Table 6.6 Survival of Landowners in Halesowen, 1270–1348

Family type in 1270–82	Numbers of families	Number with descendants holding land in 1348	Percentage with descendants holding land in 1348
Rich	40	40	100
Middling	64	58	91
Poor	70	25	36
All	174	123	—

Source: Razi, 1981, 5.

land. But they also often had more heirs, and so divided up their holdings more often between multiple heirs, keeping the overall land size distribution in balance. Since Ravi's data do not allow us to know whether the small landholders were in fact suffering demographic collapse, or whether they simply either disappeared from the court rolls or left the manor, the data do not demonstrate that medieval England was experiencing the same population dynamics as occurred in later years.[18] But they are consistent with that interpretation.

This story of the reproductive advantage of the rich is also found in a collection assembled by Joerg Baten of surveys of communicants in villages in Austria and southern Germany for the seventeenth to nineteenth centuries. Villagers of higher social status and those revealed to be more likely literate had at the time of the surveys more surviving children.[19]

Thus economic orientation had a dynamic of its own in the static Malthusian economy. Middle-class values, and economic orientation, were most likely being spread through reproductive advantage across all sections of stable agrarian societies. The next two chapters consider the dynamic elements of the economy before 1800. Chapter 7 examines technological advance, and chapter 8 explores the implications of these Darwinian selection processes for people's economic behaviors.

18. Inhabitants without land were less likely to appear in court rolls since they do not show up in land transactions or as pledges.

19. Joerg Baten, personal communication.

Clark (2007)

7 Technological Advance

There be dayly many things found out, and dayly more may be which our Forefathers never knew to be possible in Nature.

—Sir Robert Filmer (1653)[1]

Despite the sluggishness of preindustrial technological advance, there was over time—agonizingly slowly, incrementally—significant technological progress. Europe of 1800 was technologically significantly advanced over Europe of 1300. And Europe of 1300, surprisingly, had a much better technology than the ancient Romans or Greeks. Even the supposedly technologically stagnant eras of the Dark Ages and the Middle Ages saw many innovations.[2]

Thus the list of basic technologies which were unknown or unused in the ancient world is surprisingly long. None of the Babylonians, Egyptians, Persians, Greeks, or Romans, for example, managed to discover the stirrup for horse riders, simple as this device seems. Ancient horse riders held on with their knees. The stirrup was introduced in China only in the third century AD, and in Europe not until the early Middle Ages.[3] The Romans and Greeks also used horse harnesses which wound around the belly and neck of the horse. Experiments in the early twentieth century by a retired French cavalry officer, Richard Lefebvre de Noëttes, suggest that horses harnessed in this way lose up to 80 percent of their traction power, since the neck strap

1. Filmer, 1653, 8.
2. Many of these same innovations were made earlier and independently in China.
3. Temple, 1986, 89–90. Lynn White, 1962, famously argued that the introduction of the stirrup to western Europe in the ninth century led to the dominance of the heavily armored knight in warfare.

compresses both the windpipe and the jugular vein. Only in the eighth century in Europe were efficient harnesses, which sit on horses' shoulders, discovered.[4] Horseshoes to protect hooves were also unknown in the Roman and Greek world.

Looking just at Europe, the Greeks and Romans also lacked windmills (first documented in Yorkshire, England, in 1185), buttons for clothing (first found in Germany, 1230s), spinning wheels (France, by 1268), mechanical clocks (England, 1283), spectacles (Italy, 1285), firearms (Spain, 1331), and movable-type printing (Germany, 1453).[5] Though the Romans had learned how to make at least primitive soaps, it was not used for cleaning bodies. That was accomplished by rubbing oil onto the body and removing it with a scraper. A Swedish windmill, the successor to a medieval innovation, is shown in figure 7.1.

Similarly China between AD 1 and 1400 saw the introduction of porcelain, matches, woodblock printing, movable-type printing, paper money, and spinning wheels.[6] The technology of the preindustrial world was not completely static.

What was the rate of improvement of technology compared to the modern world? And how did it vary over time? Can we reduce all the complex changes in technology to a single number, the rate of advance of technology per year? How do we compare the invention of the bow for hunting, for example, with the introduction of the personal computer? How much technological progress is represented by the introduction of the mechanical clock in Europe in 1285, compared to the knitting frame of 1589?

