

CHAPTER 4

The Middle Ages

Of the numerous definitions proposed for the Middle Ages, we shall adopt one of the currently more common ones, defining the Middle Ages as the period between the coronation of the Frankish king Charlemagne as western Roman Emperor in 800AD to the fall of Constantinople to the Ottoman Turks in 1453. The fall of Constantinople to the Muslims had grave consequences for Europe. On the one hand, it removed the Mediterranean from the European zone of influence; on the other hand it brought many classical scholars from Constantinople to Italy and thus contributed to the Renaissance movement. Indeed some scholars regard the Renaissance movement, the attempt to resurrect classical Greek and Roman culture as a secular enterprise, as a defining moment of the modern period. The date 800 AD is chosen as the beginning of the Middle Ages, because the crowning of Charlemagne as Roman emperor ended a period of about 300 years when the western Roman Empire did not exist and the only Roman emperor was the eastern, Byzantine, emperor. Some scholars date the Middle Ages from the fall of Rome to the Goths in 476 AD. The period from the fall of Rome to the crowning of Charlemagne as Roman emperor, i.e. 476 to 800, is then regarded as the earliest part of the Middle Ages, generally known as the Dark Ages. It was a period of great turbulence, when many Germanic tribes were on the move and conquered various parts of the dying Roman Empire. Britain was invaded by several tribes, collectively known as the Anglo-Saxons. The period is of no interest to us, as no stable civilisation was established and technology did not advance. Our discussion will concentrate mostly on the late Middle Ages and even a little beyond – when technological, economic and social developments had reached a relatively stable state, which may be considered to have laid the foundations to the next state – the rise of capitalism and the industrialisation of production.

To regard the Renaissance as the end of the Middle Ages makes a great deal of sense. Throughout the Middle Ages proper, not counting the dark ages, the church ruled supreme over all intellectual enterprise. Almost all learning was in the hands of the church or, at the very least, under the strict control of the church. Thus intellectual activity was confined to the interpretation and re-interpretation of church doctrine. Science in the sense of observing natural phenomena, or carrying out deliberate experiments, and attempting to interpret the results in a framework of scientific theories was not possible in the dogmatic mind-set dominant throughout the Middle Ages.

It is often said that technology stagnated during the Middle Ages. This is not quite correct, though it is true that no fundamentally new developments occurred. On the other hand, the craft-based technologies of the day were constantly improved and developed to a high degree of perfection. Technology developed in small incremental steps, mainly on the basis of improvements made by individual craftsmen. Sometimes the improvements were driven by a desire for perfection, sometimes by practical problems that needed solutions. There was no theoretical framework to guide technology and indeed its organisation was, like the rest of society, extremely conservative.

Throughout the Middle Ages, the strict adherence to faith as taught by the official church seemed irreconcilable with the questioning and sceptical attitude of mind necessary for successful scientific enterprise. To be a good Christian, indeed to be a good citizen, required the unquestioning acceptance of authority. Even the arts saw their task merely as one of underpinning religious faith and endeavour. The great leap forward of the Renaissance was the discovery that free artistic enterprise and free scientific investigation, in fact the very freedom

of questioning anything except faith itself, could be reconciled with religious practice and faith. The Renaissance, in a sense, discovered that scientific and artistic enterprise could be carried out in parallel with the exercise of religious faith and duties. What seemed an irreconcilable contradiction became reconciled. It was discovered that the mind was perfectly capable of working in separate compartments, the questioning compartment and the believing one, without being torn apart. Scientific and artistic enterprise was given freedom, and yet could serve the glory of God. Discovering laws of nature could be interpreted as discovering the will and the ways of God, rather than opposing church doctrine. The church did not accept these new departures without a fight and many men of the Renaissance found themselves in severe, often deadly, conflict with the church establishment. Indeed the church establishment found itself at odds not only with much science, but also with much theological thinking by the many reformers of the late Middle Ages and early years of the modern period. The reformers, such as Jan Hus (c.1370 – 1415), a forerunner of the reformation movement, and the main representatives of the movement, Martin Luther (1483 – 1546), John Calvin (1509 – 1564), and John Knox (c.1514 – 1572), to name but a few, were all critical of medieval Catholicism and demanded different interpretations and different practices of the Christian faith. They were all men demanding to be allowed to think for themselves, to go back to classical and biblical sources in order to re-interpret the Christian faith in their own way. The Reformation eventually led to more pluralistic interpretations of Christianity.

