth increased 20 fold from the 1760s to the 1860s, implying an annual productivity growth rate of 2.72% per year, faster than measured productivity growth rates in most modern economies. Thus while it took the equivalent of 31 person-hours to transform a lb. of cotton into cloth in the 1760s, by the 1860s this was done in the equivalent of 1.5 person-hours. This is shown in figure 8, where it is clear that there was sustained productivity growth over 80 years or more. We saw above that this was the product of a stream of technological innovations beginning in the 1760s, some famous but most of them anonymous.

It is also the case that the innovations in textiles alone were enough to create the upturn in productivity growth rates in England observed after 1800 in figure 6. Table 1 shows the calculated contribution of the textile industries to the overall productivity growth rate from 1770 on. Even though on average the textile industries - cotton, linen, and wool – were only about 10% of English GDP in the Industrial Revolution era, they supplied about half of all the productivity growth, an average of 0.26% per year. If we were to subtract this contribution from

[5] If we calculate sectoral productivity growth rates on a value added basis, then the weights θ_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.

the aggregate growth rate of productivity, as is done in figure 9, then we see that without the textile revolution 1760-1869 would not have been a period of unusual productivity growth in England relative to the previous 200 years. This raises another possibility. Was the Industrial Revolution just an accident of a linked series of productivity advances in textiles as opposed to systemic change in the economy?

Where did the rest of the Industrial Revolution efficiency growth come from? The other classic Industrial Revolution industries were coal mining, iron and steel smelting, and the railroads. In the appendix I calculate in similar ways their productivity growth rate and their contribution to national productivity growth, the results being shown in table 1.

The productivity growth rates estimates for freight and passenger travel are a mix of the effects of the railways (which did not arrive until 1825, late in the Industrial Revolution, with the famous Stockton to Darlington line) and improvements in road transport and shipping before 1825. On the roads significant improvements were achieved by 1825 without any technological innovations by organizational changes. The road system before the Industrial Revolution was notoriously badly maintained. Local parishes had the responsibility of maintaining the highway. But from a combination of lack of means and lack of incentives they frequently defaulted on these obligations, so that roads degenerated into barely passable morasses once the winter rains came. Also the users who had free access to the roads had no incentive to use vehicles that would not damage the surface. Road quality in the eighteenth century was improved by turning over stretches to Turnpike Trusts who were empowered by Act of Parliament to charge for access to the highway and use the money to effect improvements. The Trusts, for example, set charges that encouraged wagons to use wider wheels which did less damage to the surface. In a flood of Turnpike acts between the 1750s and 1770s more than 14,000 miles of road were turnpiked, in a country only about 400 miles from north to south and 150 miles on average from east to west. To estimate average freight transport costs throughout this period I use the difference between coal prices at the pitheads in the north east and those prices in London to final consumers of coal, net of taxes. To estimate passenger transport costs I look at the cost per passenger mile first on the roads, and then on the railway.

In general the contribution of the other famous Industrial Revolution industries is surprisingly small. Some had fast productivity growth, such as iron and steel, but small shares of their outputs in GDP. Others such as coal mining had little estimated productivity advance. Coal prices fell and its use expanded enormously mainly because coal could be transported to final consumers in the cities and countryside so much more cheaply. Thus together coal and iron and steel, for all their fame in subsequent narratives of the Industrial Revolution, explain only about one tenth the amount of productivity increase as do the textile industries. On their own the changes in textiles raised the productivity of the English economy by 30% in the Industrial Revolution. Iron and steel and coal mining explain a gain on their own of 2.5% in efficiency over the course of 100 years.

Transport improvements were much more significant than coal and iron and steel. Collectively they raised output per unit of input by 10% over the Industrial Revolution, with 7% being from road improvements and shipping and 3% from the introduction of the railway. Thus in terms of gains of efficiency no innovation other than those in textiles was in any sense crucial to the Industrial Revolution. The rest of the productivity growth came from such areas as agriculture which had a very slow rate of efficiency growth but was a very large share of the economy.

So was 1770 in England really the Dawn of the Modern World?

With these preliminaries taken care of we can return to the question of whether 1770 in England really was the great divide between the old world and the new? Unfortunately the only defensible answer seems to be that we do not know and we will most likely never know. An Industrial Revolution certainly occurred, but when and where is uncertain.

The reasons for this uncertainty are threefold.

(1) **The appropriate way to measure the rate of innovation is unclear.** The TFP measure that we use to measure the rate of efficiency advance in the economy takes productivity advance in the production of individual goods and aggregates it to the national level using as weights the share of expenditure on each good. We use this weighting because in economics we are concerned with people's welfare, and this weighting measures how much technical changes mattered to the average consumer. TFP effectively takes a poll of consumers and asks "How much are things being done more efficiently for you?"

But if we are concerned with measuring the average rate of innovation in a society this measure need not be the appropriate one. Great innovations may only have an effect on the mass of people long after they are made, because at the time of the innovation people do not happen, because of their income or circumstances, to employ such goods very much. A classic example of this is the introduction of the printing press in Europe in 1452 by Johannes Gutenberg. Before the printing press books had to be copied by hand, with copyists on plain work still only able to copy 3,000 words per day. The bible, for example, at this rate would take 136 days to copy. A 250 page book in modern octavo size would take about 37 days. Also the imprecision of hand writing meant that print had to be of larger size demanding about twice the area of page per word as modern books, driving up the costs of materials and binding.

Figure 10 shows the estimated productivity level in book production by decade from the 1450s to the 1850s, calculated as the ratio between the wage of building craftsmen and the price of a book of standard characteristics.[6] The rate of productivity growth from the 1450s to the 1550s was 2.6% per year, as fast as for cotton textiles in the Industrial Revolution. In the following 100 years productivity grew more slowly, at only about 0.8% per year. But this was still faster than most of the economy in the Industrial Revolution. From the 1650s to the 1850s there were apparently no further productivity gains in printing, however. But all this advance had no appreciable impact on the measured efficiency of the economy, since books were such a tiny share of expenditure for most of the pre-industrial era. In the first decade of the 16th century the average annual output of books was about 20,000 volumes, about 0.02% of GDP. By the 1550s this had risen to 100,000 volumes, but because of the falling prices of books that was still only 0.11% of GDP.

Books were not the only goods that saw very substantial productivity advances in the years before 1800. Other techniques were steadily improving. Unfortunately none of them were for processes that were major shares of expenditure. Thus table 2 shows the price of nails by 50 year periods, compared with wages, and the implied efficiency in nail production. A pound of nails in the early 13th century cost 2.5 d., while a day's wage for a craftsman was 2.4 d. Thus a pound of nails cost more than a day's wage. By the years 1850-69 the day wage had increased about 17 fold, to 40 d. per day. But nail prices had increased to only 3.4 d. per pound, so a craftsman could buy about 12 pounds of nails with his day's wage. (The near constancy of nail prices in nominal terms explains why still in the USA nails are designated as "2d" nails, "3d" nails). These were the prices of 100 such nails in the 14th century in England, which became

[6] We can do this since both under hand production and with the printing press the main ultimate cost in book production was labor (paper and parchment production costs were both mainly labor costs).

established as the name of that type of nail, since their price changed so slowly. But most of the gain in efficiency in nail production was achieved before the Industrial Revolution, so that the efficiency of production was 6 times as great on the eve of the Industrial Revolution than it had been in 1200. Again these productivity advances had little impact because of the tiny share of income expended on nails.

Other goods that had their prices relative to wages substantially improved before 1800: paper, glass, spectacles, clocks, musical instruments, paints, spices such as pepper, sugar, fine textiles such as silk goods, tobacco, and gunpowder. None of these had much impact on living costs simply because they were mainly luxury goods consumed by only those with the highest incomes. But if we were to measure the rate of technological advance in England from 1200 to 1869 not by looking at the consumption of the average person, but by looking at the consumption of people like us, we would have a very different impression about the relative stasis of the economy before 1800. Figure 11 thus shows the hypothetical real wage of workers with tastes like the modern consumer - priests, doctors, lawyers - in terms of foods, reading material, clothing and house furnishings compared to the actual real wage of farm workers for 1280-1869. This is a purely hypothetical real wage since I do not have any series for the average wages of the professional class in these years. All I am doing here is assuming that the wage of this group was unchanged relative to the wage of farm workers. The calculated real wage of this professional and upper class group is nearly 2.5 times as great by the mid seventeenth century as in 1280-1349. In contrast the real wage of farm workers increased by only 30% in the same interval. Also the rate of real wage gain for this hypothetical group is nearly as fast in the years 1300 to 1700 as in the years 1760-1860, those of the classic Industrial Revolution. From 1280-1349 to 1700-59 my hypothetical real wage for the rich grows at 0.26% per year. From 1700-59 to 1860-9 these real wages grow at the same 0.26% (though the growth rate for the shorter interval 1800-9 to 1860-9 is a much faster 0.67% per year).

