Econ 110A, Winter 1999
European Economic History
Gregory Clark

4. TECHNOLOGY AND MATERIAL LIFE BEFORE BEFORE 1700

"There be daily many things found out and daily more may be which our fore fathers never knew to be possible." Sir Robert Filmer (1653).

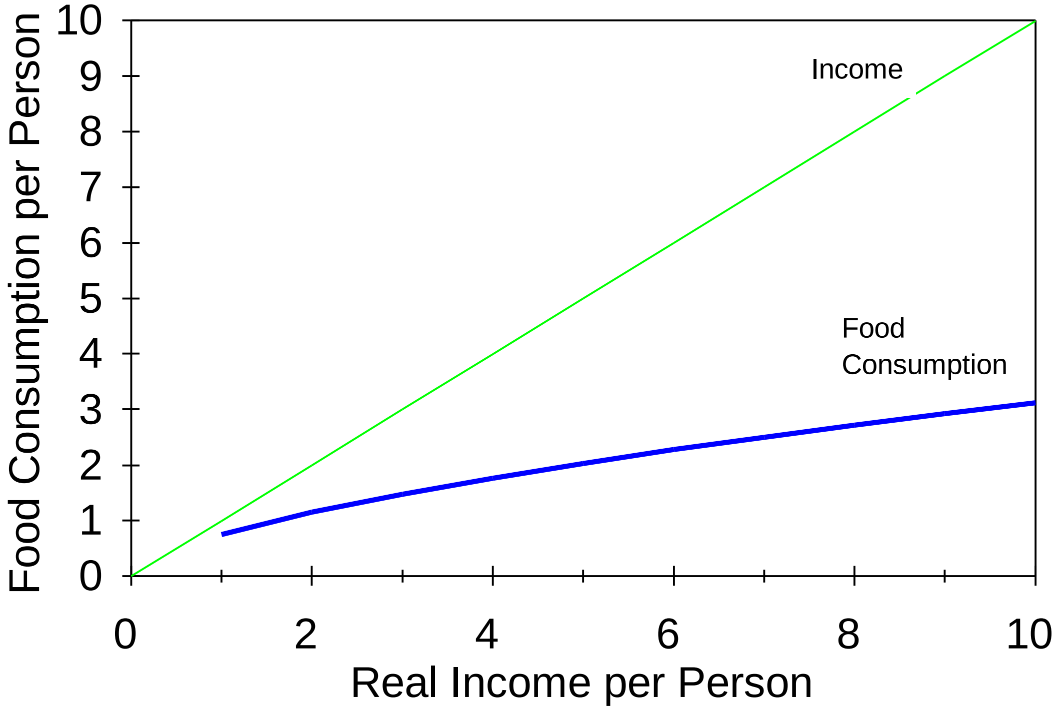
1 The Importance of Agriculture

The technology of pre-industrial Europe was very simple by modern standards. A notable feature of pre-industrial Europe is that seemingly it, like all pre-industrial societies, was largely an agrarian economy, where 70-80% of the population labored upon the land, and consequently where the population was mainly dispersed in small communities of 50-300 people across the countryside.

The reason pre-industrial societies were all generally agrarian economies stems from one simple fact about how people consume. As figure 1 shows there is a stable relationship between food consumption per person and income per person which has the form shown in the graph. At low levels of income the share of food expenditures in total consumption is very high, and has been observed to be as much as 90% for some poorer households. As incomes rise the share of income spent on food declines.[1] This effect is very strong if we measure food as the raw foodstuffs produced on the farm. People can only consume a limited number of calories per day, and they can only consume more foodstuffs by buying more expensive forms of food - meat and dairy products as opposed to grains. Consequently in a closed economy the poorer the

[1] This relationship was first discussed systematically by the Russian statistician Engel and consequently the curve relating consumption of any good and income is called the Engel Curve. The relationship portrayed showing that the share of income spent on food declines with income is sometimes called “Engel’s Law.” (Engel was no relation of the other famous Engel, the co-author of the Communist Manifesto).

FIGURE 1: FOOD CONSUMPTION AND INCOME



population typically the larger will be the share of the population employed in agriculture. In the US about 3% of the population currently produces more than enough food for the entire population. This would contrast with about 80% of the population engaged in agriculture in the poorest peasant economies.

Indeed the relationship between food consumption and income per person, and hence between the share of the population employed in agriculture and income per person is so stable that economic historians have often tried to infer income per person from the share of the population employed in agriculture.

The reason it is believed pre-industrial Europe was largely agrarian is the small share of the population located in urban areas. In the modern world there is a good relationship between the share of the population living in urban areas and the percentage of the population engaged in primary production - agriculture, forestry or fishing. Figure 4.2 shows for the 1990s the relationship between the proportion of a country's population employed in agriculture and the share of the population living in urban areas for a group of countries where both types of information are available. As can be seen the fit is fairly good, even though the definition of urban areas varies from country to country.[2] Thus it seems if we know the share of the population which was urban we can infer the share of the population employed in agriculture reasonably well.