Desiderius Erasmus (1466 – 1536), known as Erasmus of Rotterdam, is another example of a deeply religious man who nevertheless demanded to be allowed to go back to classical texts and re-interpret them in his own way. He laid the foundations to the critical study of early Christian texts and to a new humanist, non-dogmatic, education. The educational reforms initiated, *inter alia*, by Erasmus, widened the syllabus to include classic languages and, more importantly, classic secular texts. His friend Thomas More (1477 – 1535), equally embraced the ideal of classical learning, combined with free critical thought. As the famous author of *Utopia*, he may be regarded as one of the first political philosophers since the Greeks and the Romans, and particularly since Plato, who was active close on two thousand years earlier, around 400BC.

These founders of classical learning and critical thought, the humanists, were soon followed by the founders of modern scientific thinking, such as the philosopher Francis Bacon (1561 – 1626) and the father of experimental science, Galileo Galilei (1564 – 1642). The Renaissance was the watershed dividing the waning Middle Ages from the rising modern age. It marked the period of transition between blind obedience to dogma and to authority and the birth of the spirit of enquiry; between the closely confined thinking of the Middle Ages and the freely roaming thinking of the modern age. The juxtaposition of the intellectual atmosphere of the Middle Ages and that of the waxing modern age helps to create an impression of the limited capacity of medieval Europe for the creation of new thought, new knowledge, and new technology. The mind of medieval men and women was imprisoned in the straitjacket of an authoritarian doctrinaire Church and knew little intellectual activity outside the Church. Ordinary men and women were illiterate and utterly uneducated and followed the faith in blind belief, no doubt supplementing their meagre spiritual diet of bible readings and sermons with fairy tales and ghost stories told of a dark winter's night in a poorly lit, poorly heated, cramped home.

Only a tiny minority of people could read or write, and an even tinier minority had knowledge that extended beyond reading, writing, arithmetic and the bible. If ignorance is likened to darkness, then dark the age certainly was. For those of us who regard the period of the Enlightenment as one of shedding light, then by contrast the Middle Ages, with their strict adherence to church doctrine, and its medicine and other sciences based on Aristotelian principles rather than on experiment and logic, the period seems dark indeed. This is not to say that it was lacking in cultural achievement for a small class of educated men and women. Poetry thrived on a small scale, mathematics and astronomical observation made some progress, mainly owed to Arab men of science, architecture (especially cathedrals and castles) and the arts achieved great refinement and some unsurpassed pinnacles. The overall impression is, however, that humans lived in fear; fear of death and of hell, fear of sickness and starvation, fear of the authorities, and fear of war and plunder. If we define civilization as the liberation from fear, as well we may, we must regard the Middle Ages as rather uncivilized.

A gruesome example of the rein of bigotry and fear is the inquisition, first instituted in 1231 by Pope Gregory IX as a means of combating heresy, which by this time had become organised in large sects, such as the

Cathari and Waldenses, and was regarded as a threat to society. The rigidly hierarchical Roman Catholic Church felt seriously threatened by heretics, who disagreed on various points of doctrine and often expected Christian leaders to live a life of poverty. However, medieval inquisition at first imposed relatively mild punishments and the use of torture was not authorised till 1252. The worst cruelties and excesses of a fanatical faith, in the service of racial and religious intolerance, became institutionalised in the Spanish Inquisition, which began in 1478 and was not finally abolished till 1834, thus falling mostly without the medieval period. It is thought that under the rule of the first grand inquisitor in Spain, the notorious Torquemada, appointed in 1483, about 2,000 people were tortured and burnt at the stake and innumerable victims had their property confiscated.