Thus the dynamism of the English economy in different periods seems to depend crucially on the consumption interests of the observer. From the perspective of the lowest paid workers, farm laborers, even by the end of the Industrial Revolution they had not attained the living standards of the golden years of the later middle ages. From the perspective of someone with middle class consumption habits in modern America there was a world of change in consumption possibilities even before 1800. These changes made it possible to live in light flooded houses, with painted or papered walls, and eat a wide range of tasty foods from fine china and glassware. They made reading a daily newspaper possible. They extended the length of the day by providing cheap artificial illumination.

If innovation were an activity that followed an economic logic where the budget of innovative effort was devoted to producing the maximum value of productivity advance per research dollar, then the TFP standard would be the most appropriate of measuring the innovation rate of a society. But if instead innovative activities were guided mainly by non-economic forces – curiosity, a love of novelty, a desire to impress others – then TFP growth might provide a very poor guide to the rate of innovation in a society, or to the relative innovativeness of societies.

(2) **The geographic area over which we should measure the Industrial Revolution seems arbitrary**. Because statistics tend to be collected along political boundaries the area conventionally used is England or Great Britain. But if I want to make the Industrial Revolution a much sharper break with the past then by choosing Lancashire, the heartland of the textile industry, as the location to be analyzed we could generate a sharp break. Whereas if I want it to

be as gradual as possible I would choose the whole of Europe as the area to be analyzed. Then the change would be much distinct. But what is the “correct” area to choose?

To see that the choice of geographic area is crucial to how abrupt the Industrial Revolution appears consider table 3 which shows the distribution of occupations for some important Industrial Revolution industries across England as a whole, and for selected sub areas. Cotton textiles, the industry with the most dramatic productivity growth, was concentrated in the north west (Lancashire and Cheshire). In these areas 22.4% of adults were employed in cotton textiles, almost one in four workers. In the south in contrast only 2% of adults were employed in the textile industry. Another difference was that the south still had 30% of the labor force employed in agriculture, while this was a mere 13% in Lancashire and Cheshire. Since productivity growth rates were so different across industries the uneven distribution of industries implies that the rate of TFP growth for different regions of Industrial Revolution England had to differ a lot.

Figure 12 shows the TFP growth rate for England as a whole from 1600 to 1869, smoothed as a three decade moving average. Also shown are the TFP growth rates for the northwest of England (which had about 14% of English population), compared with the south of the country which had 71% of the population. As can be seen if we choose to analyze the Industrial Revolution using northwest England as the geographic area there is a sharp and very abrupt transition to TFP growth rates even faster than for the average modern economy around 1770. If however we were to concentrate on southern England we would, as figure 12 shows, find little sign of any big upturn in productivity growth rates around 1770. Since southern England was presumably like much of the rest of Europe that implies that the wider the geographic area we include the less sign there would be of any discontinuity. If all of Western

Europe was included there would be little sign of any major upturn in TFP growth rates, and the Industrial Revolution would appear only in the late nineteenth century.

How would we defend one choice of geographic area as opposed to another? One argument for using political units such as England is that if national economic policies matter, and if factors of production and technological know-how are mobile within political units but not across countries, then it will be at the national scale that we will observe differences in economic performance. But the evidence from Industrial Revolution England contradicts any such assumption with respect to TFP growth. So there is no natural geographic area over which to measure when the Industrial Revolution occurred.

(3) **Rapid population growth in Industrial Revolution England magnified the effects of technological innovations on national productivity growth.** English population in the 1760s, at 6.25 million, was not much above its medieval maximum of about 6 million in the 1310s. In the course of the Industrial Revolution English population swelled to 20 million by the 1860s, a much greater population gain than any other country in Europe in these years. The precise coincidence of this unprecedented population boom and the unprecedented productivity growth of the Industrial Revolution is mysterious. For there is no sign that the productivity growth was in any way the result of England's unusual productivity growth. Population growth had to be caused by some combination of mortality rate declines and fertility rate increases. There was little if any gain in life expectancy in the Industrial Revolution era. So most of the increase in population came from fertility increases.

As we saw already the birth rate was restrained in pre-industrial England by the marriage pattern which consisted of women on average marrying late, large numbers of women never marrying, and women remaining celibate outside marriage but exercising no detectable restraint on fertility within marriage. Even though fertility was unrestricted within marriage, this marriage pattern at its extreme around 1650 avoided about half of all possible conceptions.

For unknown reasons, in the early eighteenth century the age of first marriage of women began to decline. Figure 13, which shows the information by decade reveals that this drop began in the 1720s. This decline in age of first marriage was enough on its own to raise the birth rate by 20% by 1800. At the same time as women began to marry at younger ages more of them were getting married. It is estimated that circa 1650 about 20% of women never married. By the early eighteenth century this was down to 10%, and the rate remained at this lower level through the Industrial Revolution. This added another 12% to the increase in fertility. Finally illegitimate births increased. By the end of the 18th century about a quarter of all first births were illegitimate. Another quarter of first births were within marriage but conceived before the marriage took place. Increased illegitimacy added about another 5% to the rate of fertility. Multiplying these factors together we get an increase in fertility between 1650 and 1800 of about 40%. Thus while in 1650 there were only about 1.93 children per women who survived into adulthood, by 1800 there were 2.68 surviving children per woman.

The sources of these changes in nuptiality do not seem to be economic. They occurred in both the north and the south of England even though the north was much more transformed by the Industrial Revolution than was the south. And it occurred in parishes where employment was mainly in agriculture as well as in parishes mainly engaged in trade, handicrafts and manufacturing, as table 4 shows. The only feature of this period that might be an explanation of these trends is that though overall mortality declined little, in the course of the Industrial Revolution the chances that a woman would die from complications from a pregnancy did decline substantially. In the seventeenth century almost 1.5% of pregnancies ended with the death of the mother (see table 5). That meant that a women marrying at 25, who would give birth to the average of 5.6 children for such marriages, would have about a 9% chance of dying as a result of the complications of pregnancy in the seventeenth century. But the early nineteenth century these chances had dropped to about a third of their earlier level (in contrast the chance of dying as a result of the complications of pregnancy in England in 1988 were 0.006% per birth). Women would be well aware of the mortality risks of marriage. The high risks of marriage to women in the seventeenth century might thus explain both delaying marriage as a way of reducing these risks, and also the decision by many women not to get married at all.

This population boom, the rise of real incomes in the Industrial Revolution, and the fixed land area of England soon created an inability of domestic agriculture to meet the food and raw material demands of the English economy. As table 6 shows while population more than tripled in the course of the Industrial Revolution domestic agricultural output did not even double. By the later years of the Industrial Revolution England moved from being a country where food and raw material imports were unimportant to one where they were substantial relative to GDP. In the 1860s net food and raw material imports were equivalent to 22% of GDP.

These food and raw material imports had to be paid for by exports of manufactured goods. It was this, rather than technological advances, that made Britain "the workshop of the world." Had English population remained at 6 million into the 1860s its domestic agricultural sector would have been able to feed and provide raw materials for the English population. The exports of manufactures which constituted by the 1860s nearly 20% of GDP would have on net been close to zero. English wages would have risen even more making foreign textile and manufactures producers more competitive. In this case the discontinuity in English TFP growth rates would have been much less, since most cottons and a large share of woolens were produced for export.

Population growth combined with limited land supplies also increased the size of the transport sector, another area of productivity gains. As the share employed in agriculture declined the population urbanized. Proportionatley more food and raw materials now had to be carried some distance from the domestic or foreign producers to the urban consumers.

Conversely had England experienced a substantial agricultural revolution instead of industrial productivity advance, the rapidly growing population would have reduced the effects on national productivity advance.

Thus three important accidents conspire to make the English Industrial Revolution seems like a sudden and unanticipatable departure from a pre-industrial stasis. The first is that technological innovations in the years 1770-1870 affected goods with mass markets, and high price elasticities of demand, so that they resulted in large measured productivity advances at the national level. The second is that England was a small enough political unit so that what was essentially regionally located productivity advance in textiles created at the national level still a period of unusually rapid productivity gains. The third is that population growth in England multiplied further the demand for goods with high rates of productivity advance.