Economists measure the rate of technological advance in a particular way. The lower curve in figure 7.2 shows the typical preindustrial connection between land per person and output per person, the *production function* of the society. Technological change in this measure is an upward shift in the production possibilities at any given amount of land per person, again shown in figure 7.2. If A is the measure of the level of technology, the rate of technological advance, g_A, is the percentage upward movement per year of the production function at any given amount of land per person. For example,

4. Mokyr, 1990, 36. Again such harnesses are claimed to have appeared in China much earlier, before 300 BC; Temple, 1986, 20–21.

5. Mokyr, 1990, 31–56.

6. Temple, 1986, 75–122.

Figure 7.1 A windmill, unknown in the world of Plato, Aristotle, and Euclid but introduced in the Middle Ages (Faro, northern Gotland, Sweden).

if g_A is 1 percent per year, at a given land-labor ratio the society is able to produce 1 percent more output per year.

This measure of the rate of technological advance has the property that

$$g_A = \theta_1 g_{A_1} + \theta_2 g_{A_2} + \dots + \theta_n g_{A_n},$$

where the θs are the values of the output of each industry of the economy divided by the total value of the final outputs, and the g_{A_i}s are the growth rates of efficiency within each industry.

Economists use this weighting because it measures how much technical changes matter to the average consumer. It measures efficiency by looking at the changes in the efficiency of production of each good within the economy weighted by how much of each good is consumed. This productivity measure effectively takes a poll of consumers and asks "How much more efficiently are things being done for *you* this year as opposed to last year?"

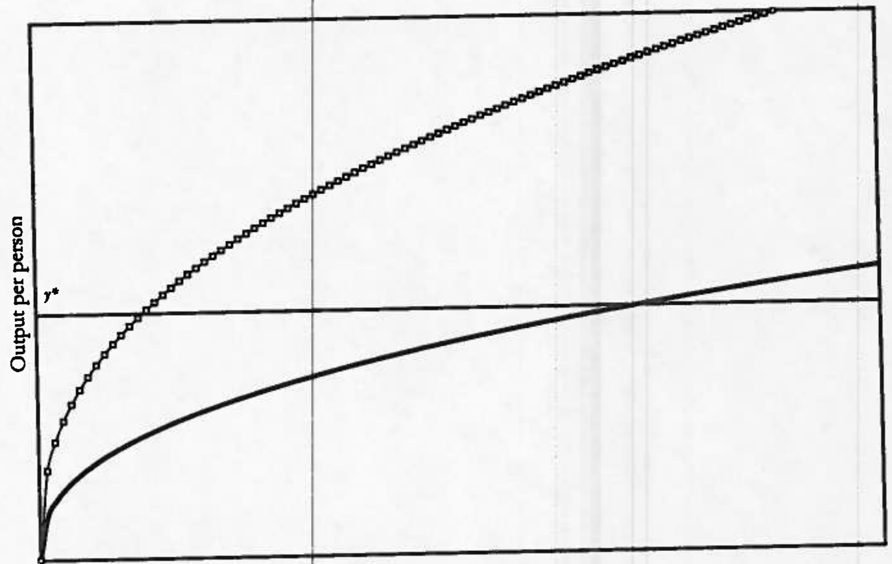

Figure 7.2 Effects of technological advance before 1800.

Measuring Technological Advance from Population

In figure 7.2 the Malthusian mechanism stabilizes population at the level at which the land per person produces just the subsistence income y^*. Technological change in this world showed up as an upward shift in the production possibilities.[7] But as long as income was constrained to return to the subsistence level, y^*, population would grow after technological advance until land per person fell sufficiently so that output per person was again y^*.

For one preindustrial society we can actually plot this curve over a wide range of acres per person. That is England during the period 1240–1600, when production technology seems to have been static but population varied by a factor of nearly 3 because of losses from the plague after 1348. The data points in figure 7.3 show output per person for each decade from the 1240s to

7. Here *technology* is used in the broadest possible sense to include any element of invention or social organization that affects output per acre. Thus legal innovations that increase output through better defining property rights will be included in the technology of a given period.