No doubt the inquisition used ingenious technical means to inflict maximum pain on its victims. There can also be no doubt that here technology fulfilled the demands of the ruling elite. The demand for instruments of torture and their delivery by the artisans and inventors of the day is a classic case of market pull, or market-led innovation, albeit in the guise of a cruel caricature of the general principle. Not, I suspect, an example of market pull that even the most ardent believers in the benefits of market forces are proud of. It is undeniable, however, that technology, as ever, proved a faithful servant of the mighty and the powerful. In a very real sense, it was technology that made it possible for early hordes of primitive humans to become societies, and for wealth and elites to emerge. And ever since societies established hierarchies, technology has been a servant of the top echelons of society. Technologists have always produced what was demanded of them by those whose demands were backed by power and by money. It is only in more recent times that technology became more pro-active in the provision of goods and has become the prime mover of economic growth and the creation of wealth. Technology is now seen as the main provider of ever new means of making money and of ever new ways of creating a luxurious life. Unhappily these remarks are true only for the wealthy societies of this world and are almost wholly irrelevant for the world's majority of people, who live in dire poverty.

As in all preceding periods, wealth in medieval times consisted predominantly of land, though in the later Middle Ages large money fortunes were made from trade, and these laid the foundations to emerging capitalism. Most of the Middle Ages are characterised by the manorial system. Land was owned principally either by ecclesiastic or by secular large landowners, the lords of the manor. Bishops and abbots of monasteries could be lords of manors and hold large areas of land. On the worldly side the landowners were aristocrats and knights of various grades, many of them having risen to their position through military leadership. There were great variations in the size of the estates and in the division of the land between that farmed under the direct control, and to the sole benefit, of the lord, known as the demesne, and the land rented out in small parcels to tenant farmers, the villeins. The manor was a more or less direct successor to the Roman villa and, in Britain, passed from Roman into Anglo-Saxon and, after 1066, into Norman hands.

The tenant farmers were mostly serfs and thus were not only obliged to pay rent for their land and work on the demesne, but were severely restricted in their freedom. They were not allowed to move, marry, give away a daughter in marriage, buy property or do anything else of importance without permission from their lord. Their status was only slightly better than that of slaves and indeed many serfs were freed slaves. Others came into serfdom by seeking protection from a powerful lord against the vicissitudes of those violent and uncertain times. Some tenant farmers were freemen, and their number increased in the course of time as more serfs either purchased their freedom or obtained it as a reward for good services from their lord.

The tenant farmers lived in villages and farmed mostly open fields. That means that a large area of arable land was divided into smaller strips and each farmer was allocated a certain number of such strips, not necessarily forming a continuous area. The method of strip farming and the fact that the tenant farmers lived in clustered villages enabled them, indeed forced them, to cooperate in tilling the fields. The facility for cooperation made it possible to develop and use an advanced form of the Roman plough, the heavy plough known as the *carruca*.

As agriculture spread from the Mediterranean to the North, including Britain, the plough had to become able to tackle much heavier soils than the light soils prevalent in the Mediterranean region. The Roman plough generally had a wooden share, often tipped with iron. The later *carruca* had an iron share that could penetrate deeper into the soil. The *carruca* was usually equipped with a coulter knife, fixed in front of the share, that cut into the soil to create and direct the furrow. From about the tenth century, ploughs were equipped with a

moulding board, mounted in parallel with the share, that turned the cut soil on its side. The *carruca* generally had wheels, thus greatly reducing the tractive effort needed to move the plough forward.

Another circumstance that necessitated the use of a heavy plough, and a strong team, was land clearance. In the early Middle Ages many forests were cut down, marshes drained, and other unproductive land taken into agricultural production. These new, previously untilled areas, constituted a challenge to the plough. The consequence of a heavy plough used on heavy soil was the need for stronger and better-harnessed draught animals. Oxen were employed in teams of up to five pairs and their harness consisted of a yoke across their withers, hitched from the shoulders and linked to the plough by traces tied to a swingletree. As a large team of oxen could not manoeuvre tight turns, it was necessary to plough large furlongs. All this added up to an operation run jointly by several families: a large team of oxen, an expensive plough, and the need for large fields. It was a technology compatible with farmers living in clustered villages and cooperating in tilling strips in large open fields.

In the course of the Middle Ages, beginning particularly from the late 14th century, the process of enclosure gathered pace. The number of farmers who held their land in severalty increased as the open fields gradually gave way to enclosed fields, worked by individual farmers. The process of enclosure continued for several hundred years and was not fully completed till the middle of the 19th century. As the areas of virgin land to come under the plough decreased and the size of fields diminished with enclosures, so the need for teams of oxen declined. In the meantime heavy powerful horses, capable of carrying fully armoured men, had been bred and pairs of such horses were gradually replacing teams of oxen. The harnessing of horses had improved and the horse offered a great advantage in speed over the ox.