One of the mysteries of the Industrial Revolution is why it coincided so closely with the break in English demography from the patterns of the pre-industrial era. The claim here is that there is indeed a connection rather than a pure accidental coincidence. But the connection is that the population growth magnified the apparent discontinuities of the Industrial Revolution era: discontinuities in the rate of productivity growth, the growth of total output, the share of output exported, and the degree of urbanization.

Instead the view I would emphasize is that there was a much longer and less abrupt transition between a society with very slow rates of innovation to one with the high rates characteristic of the modern world. This transition was certainly under way in England by 1600, but may have begun even earlier, and was not completed until the twentieth century.

Patent Statistics and the Industrial Revolution

This gradualist account of the Industrial Revolution still has to face the problem of the suggestive patent statistics illustrated by figure 2. If so much was continuity with what went before, with only a modest increase in basic innovation rates in the economy, then why the abrupt break in patenting rates in the 1760s?

The patent system seems to have been substantially the same from 1660 to 1852. The procedure was actually instituted by an act of 1535 in the reign of Henry VIII. The applicant had to undertake a sequence of steps, which included visiting in sequence a number of government offices and obtaining the signature of the sovereign twice. Each official the applicant dealt with received a fee, the system having been designed back in the sixteenth century to help finance a series of unsalaried government clerks. English applicants had to make their application in person in London. It was estimated in 1829 that all these steps took 6 weeks, and cost about £100.[7] Assuming these fees were thus fixed in nominal terms we see two forces over the eighteenth century reducing the cost of patents. The first was the rise in nominal incomes relative to patent fees. Taking building craftsmens' wages as a guide wages increased from £30 per year in the 1750s to £60 by the 1810s. The second was a substantial decline in the time costs of travel to London to lodge the patent. There were significant improvements in journey times and travel costs between 1660 and 1760, as the road system was improved in the mid eighteenth century. Thus travel times between Exeter and London fell from 4 days in the 1650s to 32 hours in the 1750s. Thus though the formal processes for patenting did not change, inflation, rising real incomes and declining transport costs may all made patenting less costly in the late eighteenth century.

Another important consideration is that patent activity varied dramatically across different sectors of the economy, both before and after the Industrial Revolution.

[7] Boehm (1967), pp. 19-22 summarizes the procedures before 1852.

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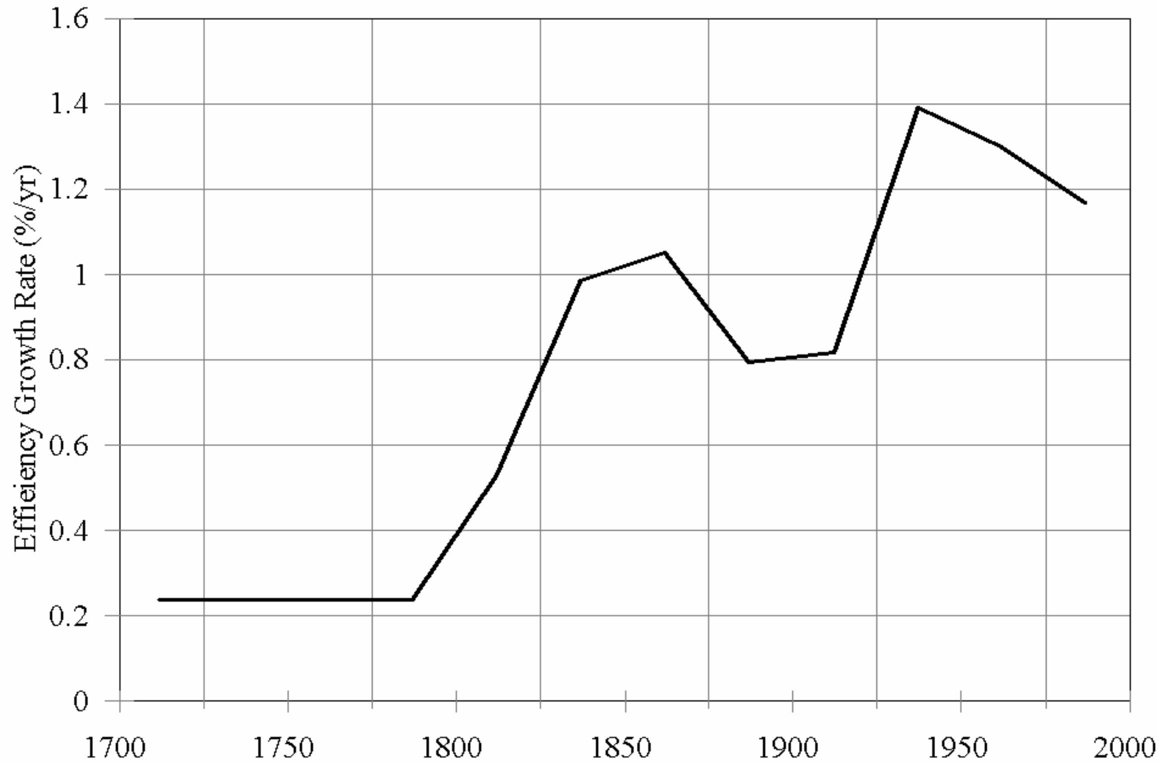
Figure 1: Estimated Efficiency Growth Rates, England 1700-2000



Source: 1700-1831, Crafts and Harley (1992).