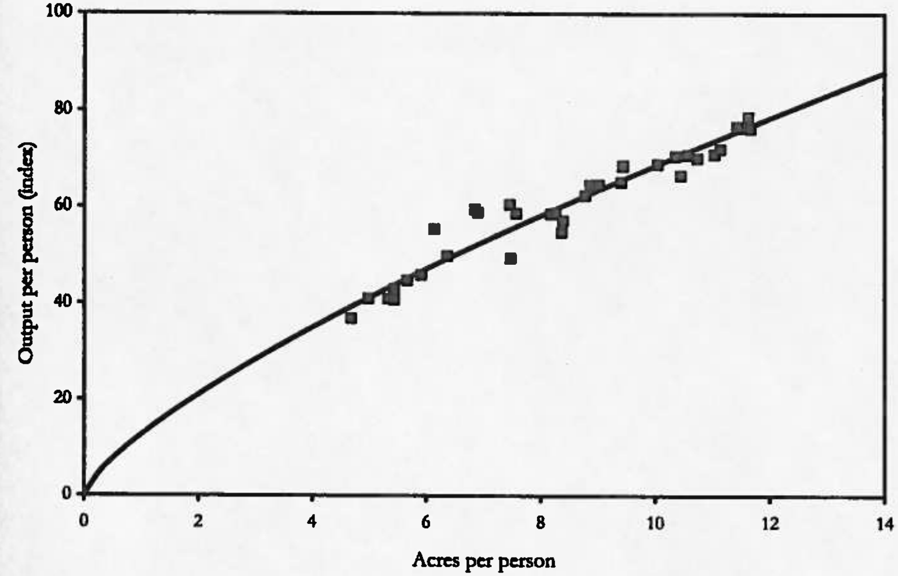

Figure 7.3 Output per person versus land per person in England, 1240s–1590s.

the 1590s. Also shown is the single production function that best fits these data. The static nature of the technology over these years is well illustrated by how well this single curve fits all these observations.

If we can represent aggregate technological advance in this way, as the upward shift in the production function, then measuring technological advance over long periods using population data becomes easy.

Let N be population and g_N the population growth rate. If c is the share of land rents in income in preindustrial society, then

$$g_N = \left(\frac{1}{c}\right) g_A.$$

The detailed derivation of this relationship is provided in the technical appendix.

This simple formula says, for example, that if the share of land rents in income was one-fifth, then a 1 percent improvement in the technology will increase population by 5 percent. To use this formula to measure the rate of preindustrial technological advance all we need is some estimate of the share of land rents in all sources of income and of the rate of population growth.

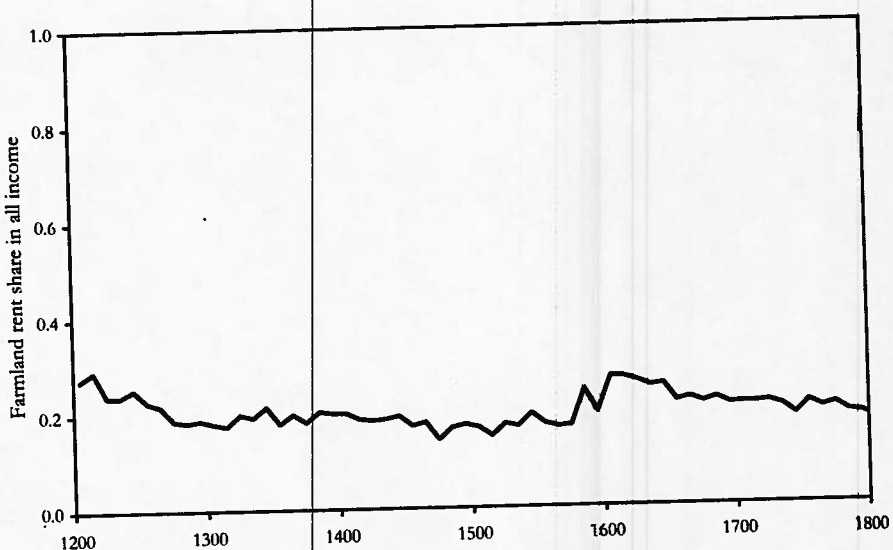

Figure 7.4 Land rents as a share of all income in England, 1200–1800.