As in any society and at any time, the social arrangements have to be suitable for the operation of the technology of the day. We can turn the argument round and say, with equal justification, that the technology employed must fit the social arrangements of the time. Technology and society form a system, and the system can function only if society and its technology are suited to each other to form a workable system, ideally an efficient one.

The large estates and the villages that housed the tenant farmers were the centres of social life during the early Middle Ages. Towns and cities were few and far between and trade was at a low ebb. The aristocracy held all the power in the land and its main interest was agriculture. Labour was cheap and, during most of the period, plentiful. Thus the incentives of the aristocracy for technological innovation or progress were minimal. In fact most of the lords were more interested in building castles and indulging in jousting and hunting than in productive investment. It needs to be said that castles were not pure luxury; they provided shelter in times of need and served as a base for the knightly warriors. The Normans built large numbers of castles that served as the military bases of their rule over England.

The lord of the manor derived his income from the sale of agricultural produce to the few towns and cities and to non-agricultural workers. In the fully-fledged feudal system, the lord of the manor also fulfilled many administrative and judicial duties of the state and was obliged to render military service as and when required by the king. The state functioned through the manors and the lords gave their services to the king in return for their land. Many of the lords of manors, particularly the owners of large estates, sub-let (sub-infeudated) parts of their estates to knights who, in return, were obliged to render military service for the manor as a whole. Alternatively, the lord could pay for knights to provide the service required of the manor and/or send his sons to do military service. Though the knights did not do full-time military service, they were nevertheless professional soldiers and formed the heavily armoured cavalry of the day. This was particularly true in the 12th century, though it continued till the knights became obsolete owing to the development of a superior infantry, armed with the longbow and the crossbow, in the 14th century. Military technology did not stand still during this period. The tenants were also obliged to render military service, whether as ancillaries to the cavalymen or as infantrymen. There is a clear relationship between developments in military technology, i.e. the rise of heavily armoured cavalry, and the political system, which extended the more ancient manorial system into the arena of military service. The lord of the manor was converted into a knight and the knight into a landowner.

The military aspect of the feudal system, coupled with many religious, political, economic and social factors, is closely associated with the curious phenomenon of the crusades, which took place from the end of the eleventh to the end of the thirteenth century. They were a curious expression of the very essence of the medieval

spirit, even though the causes of the crusades remain a moot point. A full understanding of a complex phenomenon such as the crusades may never be agreed upon among the specialists. It is clear, however, that religious fervour was one of the underlying causes. Perhaps this fervour was created by certain commercial or political interests, but it certainly provided very strong motivation for a large number of crusaders. To free the holy land from Islam and re-instate Christianity as the rightful faith was a fervent wish, and the belief that this was God's will was a fervent belief. The Middle Ages were a period when fervent beliefs were common – in fact religious fervour and strongly held beliefs are characteristic of the time. The second motivation (second merely in our listing, which is no reflection on the order of importance) was greed. The crusaders hoped to make fortunes by looting and in many cases these hopes were fulfilled. The spirit of adventure undoubtedly played its role with the romantic notion of reaching fabulous foreign lands in the service of God and King. Many of these dreams were left unfulfilled, as disease, hardship and enemy action killed large numbers of crusaders. The proportion of those who returned healthy and wealthy was far less than the proportion of those who never returned. As usual, the positive motivation – the pull – was supplemented by a push. Landless labourers and members of tenant farmer families were largely poverty stricken. They worked all hours of daylight and had very little to show for it. Poor housing, a poor diet, poor clothing and no money for any luxuries, even for the smallest expenditure beyond the barest necessities. Life was hard and monotonous; with practically nothing that might be called entertainment. Church and the bible and maybe some story telling were the only diversions. Apart from dreaming of adventure and heroic deeds, they dreamt of getting away from their arduous labour and from the dreariness of their lives. The desire to achieve something combined with the desire to escape from something. Strong motivation commonly consists of a pull and a push component: the wish to get somewhere and the will to get away from something.