Figure 2: Patents per Year, 1660-1851

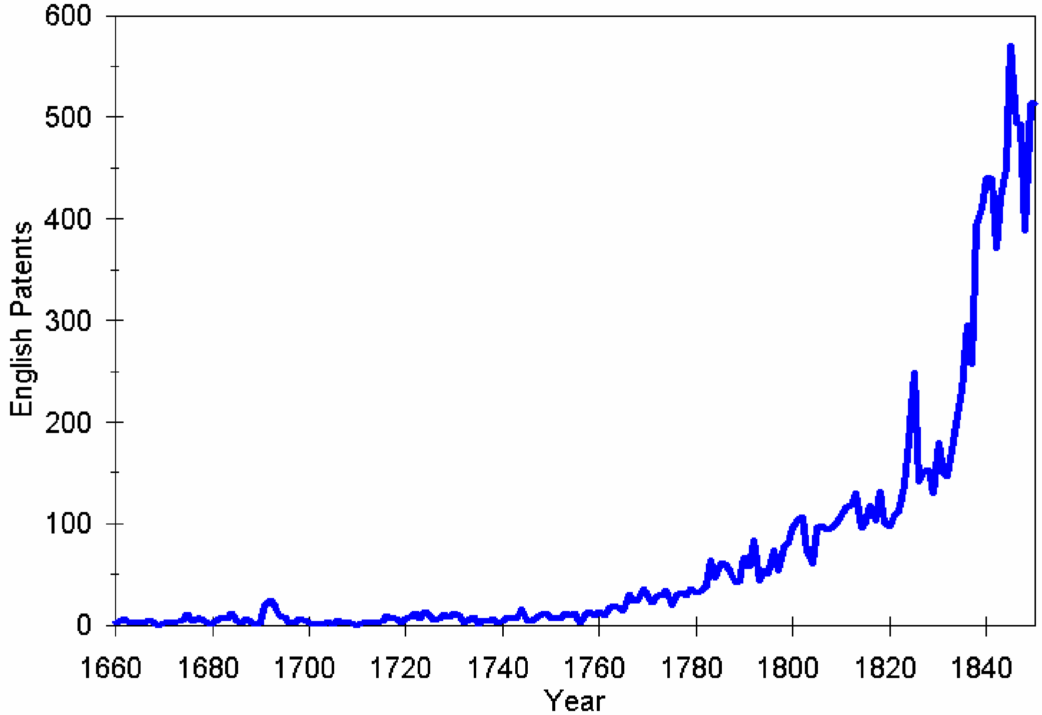


Figure 3: English GDP over the Very Long Run

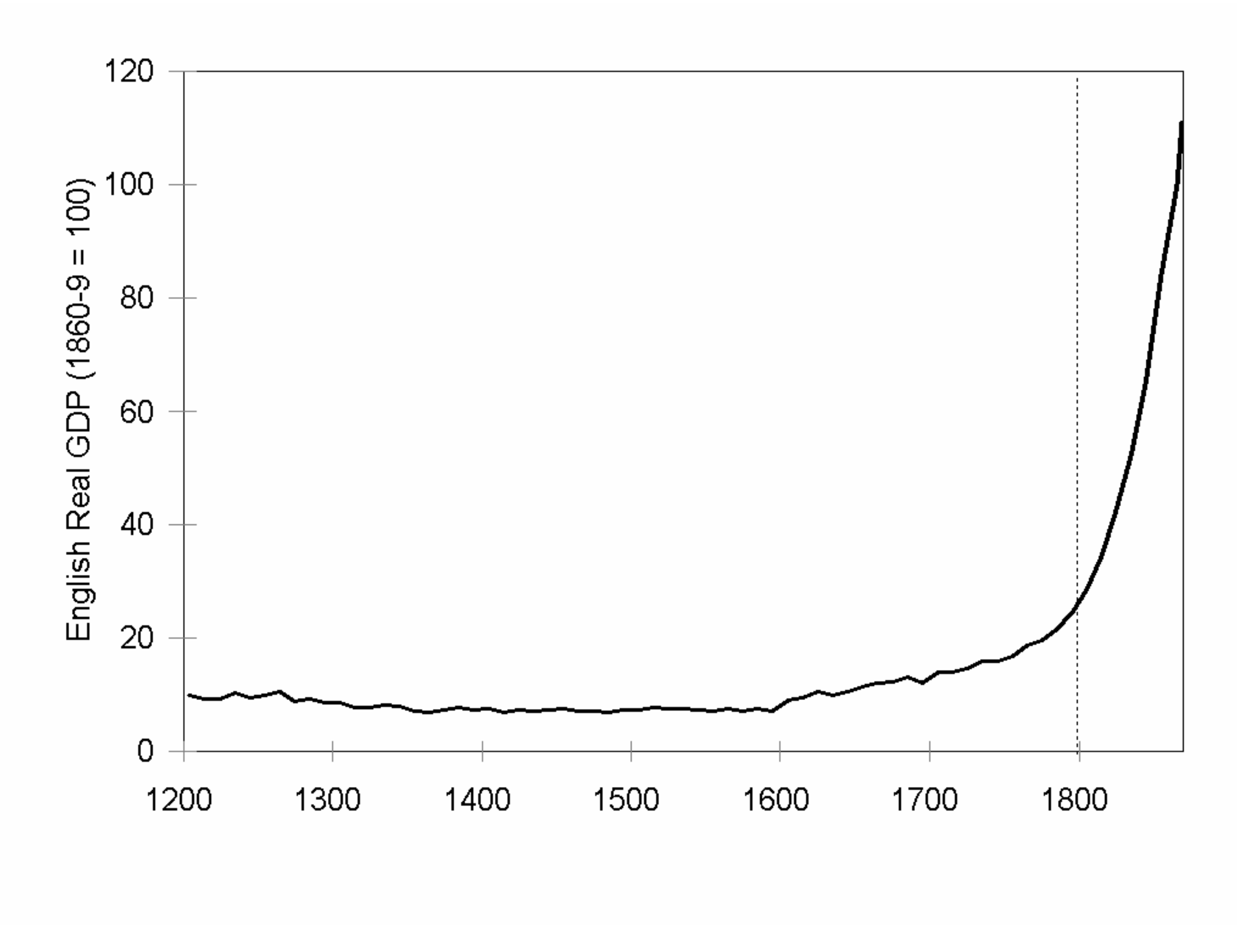
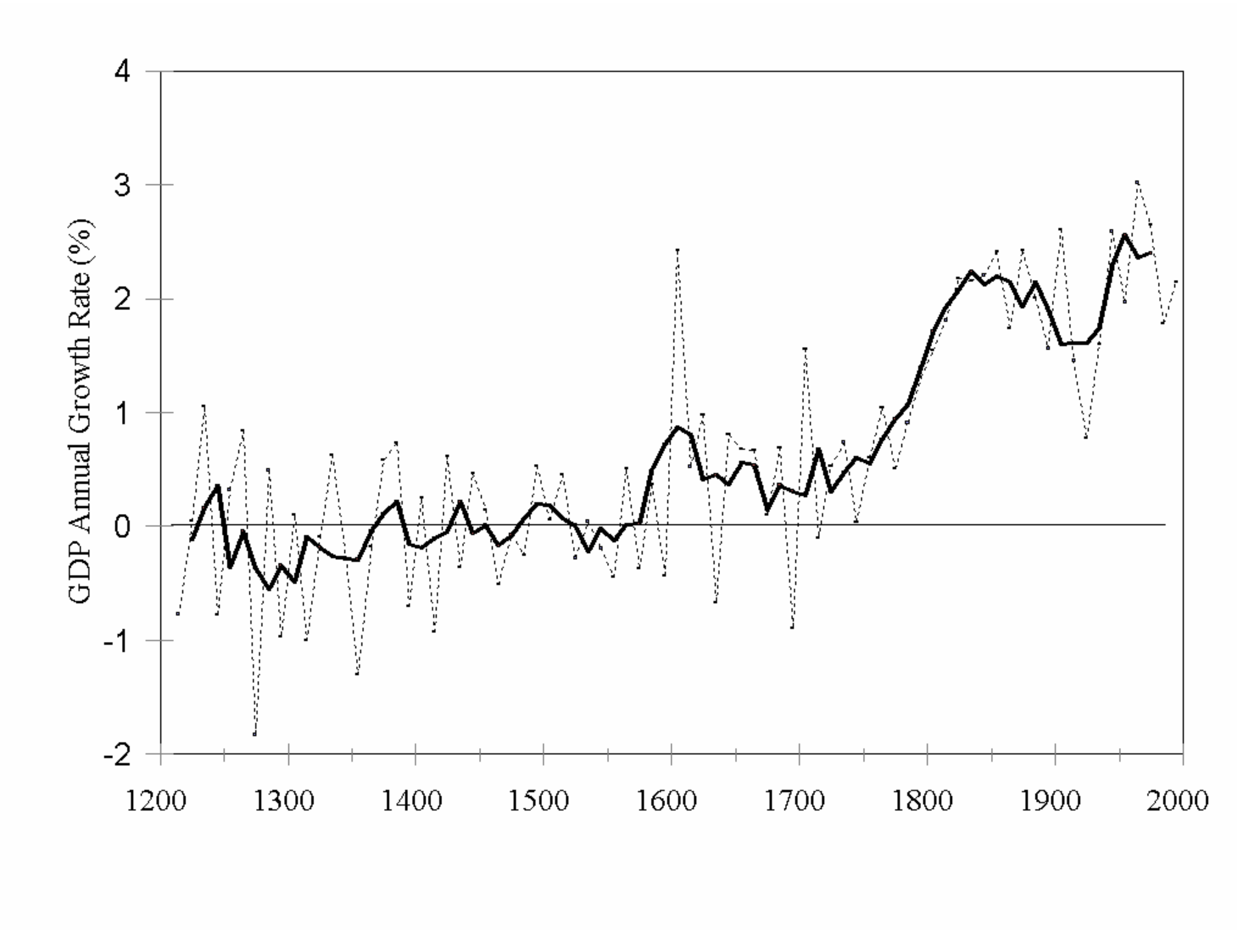


Figure 4: The Annual Growth Rate of Output, England, 1200-2000



Notes: The dotted line gives the percentage growth rate of real output per year from the previous decade. The solid line gives the 50 year moving average of output growth rate.