A recent attempt to get a systematic estimate of the urban population of Europe from 1500 to 1800 gives the results shown in table 1. The cutoff size used for urban communities is a little large at 10,000 people, but the reason for this large cutoff level is that it is easier to identify

[2] In Canada an urban area was any place with a population of more than 1000, while in Japan the population had to be 50,000 or greater.

FIGURE 2: SHARE OF MALES EMPLOYED IN PRIMARY SECTOR AND THE URBAN POPULATION SHARE, CIRCA 1994

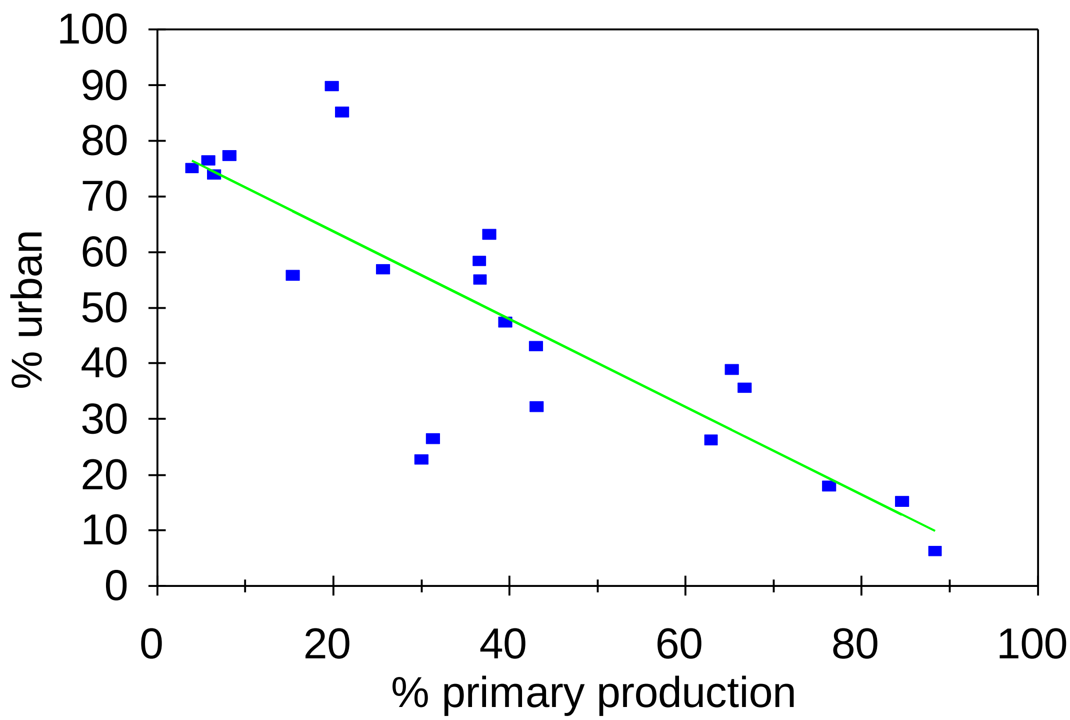


TABLE 1: POPULATION SHARE IN TOWNS OF MORE THAN 10,000 (%)

YEAR	1300	1500	1600	1700	1800
All	(<5)	5.6	7.6	9.2	10.0
England		3.1	5.8	13.3	20.3
Netherlands		15.8	24.3	33.6	28.8
France		4.2	5.9	9.2	8.8
Germany		3.2	4.1	4.8	5.5
Spain		6.1	11.4	9.0	11.1
Italy		12.4	14.7	13.4	14.4
Poland		0.0	0.4	0.5	2.5

Source: de Vries (1984), pp. 39-43.

such larger towns and get estimates of their population size. As can be seen the urban share of the population is always extremely small, though it grows over time.

Before the Black Death came in 1348 when medieval population was at its maximum it is estimated that there were only six cities in Europe with populations greater than 80,000: London, Paris, Milan, Venice, Genoa and Florence. In England only four other towns (York, Winchester, Norwich and Bristol) had populations of more than 10,000. In contrast in 1600 when the level of population in Europe was still below the level of 1300 the sizes of towns and cities had grown greatly. By 1600 both Seville in Spain and London had about 150,000 people, and Paris and Naples had reached 250,000. Amsterdam had grown from 10,000 around 1500 to 100,000 in 1600. Urban populations in general in Europe were greater by 1600. And the growth continued in the following 150 years leading up to the Industrial Revolution. By 1750 when the population of Europe was still only about the same as in 1300 London is estimated to have had a population of 676,000, 11% of the population of England. Paris had grown more slowly but still is estimated at 560,000.[3]

The increase in urbanization took place typically in those regions assumed for other reasons (such as travelers reports or the volume of trade) to be advancing economically. Typically the economically advanced areas show the most urbanization. The Netherlands, for example, is believed to be the economy with the highest standard of living and greatest efficiency

[3] See Cameron (1989), p. 96. Britnell (1991), pp. 21-35, Hohenberg and Lees (1985), pp. . The population of early cities is estimated very imprecisely because we only have accurate population cencuses for a few cities. Sometimes the size of the population is estimated by calculating the area within the city walls at various dates and multiplying it by an estimated population density (calculated from other cities where both population and area is known). At the density of population of medieval Winchester of 30 people per acre, all of London in 1300 could have been fitted into 4 square miles, which would be a smaller area than the Davis campus.

in 1600 in Europe. Back in 1500 northern Italy was still a very advanced area. Poland is regarded as a very poor region of Europe.