In the upper echelons of the crusader movement somewhat different motivations were at work. On the one hand was the lust for power. Capturing foreign lands has always been a dream of the mighty. Enlarging the dominion, gaining power and wealth by expansion of the realm, have been goals of the mighty for as long as might itself has existed. Additionally, motivation to join a crusade was provided by the problem of the younger sons among the land-owning aristocratic families. The eldest inherited the estate, but the younger sons had to seek their fortunes elsewhere. The church was one outlet, armed service another. The image of the knight in armour riding against the enemies of Christ was a powerful image and a potent vision for many a younger son of wealthy families. The lure of the shining knight and the desire to get away from a dead-end situation at home provided the pull and the push needed for strong motivation.

Battles, exhausting marches and disease decimated the forces, but looting proved highly profitable. The hardships endured by the crusaders can only be imagined. The heat must have been unbearable, especially if armour of any description was worn. The havoc wreaked by vermin – lice, fleas, and other bugs – underneath the armour can barely be imagined. As opportunities to wash must have been rare, the stench of stale sweat defies imagination. The shining knight and the simple foot soldier were very likely soon reduced to smelly, itchy, bundles of misery. Add the hazards of infectious diseases carried by dirty water and vermin and caused by rotten or infected food, and one can imagine that enemy action was probably not the greatest hardship the crusaders endured.

The weaponry of the crusaders was essentially that developed by the Romans, though with some considerable modifications. The most substantial change was the greater emphasis on, and changed status of, the cavalry. The cavalry now consisted of armoured knights who had established for themselves a high social standing and had developed a whole mythology and code of behaviour known as chivalry. I do not suppose that the knights in the field bore much resemblance to the chivalrous knights familiar to us from medieval poetry. Development of heavy armour had continued apace, both with a view to technical improvement and with changes in fashion. The production of armour required high quality steel and great skills, and both of these had been developed in the early Middle Ages. Similarly, the sword had undergone much improvement and much change owing to fashion. The improvement was in the steel. A sword needs to be flexible rather than brittle and yet needs an edge that can be sharpened and will retain its sharpness. This posed quite a challenge to steel-makers and to sword-smiths alike. Fashion played quite a role in knightly equipment and indeed the role of fashion in technology in general should not be underestimated.

The politics of the crusades were extremely complex. The Byzantine Empire was surrounded by enemies on all sides and was glad to receive some help and relief in the shape of Christian soldiers. On the other hand, the schism between the Eastern and Western churches ran deep and thus the Byzantine Emperor had rather mixed feelings when hordes of Roman Christians turned up in his country. Some of the crusaders were disciplined soldiers, who pursued their goal of capturing the holy land, others were undisciplined hordes intent on plunder and were rather unwelcome in Constantinople. One of the crusades was diverted from its initial goal and turned on Constantinople instead, not exactly contributing to friendship between the Eastern and Western inheritors of the Roman Empire.

Many crusades disbanded, or were diverted, even before they reached the holy land and true success was achieved only for a relatively brief period by only a few of the many crusades. The very first crusade, known as the "Peoples Crusade", was soon annihilated by the Turks. The first properly equipped and organised crusade, known as the first crusade, started out in the summer of 1096, and consisted of four armies, with an estimated total of 200,000 warriors. The armies travelled by different routes, some travelling across the Mediterranean, some taking the land route over the Balkans. It is estimated that at one time there were about 4,000 mounted knights and 25,000 infantrymen in and around Constantinople, causing the Byzantine authorities more than a few headaches. By the time the crusaders reached Jerusalem in 1099, their number was reduced to about 12,500 men fit to fight.

Nevertheless, theirs was the major success of the crusades when, in 1099, they captured Jerusalem from the Muslims and founded the Christian Kingdom of Jerusalem. Jerusalem itself was re-captured by the Muslims under Saladin in 1187. The Christians retained a foothold in the holy land for another century, until their kingdom finally succumbed to Muslim attacks in 1291. The title of King of Jerusalem was kept alive on the island of Cyprus till the late 15th century.