Figure 5: English Productivity over the Very Long Run

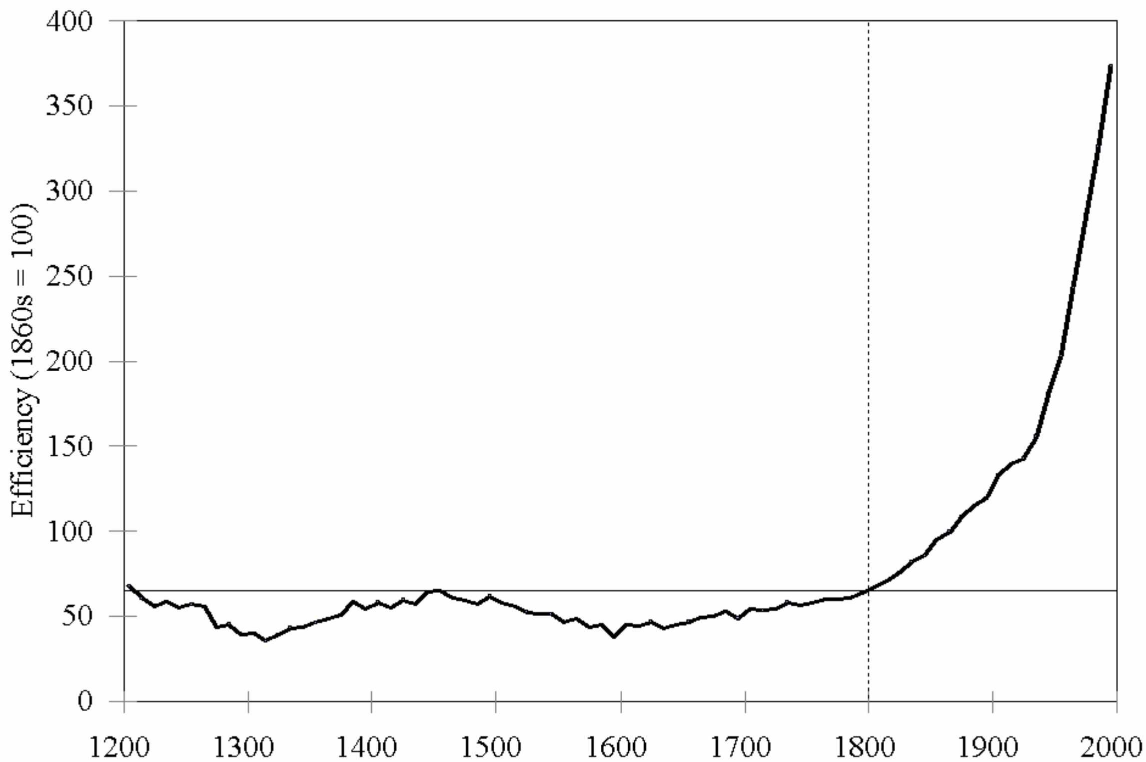


Figure 6: Efficiency in England around the Time of the Industrial Revolution

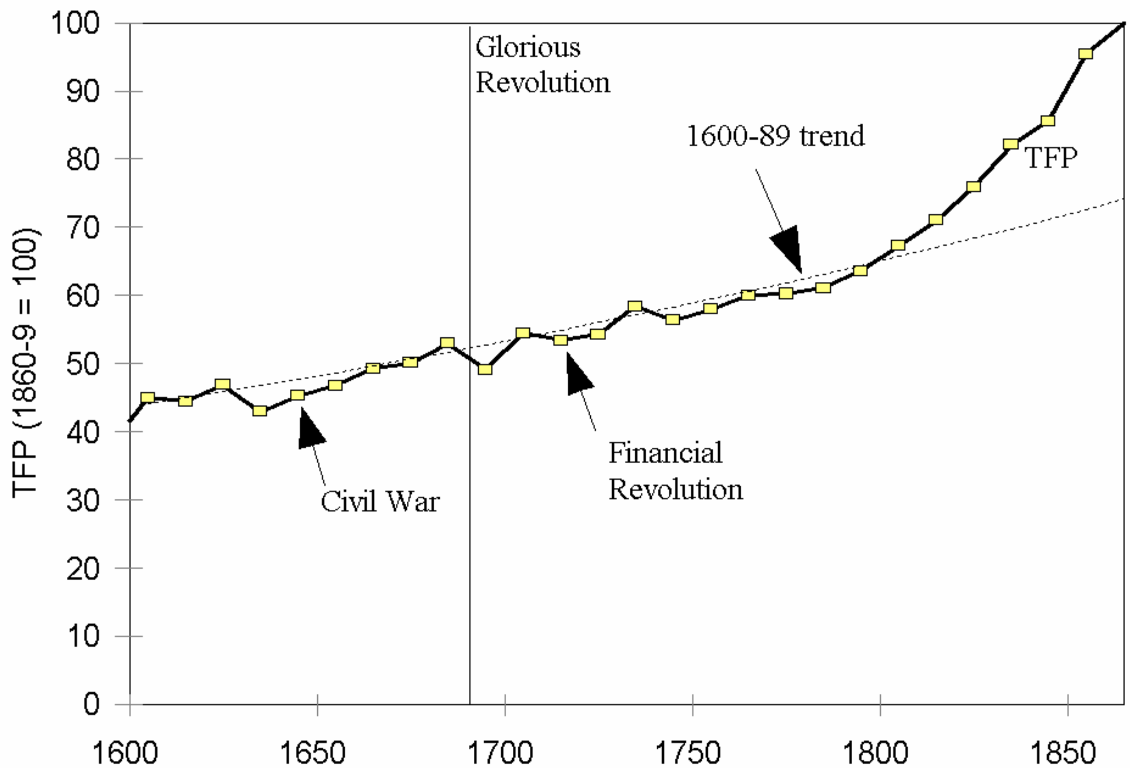


Figure 7: Wheat Yields in England, 1211-1453

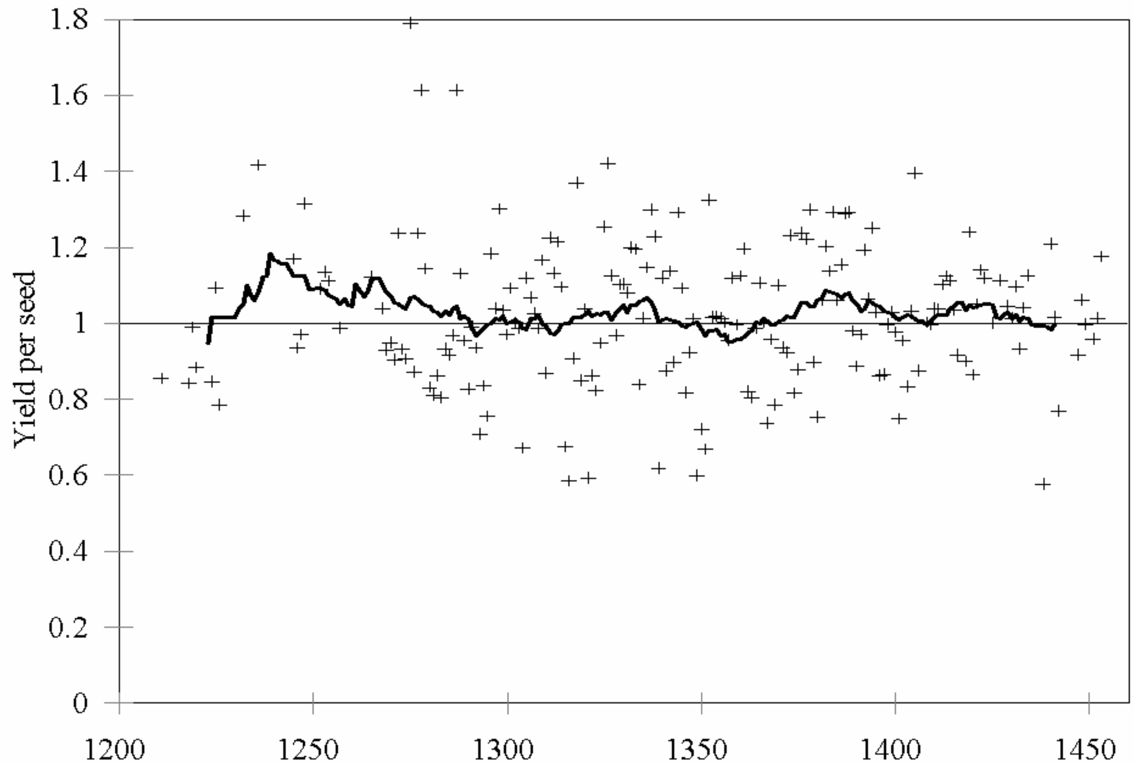
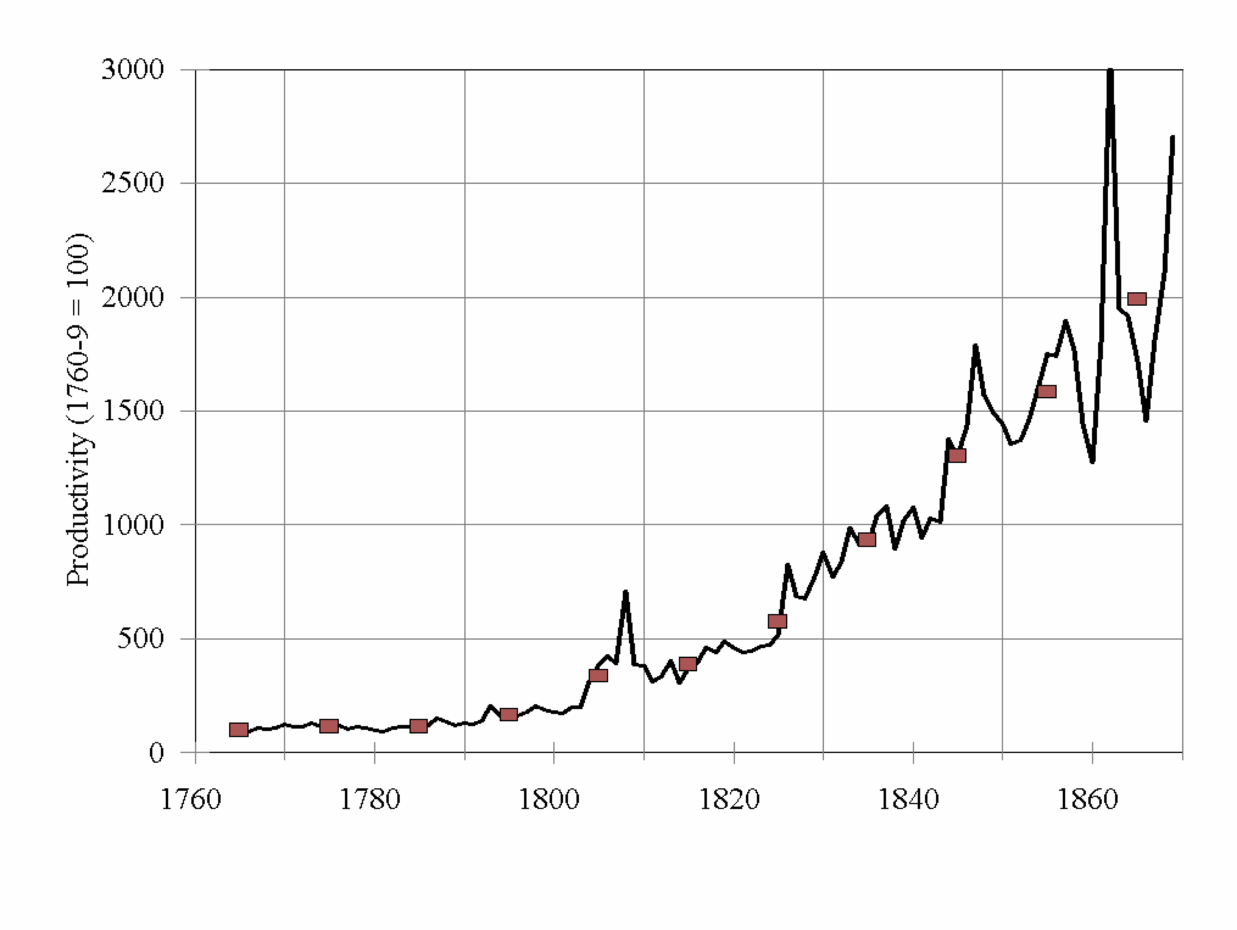