2. Productivity Advance in Agriculture

Since agriculture was the most important activity in pre-industrial societies, any sustained improvement in technology had to involve an increase in the productivity of agriculture. But while agriculture was seemingly the main activity, agriculture in pre-industrial Europe was extremely unproductive by modern standards.[4] The land in northern Europe was divided into arable or plowed land on which the grain crops were grown, pasture and meadow, and woodland. In periods of greater population such as 1300, as much as 80% of the land would be devoted to arable in areas such as southern England. The arable was very infertile with yields of only 3-6 grains per seed planted.[5] Wheat in southern England, for example, gave a gross yield of only about 11 bushels per acre from 1200-1400. Modern yields in this area would be more than 70 bushels per acre. Yet to maintain even this very low fertility 25-50% of the arable had to lie fallow each year, as compared to no fallowing now. This meant that the net yield of wheat would be about 360 lbs. per arable acre. Since a lb. of grain yields from 800-1200 kcal depending on how it is milled, and people need about 2000 kcal per capita per day to be reasonably fed, it would require about 2 acres of arable per person to support the population in northern Europe if they were eating the cheapest possible diet.

---

[4] Cipolla (1993), pp. 121-126.

[5] See Cipolla pp. 100-103, where the figures for England and Italy are given. In Italy wheat yields per seed before 1700 varied widely from about 2 to 7.

The land had not only to feed people, however, it also had to supply the food for animals who provided much of the power for cultivating the land and transporting goods and people. It further had to provide much of the raw materials for clothing, furniture, utensils, housing, heating and lighting. Wool and flax were the major fibers used for clothing, and wood was used for most machinery, carts, furniture, utensils, for buildings, and for fuel. Candles were made of tallow from animals.

The land was plowed by oxen or horses which pulled heavy wooden plows made of wood tipped with iron in northern Europe.[6] Animals in pre-industrial Europe were very small by modern standards.[7] In Italy the deadweight of cattle in the 17th century was less than one third of modern weights. Archeological evidence from animal bones found in 14th century settlements suggests that both sheep and cattle were only about half their modern stature.[8] Thus the plow would be pulled by a team of 8 oxen, which required a driver and a holder to control. These implements could only plow an acre or less a day. The large teams of oxen in turn required many acres of pasture to feed them.

The low yields on the arable, and the need to use land to provide for industrial raw materials and animal power thus help explain why the populations given above for pre-industrial Europe were so low. The population of England, to take an extreme example, was at its pre-industrial maximum about 6 million in 1300 compared to 50 million now, despite the subsistence

---

[6] Iron was too scarce to be used for the whole of the plow.

[7] Cipolla, p. 126.

[8] Milk yields were certainly far below modern levels. Milk was so scarce that in 14th century Europe even the tiny sheep of this period were milked to produce cheese. The milk yield per sheep was about 70 pints per year, less than a cup per day.

wages of 1300. France had about 20 million compared to 54 million now, Italy increased from 15 to 56 million.

Agriculture was seemingly very labor intensive. When the land was plowed for grain, it was weeded by hand, and then harvested with a sickle or a scythe. In harvesting with the sickle each worker could harvest about 1/3 of an acre per day. The grain was stored in barns in northern Europe and threshed by hand over the winter. Threshing consisted of beating the grain with a long pole to separate the grains from the straw. It was a technique essentially unchanged from 1000 till 1800. Then the grain would be winnowed from the chaff by using natural wind or by using a winnowing sheet to create a draft. The grain produced was milled into flour by hand, water and later windmills.

A variety of animals were kept to produce milk, cheese and meat. Sheep, for example, were mainly kept for their wool but frequently they were also milked though they produced less than a pint of milk per ewe per day on average. The milking of these sheep must again have been very labor intensive.

Major amounts of labor were also used in collecting animal dung and returning it to the fields, in pruning hedges (the prunings being used for fuel), and in putting lime and marl onto the ground to correct the acidity.

3. Why was Agricultural Productivity so Low?

There has been puzzlement about why grain yields were so low. One argument called the **Postan Thesis** (after M. M. Postan, a famous medieval historian) has been that yields were so low because of soil exhaustion. In pre-industrial Europe, he argued, the pressure of population drove people to mainly cultivate grain, which could produce more calories per acre than pasture land. But the continuous grain cultivation depleted the soil of vital nutrients which kept yields at very low levels. In other words, Postan thought that medieval Europe was locked in what we would now call an Ecological Crisis.