From our point of view, the importance of the crusades lies in the demand they created for weapons, armour and transport, and the fact that European political and trading centres were re-established in the eastern Mediterranean. This in turn led to increased trade across the Mediterranean and to increased demand for shipping. Trade with the Byzantine Empire and the re-established European trade with the eastern Mediterranean brought many luxury goods onto European markets. Gold and silverware, fine cloths, religious relics, fine steel, and spices and aromatics were the main imports. Alas, the trade in slaves also flourished throughout the period. The main exports from Europe were timber, iron, copper and its alloys bronze and brass.

Disease was rife throughout the Middle Ages. The Black Death¹, that is estimated to have killed about one third of the population of Europe, arrived from the Middle East in 1347. It is said to have been brought to Europe by an early instance of biological warfare, when Kipchak warriors threw corpses of victims of the plague over the walls of a fortified Genoese trading post in the Crimea. Other common infections that occasionally reached epidemic proportions were leprosy, smallpox, tuberculosis, scabies, anthrax, trachoma, and cholera. It was a period when life expectancy was very low. Poor sanitary and living conditions allowed many infectious diseases to spread rapidly and ill-nourished people were easy prey for disease. Poor hygiene, poor living conditions, poor nutrition and medical ignorance caused infant mortality to be a constant scourge.

While the production of technological artefacts was based entirely on empirical knowledge – progress was achieved by trial and error and by accumulated experience – other aspects of life in the Middle Ages were dominated by dogmatic theories. The dominant theory was, of course, Christian theology. Even medicine was based largely on philosophy rather than on practical experience. The theories of Hippocrates (born c. 460 BC) and Galen (born c. 129 AD) dominated medicine into the late Middle Ages. There was a close correspondence between medical theory and Aristotelian theory. Thus health was thought to be achieved if the four humours in the body – corresponding to the four elements of Aristotle, i.e. fire, water, air and earth – were in equilibrium. The four humours were: hot and dry (corresponding to fire); cold and wet (corresponding to water); cold and dry (corresponding to earth); and hot and wet (corresponding to air).

The famous – or infamous – blood-letting (phlebotomy) must be seen as an attempt to restore equilibrium by removing surplus humours from the body. Blood-letting was used against acute illness and it is anybody's

¹ The term black death probably covered both bubonic and pneumonic plague.

guess how many deaths it caused. But it was also used as a precautionary measure. In some monasteries the monks underwent blood-letting up to once every six weeks. By the 16th century this was reduced to 4 or 5 times a year. Cauterisation, consisting of applying a hot iron to the body, mostly to the head, sometimes to wounds, was another technique designed to expel excessive humidity and coldness. However, apart from the techniques of phlebotomy and cauterisation, medicine did provide various herbal medicines against a variety of ailments. This aspect of medicine was certainly less painful and, hopefully, a little more successful.

The syllabus of medical faculties throughout Europe in the late Middle Ages consisted of a high proportion of philosophy and medical theory, coupled with medical practice. At Oxford University, as at most other universities, theology was the subject that attracted the most students. In the course of the 15th century, about 500 doctorates in theology were awarded, as compared to a mere 40 in medicine.

From 1169 clerics were officially banned from soiling their hands with blood, and thus had to withdraw from practising surgery. Medicine remained, to a considerable extent, in the hands of clerics and of monasteries. The edict was not always strictly adhered to, but nevertheless surgery became largely the domain of laymen, whether they be surgeons trained in universities or barber-surgeons, trained by apprenticeship, with fathers often passing on their skills and their businesses to their sons. Apart from cutting hair and shaving beards, barber surgeons were generally allowed to perform only the simplest of surgical operations, such as cupping (blood-letting), the application of leeches, the lancing of boils, the extraction of teeth, and similar.

Rudimentary anaesthesia was obtained by the use of the so-called soporific sponge. This was a sponge boiled in a mixture of opium and a variety of juices, including hemlock. The sponge was placed under the nose of the patient and induced a deep sleep. To wake the patient, a similar sponge, soaked in vinegar or similar, was placed under the patient's nose.

Anatomy was a much-neglected subject, as the dismembering of the human body was forbidden by the church. Because of the objections of the church, the proper study of anatomy was very slow to develop and most medics and even surgeons had to make do with learning from books based on Greek and Arab sources, or animal cadavers. In the later Middle Ages a limited number of bodies of executed criminals became available for the instruction of students of medicine and surgery, but even then the students had to be content with watching rather than doing.