Figure 8: Productivity Levels in Cotton Cloth Production



Note: Productivity is calculated for the process of transforming raw cotton into cloth.

Table 1: The Sources of Productivity Growth in the Industrial Revolution, 1760-1869

Sector	Productivity Growth Rate, 1760s-1860s (%)	Average Share of Output Value/GDP	Contribution to Productivity Growth Rate (%)
Textiles			
Cottons	2.72	0.060	0.192
Linens	(2.72)	0.006	0.019
Woolens	1.13	0.043	0.049
ALL TEXTILES	**-**	**0.109**	**0.260**
Iron and Steel	1.40	0.014	0.022
Coal Mining	0.17	0.016	0.002
Freight Transport	1.14	0.046	0.052
Passenger Transport	1.60	0.019	0.028
Foreign Shipping	0.95	0.011	0.012
ALL TRANSPORT	**-**	**0.076**	**0.092**
Agriculture	0.27	0.300	0.070
Identified Productivity Advance	**-**	**0.514**	**0.446**
WHOLE ECONOMY	**0.51**	**1.00**	**0.51**

Source: See appendix.

Figure 9: Efficiency in England around the Time of the Industrial Revolution, minus the textile industry

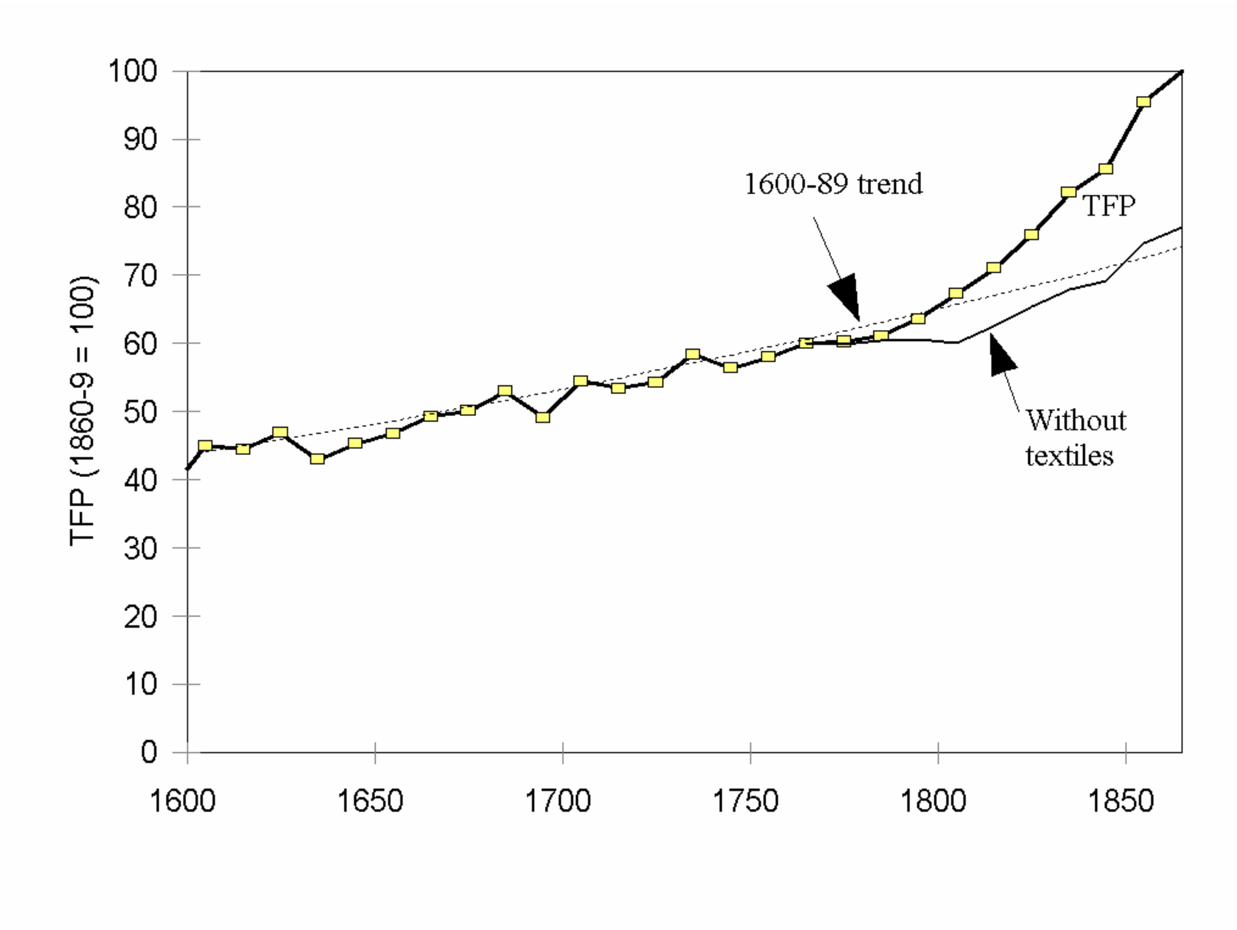


Figure 10: Productivity in Book Production in England, 1450s – 1850s

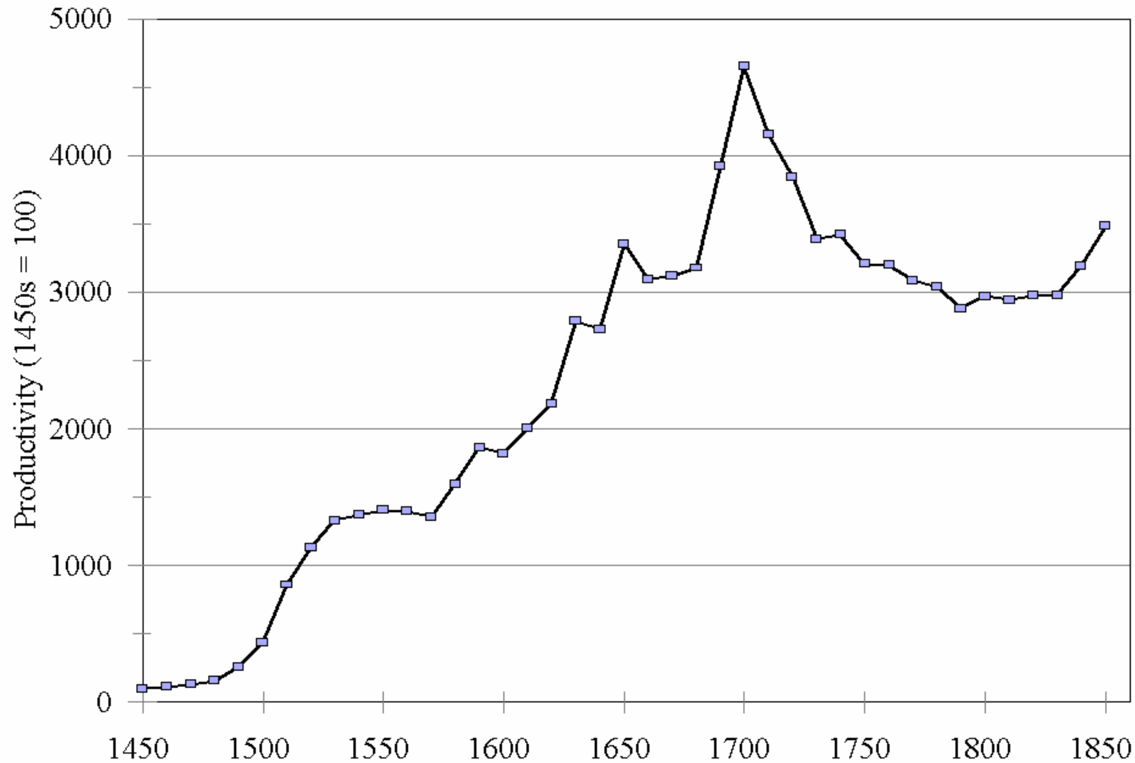


Table 2: Productivity Growth in Nail Production, 1200-1869