Any agricultural system removes from the ground various nutrients with each crop produced - nitrogen, phosphorus, potassium, magnesium, sodium, etc. When these crops are consumed by humans the nutrients in them are generally lost to the agricultural system either to the air or in waste water. In the long run the system will only be sustainable if the outflow of nutrients is balanced by a combination of the production of the nutrients within the soil and an inflow from other sources. i.e.

outflow =   internal production + inflow

(this is an exact parallel with the stipulation we had in chapter 2 that for the human population in pre-industrial societies in equilibrium births = deaths).

Our best understanding is that crucial depleted nutrient was organic nitrogen. When systematic experiments were first conducted in growing grain under various rotations in Rothamsted in England in 1842 it was soon found that under cultivation conditions similar to those of pre-industrial agriculture, additions of nitrogen alone to plots sown with grains increased wheat yields by over seven bushels per acre and barley yields by over sixteen bushels. These increases were maintained on land continuously sown in grain with additions of only nitrogen for over sixty years. Land under continual wheat cultivation produced twenty bushels per acre annually as long as nitrogen alone was supplied, and land under barley produced twenty nine bushels per acre, much greater than the equivalent medieval yields. Additions of a combination of all other major plant nutrients - phosphorus, potassium, magnesium, and sodium - without extra nitrogen increased per acre yields of wheat at Rothamsted by only two bushels and yields of barley by only seven bushels per acre. Figure 3 shows the nitrogen economy of the pre-industrial agricultural system.