Preindustrial England again supplies estimates of the share of land rents in national income all the way from 1200 to 1800. Figure 7.4 shows this share by decade. Though the share varied somewhat it was remarkably stable over time at an average of 20 percent of income. The constancy of the share of rent in all income allows us to infer simply how much technological progress would change the population. (To be precise, the production function is Cobb-Douglass.)

In preindustrial England the rent share in agriculture (as opposed to the economy as a whole) was 30–40 percent.[8] In comparison in Sichuan, China, in the eighteenth century sharecroppers paid 50 percent of farm output as rent.[9] Evidence from Babylonia in the time of Hammurabi (1792–50 BC) suggests a share of one-third for farmland rents.[10] So the share of land rents in national income could vary between 0.2 and 0.4, taking into account that farm output was 60–80 percent of all output. But for our purposes the exact number hazarded makes little difference in estimating the rate of preindustrial technological advance.

8. Clark, 2007b.
9. Zelin, 1986, 518.
10. Harris, 1968, 728.

Table 7.1 Population and Technological Advance, 130,000 BC to AD 1800

Year	Population (millions)	Population growth rate (%)	Technology growth rate (%)
130,000 BC	0.1	—	—
10,000 BC	7	0.004	0.001
AD 1	300	0.038	0.009
AD 1000	310	0.003	0.001
AD 1250	400	0.102	0.025
AD 1500	490	0.081	0.020
AD 1750	770	0.181	0.045

Source: Durand, 1977, 285.
Note: The estimate for 130,000 BC was made based on the idea that the range of animals man could hunt expanded greatly in this era. See Stiner, 2001, 2005.

What is the history of world population up until 1800? The second column of table 7.1 shows rough estimates of world population from 130,000 BC, when anatomically modern humans first appeared, to 1750. There is huge error in these estimates. For example, the population in 10,000 BC before the onset of the Neolithic Revolution is estimated using the observed densities of modern foraging populations. We know from archaeological evidence that in the years leading up to the Neolithic Revolution humans were steadily expanding the range of foods they consumed from hunting and foraging, allowing for greater population densities.[11] In the table I guess at a population of 100,000 people in 130,000 BC, but the time scale is so long here that the exact number matters little.

The last two columns of table 7.1 show the implied rate of population growth, and the implied rate of technological advance according to the formula above, with the assumption that land rents constituted a quarter of all income before 1800.[12] The low rate of technological advance before 1750 is

11. See Stiner, 2001, 2005.
12. The crudeness of these estimates is illustrated by the fact that there is tremendous uncertainty about even the population of Italy in AD 14. Estimates of seven million and seventeen million both have supporters. See Brunt, 1971.

immediately apparent. Since the Industrial Revolution rates of technological progress for successful economies have typically been 1 percent or greater. For the preindustrial era, at the world scale, rates of technological advance over long periods never exceeded even 0.05 percent per year. At a rate of 0.05 percent the production possibilities curve, shown in figure 7.2, shifts upward by 5 percent every hundred years. Thus the Industrial Revolution was an abrupt shift in the character of the economy, represented in the first instance by the rate of technological advance seemingly shifting abruptly upward.

Another suggestion that emerges from the table is that within the Malthusian era the rate of technological advance increased over time. The Malthusian era was not completely static, and indeed it showed signs of greater dynamism as it approached its end. But even at these higher rates of technological change, things happened very slowly. In the 1,750 years between the birth of Christ and the eve of the Industrial Revolution the technology improved by a total of 24 percent, based on these population estimates. That is, on aggregate economies in 1750 produced only 24 percent more output per acre of land, at a given level of people per acre, than in AD 1. That was why the world was trapped in the Malthusian era for so long.

The Locus of Technological Advance

Just as we can use population densities to measure roughly the rate of technological advance before 1800, we can also use them to measure which societies had the most advanced production technologies. Figures 7.5 and 7.6 give the numbers of people per square mile of farmland in the various regions of the world circa 1500 and 1800. Four regions show up as having high populations per acre: central Europe, the Middle East, India, and East Asia, particularly Korea and Japan. Though population densities had increased everywhere by 1800, as the result of technological advance, the world shows a very similar pattern of densities. As in the modern era a large share of world population is found in Europe, India, and East Asia.