Half Century	Cost of nails (d/lb)	Day Wage (d/day)	Efficiency of Production	Efficiency Growth Rate (% per year)
1200-49	2.50	2.37	100	0.91
1250-99	2.26	2.45	114	0.08
1300-49	2.43	2.54	110	-0.36
1350-99	4.51	3.95	92	0.57
1400-49	3.69	4.59	131	0.25
1450-99	3.62	4.82	140	0.16
1500-49	2.98	5.04	178	0.68
1550-99	4.34	8.65	210	0.26
1600-49	4.32	11.8	288	0.68
1650-99	4.41	16.5	393	0.71
1700-49	3.93	18.4	492	0.32
1750-99	3.75	20.7	583	0.28
1800-49	4.48	36.7	863	1.24
1850-69	3.40	40.0	1,238	0.53
1200-1799				0.32

Notes: The efficiency growth rate for each period is calculated as average efficiency growth between the beginning of the half century and the end. This is why efficiency growth in the period 1300-49 is negative. Nail prices relative to wages increased sharply after the Black Death struck in 1348. This may be because some wage rates were underreported in the decade after the onset of the Black Death because the Statute of Labourers of 1350 limited wages that could legally be paid to those prevailing before the wage onset.

Figure 11: Real Wages of Farm Workers and, Hypothetically, Modern Consumers (1860-9 = 100)

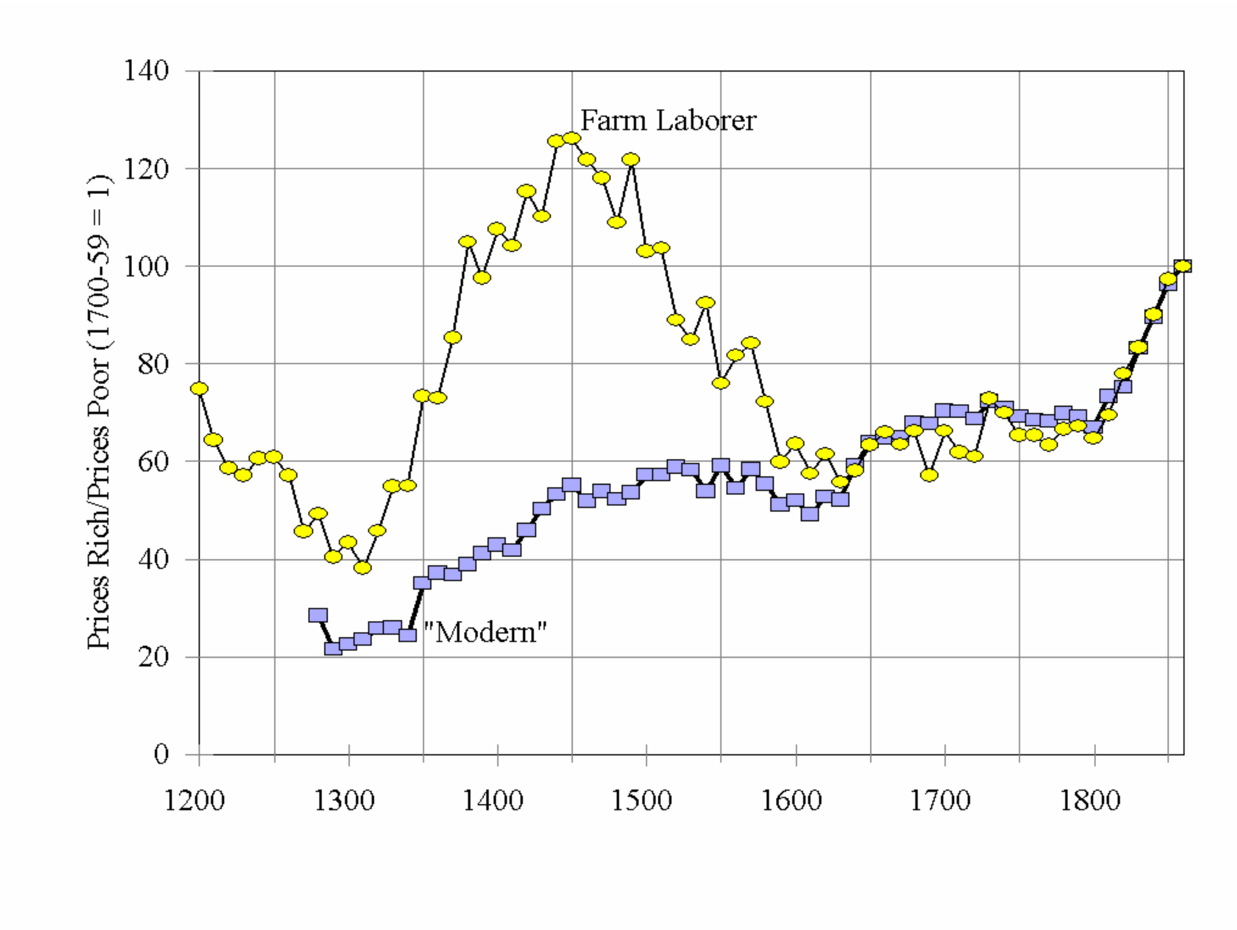
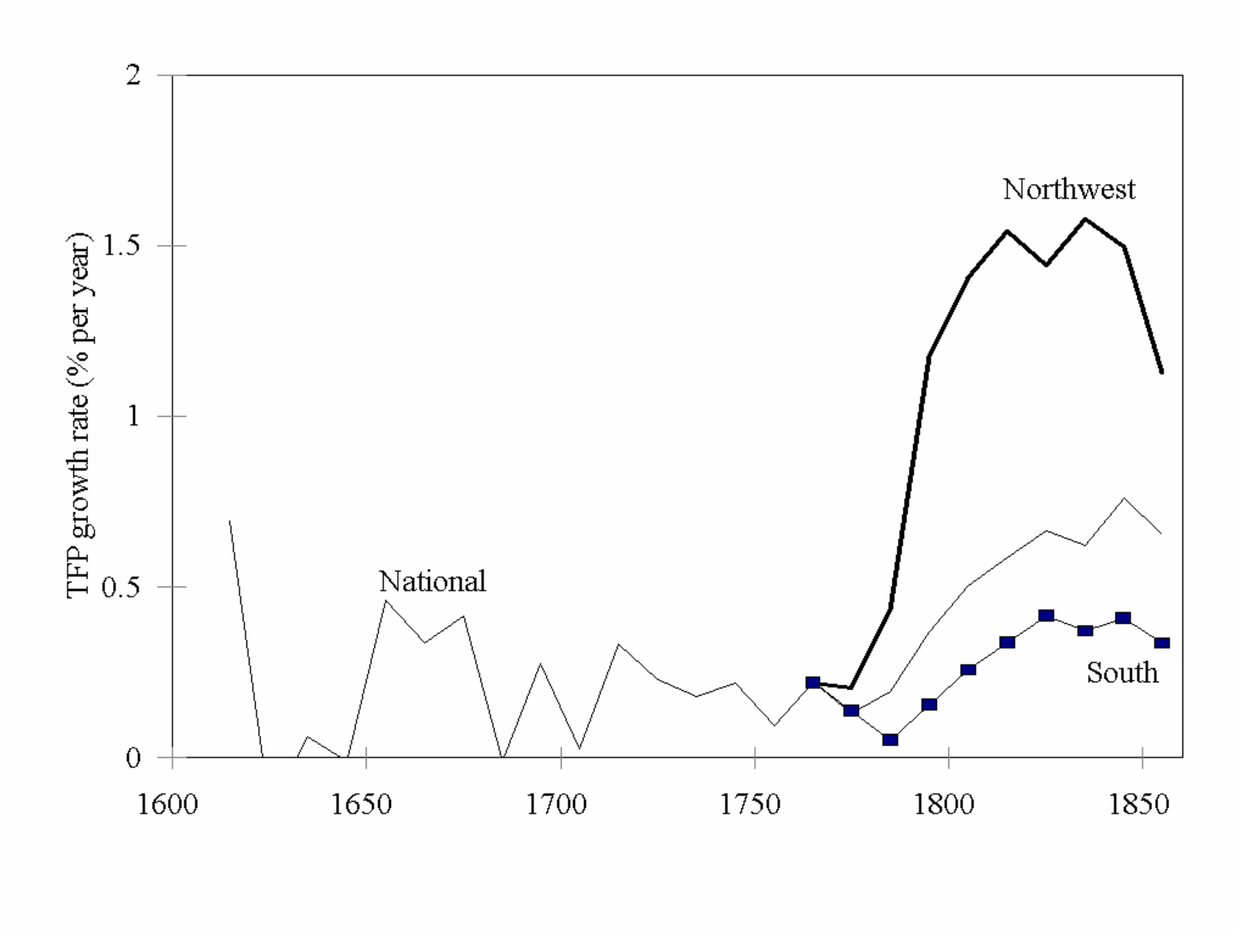