In the nineteenth century growing each bushel of wheat required about 6 lbs of nitrogen (all proteins contain nitrogen). Uncultivated land in temperate latitudes contains about 5000 lbs of nitrogen in the soil per acre. Since a modern crop of 70 bushels per acre would require over 400 lbs of nitrogen in the nineteenth century, it would exhaust the soil reserves in about 12 years.[9] In agriculture in the modern industrialized world this condition does not constrain agricultural output, since we can replace most of the soil nutrients at low cost with <u>manufactured</u> fertilizer. Indeed modern agriculture is a completely non self-sustaining system. It depends on huge inflows of nitrogen, potassium, etc. which are either manufactured using petroleum or mined from soil deposits. If the industrial basis of our agriculture were removed yields would collapse. Figure 3 shows the dramatic rise of fertilizer use in Britain and Germany from 1880 on. In the US over 90% of the nitrogen applied to soils is from chemical fertilizers. Indeed from 1950 to 1980 the world use of chemical fertilizers increased sevenfold.

---

[9]The first major nitrogen-containing manure used in the 19th century was guano found on islands off the cost of Peru. There the guano was up to 6 feet deep. Britain and Peru nearly went to war because of Peru's monopoly of the guano trade in the nineteenth century.

FIGURE 3: THE PRE-INDUSTRIAL NITROGEN CYCLE

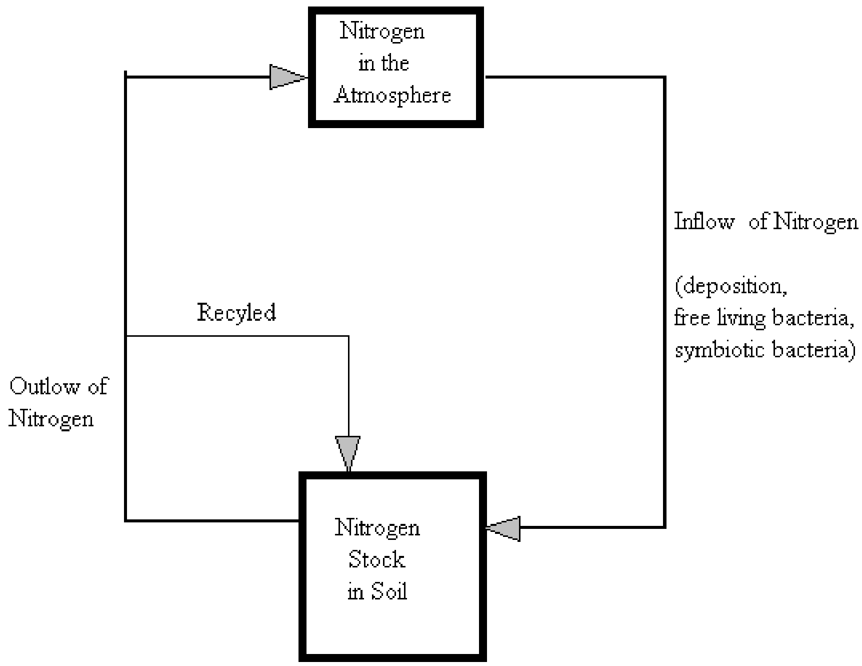
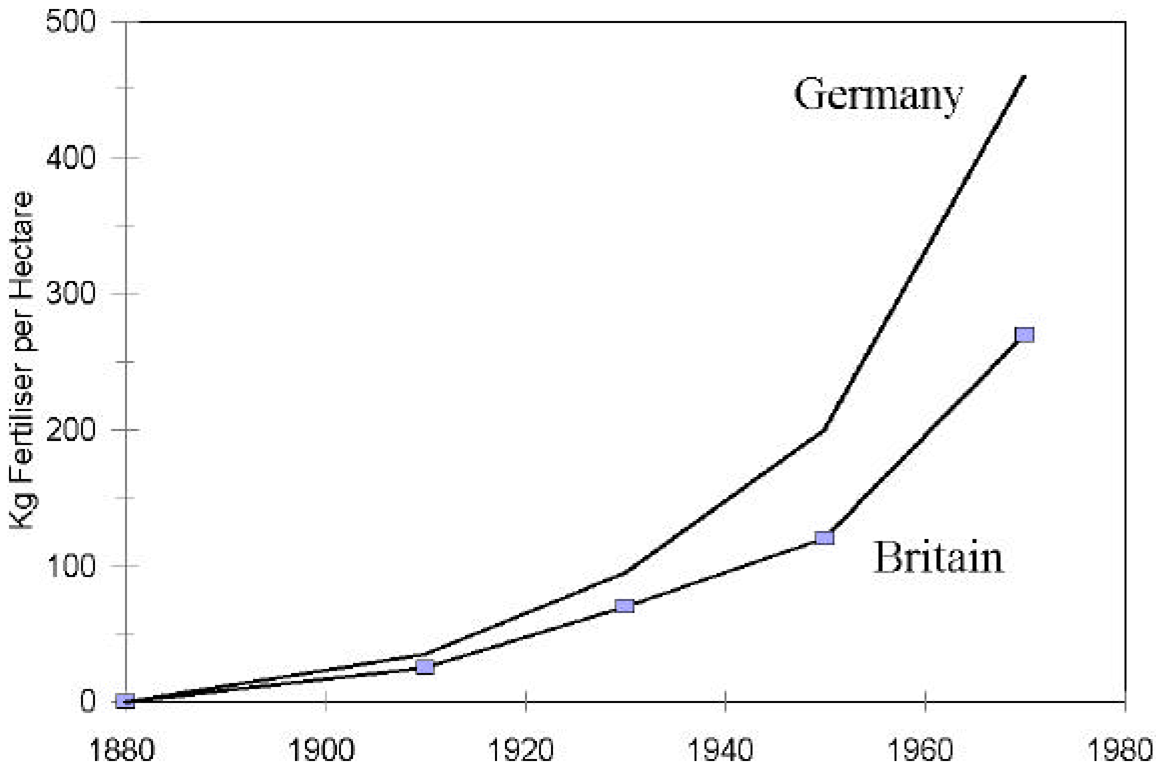