In particular, there is little sign of any great difference in the implied technological sophistication of Europe and either the Indian subcontinent or East Asia on the eve of the Industrial Revolution. If living standards were the same across these societies than there is nothing that would highlight Europe in 1800 as having a more advanced technology than any number of eastern societies, including China, India, Korea, and Japan.

Figure 7.5 World population densities, circa 1500. The figure is drawn using the admittedly wildly speculative numbers of McEvedy and Jones, 1978, for population. Farmland areas are those for modern times as reported by the Food and Agriculture Organization (FAO).

Figure 7.6 World population densities, circa 1800.

The population density figures show aggregate population densities for large areas. If we concentrate on smaller regions and subregions, such as the Yangzi Delta in China, population densities circa 1800 were dramatic by European standards. In 1801 England, then just moderately densely populated by European standards, had 166 people per square mile. In contrast Japan as a whole was supporting about 226 people per square mile from 1721 to 1846, and the coastal regions of China attained even higher population densities: Jiangsu in 1787 had an incredible 875 people per square mile. It may be objected that these densities were based on paddy rice cultivation, an option not open to most of Europe. But even in the wheat regions of Shantung and Hopei Chinese population densities in 1787 were more than double those of England and France. Thus in terms of the major production activity of these societies, agriculture, if there was any technological advantage in 1800 it likely lay with the coastal regions of East Asia.

However, as we saw, at least in the cases of India, China, and Japan there are indications that material living standards were far behind those in England, and indeed were likely lower than those of most Malthusian economies.

Technological Regression

Before 1800 there were also long periods in which technology either showed no advance at all or even regressed. Australian Aboriginals, for example, are believed to have arrived in that country between forty and sixty thousand years ago, long before people first arrived in the Americas. But technology seemingly remained frozen on the Australian continent throughout the long period up to the arrival of British colonizers in 1788, judging by the technology of the Aboriginals at first contact.

Furthermore, there are signs of actual technological regression. The Aboriginals are presumed to have reached Australia by sea. Yet by 1788 they no longer had seaworthy craft in most of Australia. In Tasmania, where a community of about 5,000 Aboriginals was cut off from the mainland by rising sea levels for about twelve thousand years, the technological regression was even more dramatic. When encountered by Europeans in the late eighteenth century, the Tasmanians had a material culture at the level of the early Paleolithic, more primitive than that with which they had been endowed by their ancestors. Despite the cold they had no clothing, not even animal skins. They had no bone tools, and no ability to catch the fish abounding in the sea around them. Yet archaeological evidence shows that they had once had such bone tools, and that fish was once an important part of their diet. The gap between their technology and that of the English in 1800 was, as illustrated above, reflected in the respective population densities of the societies. Tasmania, about half the area of England, had an estimated five thousand inhabitants at a time when England had eight million.[13]

13. Jones, 1977, 1978.

The statues of Easter Island similarly pay mute testimony to a technological and organizational ability that the inhabitants had once had but no longer possessed by the time of European contact. The inhabitants of Hawaii had arrived there by sea voyages they were no longer capable of undertaking. Allegedly they had lost the knowledge of where they had come from and so were surprised to find that any other people existed in the world.[14]

In Artic Canada the Inuit, on first contact in the nineteenth century, had a material culture considerably less complex than that of their ancestors the Thule of five centuries before. The Thule were able to hunt large sea mammals in open water, and they wintered in permanent houses that were stocked with ingenious and elegant artifacts, including games and children's toys, harpoons, boats, and dogsleds. Sometime between the sixteenth and eighteenth centuries the Inuit lost much of their material culture. Hunting of sea mammals in open water disappeared, or was restricted to smaller species. Winter was now spent in transient snow-houses, since the Inuit were unable to procure sufficient food supplies to winter in one location. Artifacts were simpler, and decorated or ornamental objects were produced in only a few areas. So marked was this difference that it took archaeologists a long time to accept that the Inuit were indeed the descendants of the Thule.[15]