Table 3: Distribution of Occupations, 1851

Region	Productivity Growth Rate (%)	England and Wales	England and Wales (%)	North West (20+) (%)	North (20+) (%)	South (20+) (%)
All Occupations	-	6,313,053	5,632,026	795,193	1,652,436	3,979,590
Cottons	2.7	392,509	**6.2**	**22.4**	**13.5**	**2.0**
Other textiles	1.1	301,854	**4.8**	**5.2**	**8.4**	**2.6**
Iron and Steel	1.4	76,610	**1.2**	**0.9**	**1.1**	**1.2**
Transport	1.2	352,344	**5.6**	**7.2**	**7.1**	**5.7**
Agriculture	0.27	1,685,498	**26.7**	**13.6**	**18.9**	**30.3**
Services	0.0	825,389	**13.1**	**10.0**	**9.4**	**13.9**
Government	0.0	147,956	**2.3**	**1.7**	**1.5**	**3.2**

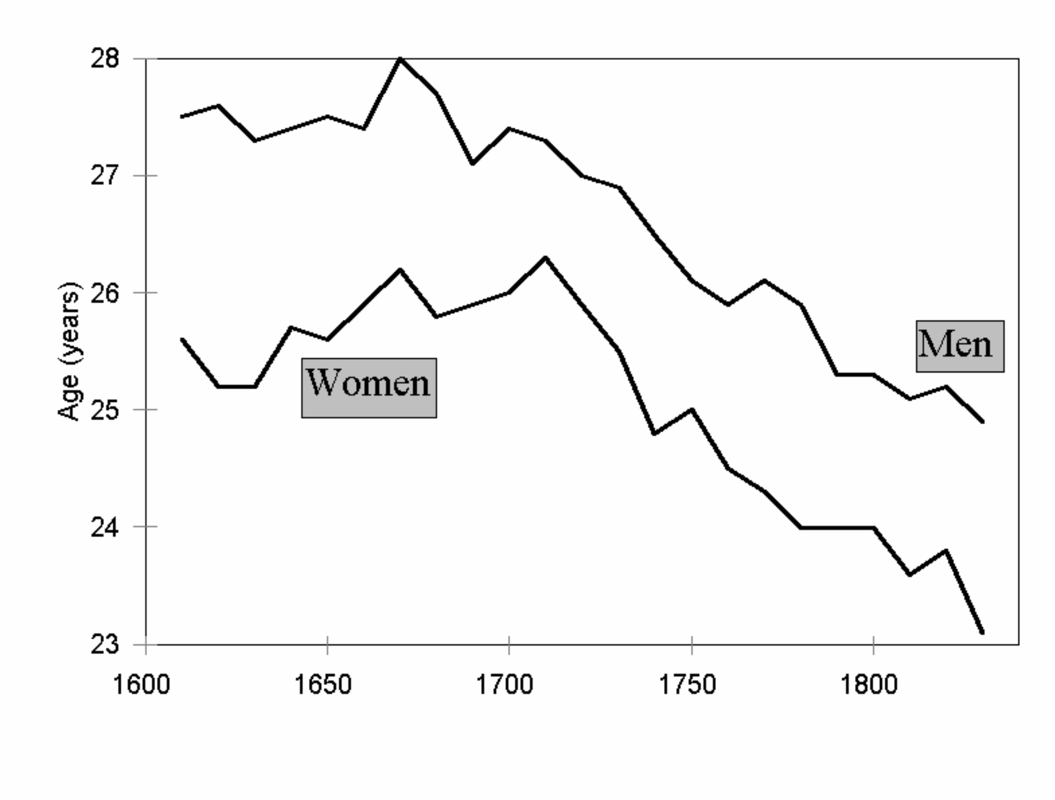
Notes: Workers in adult male equivalents based on relative wages of men, women, boys and girls. "Services" includes domestic servants, teachers and governesses, laundresses, clergy, lawyers, doctors, gamekeepers, musicians, innkeepers, chimney sweeps, hairdressers, and nurses, among other occupations. The northwest is Lancashire and Cheshire.

Figure 12: Productivity Growth Rates by Region, England, 1770-1869.



Notes: Productivity growth rates in each decade are given as a moving average of the growth rate over three decades (to smooth short term fluctuations).

Figure 13: Age of First Marriage by Decade



Source: Wrigley, Davies, Oeppen, Schofield (1997), p. 149.

Table 4: Women's Average Age of First Marriage by Parish Type

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

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

Table 5: Deaths in Pregnancy

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

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

Table 6: Population Growth and Imports (£ m. 1860-9)

	1700-9	1760-9	1860-9
Population (millions)	5.16	6.25	19.97
English Farm net output	64.7	71.4	114.3
Net Food Imports	1.7	3.2	79.8
Net Raw Material Imports	-2.1	-4.6	61.4
Net Food and Raw Material Imports	-0.4	-1.4	141.2

Notes:

Sources: Imports 1860-9: Parliamentary Papers (1870). Imports 1700-9 and 1760-9: Schumpeter (1960, tables XV, XVII). Exports 1700-9 and 1760-9: Schumpeter (1960, tables VII, IX, X, XII, XIII), Mitchell (1988), pp. 221-2).