Figure 4: Fertilizer Use Per Acre in Britain and Germany since 1880

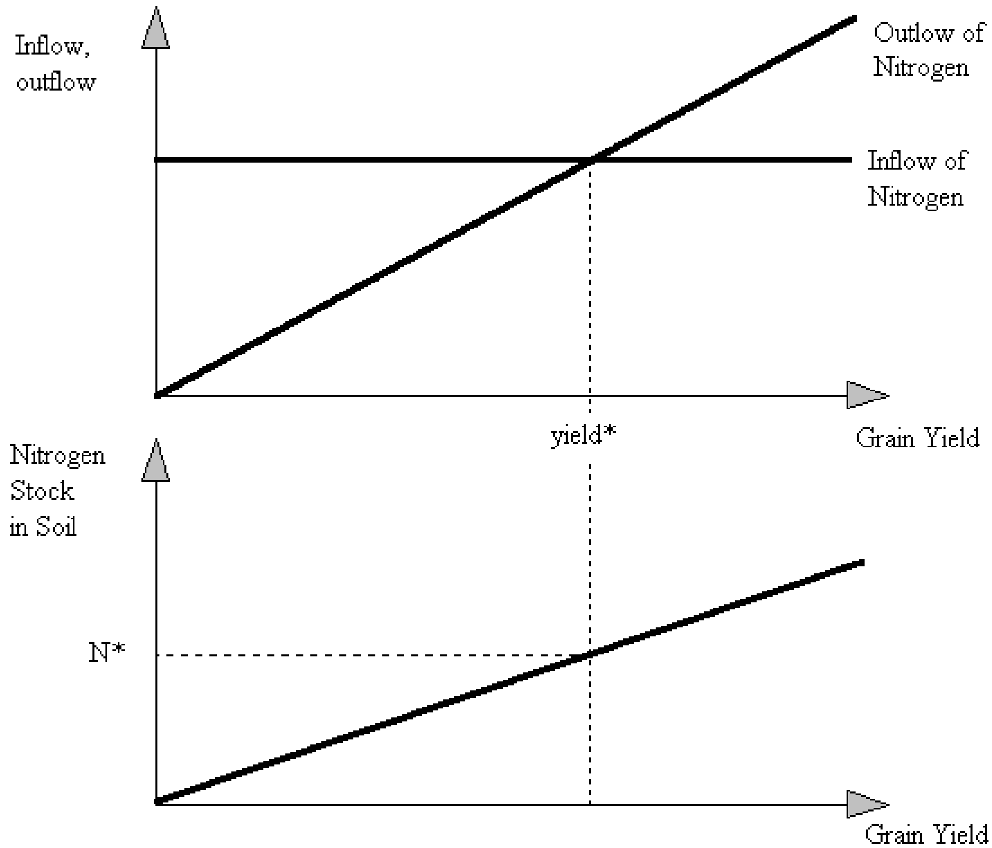


There were no manufactured fertilizers in pre-industrial Europe, however. Thus the soil nutrients depleted by crop removal had to be replaced either by returning the waste products of consumption, or by replenishment from within the soil. The system had to be self-sustaining This imposes a heavy constraint on output. Nitrogen enters the soil from the atmosphere in three ways: by direct deposition, through fixing by free-living bacteria in the soil, and through fixing by symbiotic bacteria on the roots of certain plants. We know from the Rothampsted experiments that under continual grain cultivation there are inflows of nitrogen are about 35 pounds per acre from the first two sources, rainfall and non symbiotic fixation. Since each bushel of wheat required about six lbs. of nitrogen for its growth, under the pre-industrial system of continual grain production on the arable the land can in the long run produce at maximum about six bushels of wheat per year.

The only way to increase yields without artificial fertilizers is to grow crops that fix nitrogen symbiotically such as clover or legumes. Pasture land also fixes nitrogen from the atmosphere because it contains clovers and other nitrogen fixing plants. Thus the current view as to how yields were increased between 1700 and 1850 is that there was a diffusion through English agriculture of the use of sown clover as a crop in arable rotations. The clover fixed nitrogen which was made available to the subsequent grain crops through animal manure and as soil residues. By increasing the nitrogen input the total output of the agricultural system was raised also.

Figure 5 below illustrates the nitrogen economy of the pre-industrial world. Grain yields depended on the stock of nitrogen in the soil, but this stock would only be constant when the inflow equaled the outflow (assuming recycling is 0 for convenience). Thus while when ground was initially cultivated the accumulated stock of nitrogen in the soil was large and would initially give good yields, this caused an excess of outflow over inflow, so that the stock declined until we reached the level N*, and the yield fell to yield*. To get higher sustainable yields the inflow of nitrogen had to be increased (by fixing nitrogen with clover grown in rotation with grains) and/or the outflow had to be reduced (by returning more output back to the soil as manure).

FIGURE 5: YIELD DETERMINATION IN THE LONG RUN IN A SELF-SUSTAINING AGRICULTURE



The clover/nitrogen theory is not without difficulties, however. While it seems on the above rent evidence plausible that nitrogen really was a major constraint on yields before 1850 it is not at all clear that this can be put down to the ignorance of farmers of the mechanics of crop growth. While clover was the most efficient way of fixing nitrogen, it was not much better than another simple way which had existed since at least the middle ages, convertible husbandry. Under convertible husbandry land was used as arable for 5-10 years, then switched to pasture for an equivalent length of time. In the pasture phase the land acquires stocks of nitrogen in the soil which can be utilized by subsequent arable crops. There is no doubt that even medieval cultivators knew of the fertility restoring powers of grass, so why had these techniques not improved yields long before 1770? Further detailed microeconomic studies by Overton and others on the yields of seventeenth and early eighteenth century farmers who did and did not have sown clover crops finds little sign that those who used clover had higher grain yields. The low level of grain yields before 1850 thus seems as much a choice of farmers not to invest in improving soil fertility by growing more grass as the consequence just of ignorance.

4. Other Production Technology

Clothing for the poor was made of wool and linen. Cotton garments were extremely rare, though the rich would have silk garments also. Clothing and bedding materials were relatively expensive since it took a lot of labor to make cloth. The fiber was spun into yarn using the distaff or the spinning wheel, but it would take all day to spin a lb. of yarn.[10] Then the yarn was woven on a wooden loom, before being fulled and dyed. It is estimated that a piece of cloth of 21 yds^2, which would provide tunics for 3 people, would take 90 person-days to produce.[11] The typical dress was a linen undergarment, a woolen tunic, and leather shoes.

In the middle ages housing in northern Europe was mainly constructed with wood frames filled in with wattle, plaster, or earth. The roofs were of thatch, the floors of earth. The smoke escaped through a hole in the roof, and there were a few small windows (glass was very expensive). The basic houses would be 450-675 ft^2, with two or three rooms. The amount of living space per person was 70-90 ft^2, which is more than in the modern third world. Typically all the family would sleep together in one bedroom. In many places the animals were quartered inside the house or below it so that their body warmth would help heat the house. In the late middle ages brick began to be used more in northern Europe, but it was a relatively expensive material. The furnishings of houses included straw or feather stuffed mattresses, wooden benches and tables, and a wooden chest for storage.

The richer members of the society such as merchants in the towns would have much more substantial housing. Often surprisingly there was still only one large bedroom with as many as 5

---

[10] Spinning was a major occupation for women. Thus the term "spinster" for unmarried women.

[11] Cipolla, p. 129.

beds in it, the extra space being used for "sitting rooms." Their houses were however decorated with brightly colored tapestries, curtains, and bed covers.