It is even claimed that China, which led the world in technological sophistication as late as 1400, also went into a technological decline. When Marco Polo visited China in the 1290s he found that the Chinese were far ahead of the Europeans in technical prowess. Their oceangoing junks, for example, were larger and stronger than European ships. In them the Chinese sailed as far as Africa. The Portuguese, after a century of struggle, reached Calicut, India, in the person of Vasco da Gama in 1498 with four ships of 70–300 tons and perhaps 170 men. There they found they had been preceded years before by Zheng He, whose fleet may have had as many as three hundred ships and 28,000 men.[16] Yet by the time the Portuguese reached China in 1514, the Chinese had lost the ability to build large oceangoing ships.

Similarly Marco Polo had been impressed and surprised by the deep coal mines of China. Yet by the nineteenth century Chinese coal mines were

14. The Hawaiians thus regarded Cook on first encounter as one of their gods; Beaglehole, 1974, 649–60.
15. McGhee, 1994.
16. Finlay, 1992, 225–26.

primitive shallow affairs which relied completely on manual power. By the eleventh century AD the Chinese measured time accurately using water clocks, yet when the Jesuits arrived in China in the 1580s they found only the most primitive methods of time measurement in use, and amazed the Chinese by showing them mechanical clocks. The decline in technological abilities in China was not caused by any catastrophic social turmoil. Indeed in the period after 1400 China continued to expand by colonizing in the south, the population grew, and there was increased commercialization.[17]

Why Was Technological Advance So Slow before 1800?

This is one of the great puzzles of world history, in the light of what came after 1800. What makes it so puzzling in part is that preindustrial societies differed from each other in every conceivable way socially and institutionally. Christian Europe had a horror of incest. In Roman Egypt the preferred marriage partner was a sibling. Christian Europe embraced alcohol with fervor and relish, and in good times its people consumed enormous quantities. The Muslim world abhorred it. Animal flesh was eaten with gusto in Europe. In Hindu India all but the sinful and debased avoided it. The Europeans in turn were horrified by the Aztec practice of eating the flesh of dead enemies.

Yet despite the bewildering variety of cultures and institutions, all these societies had one thing in common: the production technology improved very slowly. Indeed there were periods of regression as well as advance. But in general the drift was inexorably upward, so that cumulatively, over millennia, enormous advances occurred. A growing world population was a powerful and direct testament to these changes, as much as the written and archaeological remains of machines and devices.

But why was a society like England able to achieve modern rates of technological advance only after so many millennia? We will not address this puzzle fully until we discuss the Industrial Revolution itself. There is a common misapprehension that must be corrected first—that before 1800 the institutional framework of societies removed all incentive for people to invest in better technology.

17. Mokyr, 1990.

8 Institutions and Growth

Give a man the secure possession of a bleak rock, and he will turn it into a garden. . . . The magic of PROPERTY turns sand to gold.

—Arthur Young (1787)[1]

The popular misconception of the preindustrial world is of a cowering mass of peasants ruled by a small, violent, and stupid upper class that extracted from them all surplus beyond what was needed for subsistence and so gave no incentives for trade, investment, or improvement in technology. These exclusive and moronic ruling classes were aided in their suppression of all enterprise and innovation by organized religions of stultifying orthodoxy, which punished all deviation from established practices as heretical. The trial and condemnation of Galileo Galilei by the Holy Inquisition in 1633, for defending the Copernican view that the earth revolved around the sun (figure 8.1), seems an exemplar of the reign of superstition and prejudice that was responsible for the long Malthusian night.

There may have been societies before 1800 that fit this popular stereotype. There were frequent attempts by religious authorities to impose fallacious dogmas about the natural world. But we shall see that, as an explanation of the slow technological advance of the world as a whole before 1800, the prevailing view makes no sense. It is maintained only by a contemporary variety of dogmatism—that of modern economics and its priestly cast.

The central vision of modern economics, the key message of Adam Smith in 1776 and of his followers, is that people are the same everywhere in their material preferences and aspirations. They behave differently only because of differences in incentives. Given the right incentives—low tax rates on earnings,

1. Young, 1792, July 30, 1787, and November 7, 1787.