The major sources of power apart from people and animals were wood, water and wind. These were all renewable energy sources but this placed severe constraints on production. Iron was produced, for example, by smelting the ore with charcoal made from wood. But it took about 10 acres of wood to produce a ton of iron (which is a quantity significantly less than a cubic yard). Producing energy for heating, light and industrial production in the form of wood thus competed with using the land to produce food or clothing and construction materials. Both water and wind mills were widely used. The mills mainly ground corn and fulled cloth. Windmills were also used to drain low lying land in the Netherlands and in Eastern England.

Transportation was by horse or wagon on land. In the more developed areas in the 17th century canal systems began to appear. In the Netherlands, for example, an elaborate system of canals connecting all the major towns was in place by 1650.[12] Passenger boats ran on a fixed schedule between cities, and like modern airline shuttle systems there were standby boats to ensure all passengers were accommodated. It was possible to go from Northern France to Amsterdam entirely on canal boats in 1650. But the average speed of travel on these canals was about 5 miles per hour. In many areas up till 1700 there were not even roads but simply paths along which pack horses traveled.

Speeds of travel were very low. We shall see below that it is possible to estimate that information moved across the Roman Empire in the first few centuries AD at a speed of about 24 miles per day on average. This meant that the outlying areas of the Empire such as Britain would

[12] A horse pulling a canal boat can pull 50 times the weight it can carry in a pack.

hear about events in Rome typically 8-10 weeks after they occurred. It also meant that control of countries or empires which were large was difficult. If there was an invasion on the northern frontier or a rebellion there it would take up to 20 weeks for the information to reach Rome and a response to get back to the local commander.

By the sixteenth and seventeenth centuries speeds of travel had improved somewhat. But even in such an advanced area of pre-industrial Europe as England the usual method of travel was by horseback in the late sixteenth century. If frequent changes of horses could be arranged the traveler could cover 24-50 miles per day, but where frequent changes of horses were impossible the distance covered would be only half as much. At this rate the journey from London to York in the north would take anywhere from 4 to 16 days. After the mid seventeenth century stage coach travel became available. The speeds were on average only about 30 miles per day. On better roads slightly faster travel was possible. Thus the London York journey took 5-6 days, while the London Newcastle journey took only 6 days from 1660 on. Yet until 1732 there was only one coach per week between London and Newcastle. In the seventeenth century the mail was carried at the speed of between 3.5 and 5.5 miles per hour depending in part on the time of year.[13]

In the countryside where most of the population lived the sources of entertainment were limited for most of the year. The typical village would consist of a few hundred people and getting to town would require walking. Markets and fairs were a great source of diversion, as were religious festivals. Those who could afford it consumed large quantities of alcohol. The moralists in the church continually inveighed against the drunkenness and license which

[13] Jackman (1962), pp. 134-140.

accompanied weddings, funerals, and religious feasts. The peasant would also get diversion from poaching game, and from a variety of rough physical sports.

Reading materials were in very limited supply. Before the invention of the printing press books had to be copied by hand and were consequently expensive and owned only by the rich. Thereafter books fell greatly in price, but the surviving inventories of the seventeenth century and earlier show few books other than the Bible in most households.

5. TECHNOLOGICAL CHANGE BEFORE 1700

In the period before 1700 there were, seemingly, significant improvements in production technology. Surprisingly these changes largely occurred in the late middle ages and early modern periods, rather then in the Classical world, normally thought of as a period of high intellectual achievement. The list of basic technologies which were unknown or unused in the ancient world is a surprisingly long one. These include, for example, the nailed horseshoe, which protected hooves from soil moisture which wore hooves out quickly and caused them to splinter. The Greeks and Romans also did not use stirrups which allowed cavalry with lances to be used as shock troops in warfare. In antiquity war was mainly conducted on foot, or horses pulled chariots. The Greeks and Romans also used horse harnesses which wound around the belly and neck of the horse. Experiments earlier this century by a retired French cavalry officer suggest that harnessed in this way horses lose up to 80% of their traction power, since the neck strap presses on the windpipe and the jugular. In the medieval period horse collars which sat on the horses shoulders were introduced.

Medieval western Europe, for all its lack of high culture, made more notable advances in basic production technologies than did the Classical period. The period called the Dark Ages (AD 500 - AD 1150) saw the introduction of horse shoes, stirrups, and horse collars. A notable innovation of the High Middle Ages (AD 1150 - AD 1500) was the windmill. The first of these documented with certainty were in Yorkshire, England, in 1185. Wind mills are more sophisticated machines than water mills since they have to be turned to face the wind. They were also able to develop more power than water mills. The largest windmills could deliver 20-30 horse-power, compared to less than 10 horse-power for water mills.[14]

The medieval world also made major advances in shipping and navigation. Ships in the classical world mainly used a single square mainsail, and were steered by oars. This made them hard to maneuver, and it meant they could sail into the wind at only a slight angle. Ships basically had to sail with the wind, with all the limitations this implied. The late middle ages saw substantial improvements in ship design. New rigging with three masts that carried both square and lateen sails were adopted which considerably improved maneuverability. A sternpost rudder was added which reduced the effort in steering. Ship construction also improved. By 1300 the "carvel" construction technique diffused widely. In earlier methods the planking of the hull provided the structural strength of the ship which limited the size of ships. In carvel construction beams within the hull provide the structural strength, and the planking merely keeps the ship watertight. This allowed larger and lighter ships, which reduced transportation costs and increased seaworthiness. The Portuguese caravel was used by Da Gama, Columbus, and Magellan in their voyages of discovery. Reflecting improvements in construction and rigging the tons carried per sailor rose from 5-6 in 1400 to 7-8 in 1550, and continued to rise thereafter.[15]

Navigation also improved greatly. Greek and Roman ships seem to have not had any navigational aids, other than watching the stars and following the coastline. This limited the sailing season in the Mediterranean to the summer. The magnetic compass was introduced in the late middle ages, though it was not till after 1400 that it was used to steer ships. The ancients knew how to measure <u>latitude</u> by measuring the altitude of the polar star. But this was not used

[14]Cipolla, pp. 172-4.

[15]Cipolla, p. 130.

for navigation at sea till the late middle ages.[16] All these developments in ship construction and navigation were the prerequisites of Columbus's voyages across the ocean in 1492, and Magellan's circumnavigation of the world in 1521.

Other devices often though of as timeless were medieval innovations. One was a button in clothing that was other than just decorative. This first appeared in Central Germany in the 1230s. Despite the great technical sophistication of oriental culture it never developed the button. The Japanese were introduced to them by Portuguese traders, and consequently still use the Portuguese word for them. Another medieval innovation was the spinning wheel. The earlier method of spinning, used in ancient Egypt 7,000 years ago, was the hand held distaff and spindle. This method was so slow that for very fine yarns it is estimated it would take perhaps 700 hours to spin 1 oz. Thus spinning was a major activity in these societies. The spinning wheel, introduced in the 12th century, allowed the spindle to turn 2-3 times faster, increasing output per worker by equivalent amounts. The basic spinning wheel was improved enough in the 16th century to further double the productivity of spinners.[17] Weaving was also improved by the introduction of horizontal looms, where a foot operated treadle raised and lowered the warp threads to allow insertion of the weft. In 1589 the English clergyman William Lee devised a mechanical knitting machine which was extremely complex, but which spread quickly though Europe.

Spectacles were invented around 1285 in Italy. The fourteenth century saw the introduction of mechanical clocks and firearms. Gutenberg introduced movable type for printing in 1453. This innovation reduced the cost of producing books dramatically. The printing press spread rapidly across Europe. By 1480 there were over 380 working presses in Europe. The first

---

[16]Measuring longitude was problem that was not solved till the eighteenth century. See below.

[17]Harold Catling, The Spinning Mule (1970), pp. 9-19.

printers produced 300 pages a day. There were steady increases in productivity thereafter. By 1500 printers produced 400 pages per day, and by 1700 2000 pages a day.[18]

There were also great developments in the 17th century in science. Galileo (1564-1642) discovered the laws of motion of falling bodies and pendulums circa 1609, and Kepler (1571-1630) discovered the laws of Planetary Motion in the years 1609 to 1619. Finally Newton (1642-1727) enunciated the laws of gravitation in 1666. In mathematics analytic geometry was developed in 1637 by Descartes (1596-1650), while Newton developed Calculus in 1665.[19]

The overall impression this leaves is that from the late middle ages on we observe a society with some technological dynamism, gradually refining technologies and introducing new ones. The quote at the beginning of this lecture from Sir Robert Filmer suggests that certainly by the 17th century people had come to expect that progress was possible. It is surprising that these technological changes seem to have had little impact before 1700 on the "wage schedule," the curve relating wages and population. One factor that may explain this is that agriculture was the major activity, and yields and labor productivity in agriculture seem to have increased little all the way from 1200 to 1650. The innovations after 1200 were largely confined to activities which were a small share of expenditures - printing, glasses, shipping commodities such as wine, cloth, and spices. Some innovations such as firearms were of no social value. Some such as the laws of gravitation and the Calculus were largely of intellectual value. But the improvements in spinning and weaving should have had some impacts on living standards since clothing was a significant share of expenditure.

---

[18]Cipolla, p. 130.

[19]The 200 years before 1700 also saw tremendous progress in painting and literature. In Italy Leonardo da Vinci and Michelangelo lived from 1452 to 1519 and 1475 to 1564 respectively. Shakespeare (1564-1616) wrote most of his plays in the last decade of the 16th century.

FURTHER READINGS

Bennett, H. S. 1938. Life on the English Manor.

Cipolla, Carlo. 1993. Before the Industrial Revolution. 3 rd edition.

Coulton, G. G. 1925. The Medieval Village. Cambridge: Cambridge University Press.

Duby, Georges. 1990. Rural Economy and Life in the Medieval West. Translated by Cynthia Postan. Columbia, S.C.: University of South Carolina Press.

Gimpel, Jean. 1976. The Medieval Machine: the Industrial Revolution of the Middle Ages.

Hoffman, Phil. 1988.

Harding, Alan. The Law Courts of Medieval England. London: George Allen and Unwin, 1973.

Mokyr, Joel. 1991. The Lever of Riches.

Pacey, Arnold. 1974. The Maze of Ingenuity.