Surgeons were quite skilled in setting bones, but also tackled some quite complex operations, such as the removal of gallstones, which seems improbable when one considers the absence of anaesthetics and hygiene. Surgeons were in charge of all injuries, which were plentiful. Brawls were common, and wars were a permanent feature. Thus surgeons had to dress wounds, remove lodged arrowheads or bolts from crossbows. Occasionally they even had to mend broken skulls. Presumably they were often called upon to amputate limbs shattered beyond repair or afflicted with gangrene. The highest-ranking surgeons accompanied kings and knights into war and enjoyed a high status and high rewards.

Apothecaries formed the third strand of medical provision. Much pharmaceutical knowledge was based on the writings of classical Greek scholars, greatly expanded by Arab contributions to the subject. Virtually all remedies were herbal, at least in the sense that they were of vegetable origin. Simple people had to make do with homegrown herbs and spices, whereas the wealthier classes, including the monastic orders and the church hierarchy, used many imported remedies that were extremely costly. Then as now, people have been willing to spend up to their ultimate financial capabilities if they believe that the expenditure will benefit their health. Health has always been a profitable business.

One of the imported medicines was sugar, much favoured as a syrup for chest complaints because of its warm and moist nature, but also used to sweeten bitter medicines. Sugar had to be imported, as the only known raw material for its manufacture was sugar cane, a plant that grows only in tropical or sub-tropical regions. The manufacture of sugar from European sugar beet was not invented till the middle of the 18th century, and did not reach industrial production till the 19th century, when the nascent sugar industry in France obtained much support from Napoleon in an effort to overcome the effects of the continental blockade. This is a nice example of direct government intervention in the course of technology. Technology policy – the support of a particular technology – became part and parcel of economic policy at a time of war.

Much medical and pharmaceutical knowledge came to Europe from the Arabs, where these sciences first flourished. The first medical school in Europe was established in Salerno, followed by Montpellier, Paris, Bologna and Padua. The rest of Europe followed in due course. The school of Salerno was also the first to obtain an official seal of approval from the Holy Roman Emperor Frederick II, who decreed that no-one should practise medicine without passing an examination by the Salerno school, thus obtaining an official seal of competence. This may have been a simple case of patronage, but more likely it was an early example of state control over a professional activity that had plenty of potential for harm. Whether in those days a licensed medical practitioner was less damaging to health than an unlicensed one may be a moot point, but it is almost certainly an early instance of the state taking upon itself the regulation of a profession for reasons of safety. This role of the state has been retained to this day, and indeed has been greatly strengthened and expanded. All professions that are potentially dangerous to the health or the safety of the public, including, *inter alia*, medicine and civil engineering, are now strictly controlled in some way by the state.

The immediate post-Roman period in Europe was characterised by incessant conquests by so-called barbarian tribes, causing havoc in the cities. Feudalism became established in Europe in the 9th century as a result of a general shift of civilization away from towns and cities into the rural domain. City populations declined, and merchants almost disappeared. Long distance trade declined in consequence of the loss of the Mediterranean to European traders, as the Middle East became dominated by the Muslims. The decline in trade over middle distances may be related to a general decline in commercial life as safety in towns and on the roads declined, and neighbouring provinces in many parts of Europe constantly fought each other. There was no powerful central authority and all the Romans had built up was in decline. The roads – the famous Roman roads – virtually disappeared for lack of maintenance. On the other hand, robbers and minor local authorities demanded extortionate road-tolls and transport and travel declined. Power and wealth became concentrated in the hands of feudal landowners and their vassals. Virtually all manufacture took place on the large estates that had to be self-sufficient in fulfilling the modest demands of their inhabitants. Markets became small, insignificant and purely local. The only commodities that were traded over greater distances were salt for the general population and some spices and precious materials for the few rich who could afford them.

The feudal estates produced all agricultural produce available in the region, as well as all other essential products, such as agricultural implements, textiles, furniture, domestic equipment, and so forth. Goods were sold in small-scale local markets and their producers were strictly tied to the estates. Thus technology catered purely for the basic needs of a rather poor and simple rural population, consisting largely of serfs and some free tenant farmers. No doubt the feudal landlords and their managers, as well as a few professional people, demanded a little more material comfort and even some luxuries, and these were supplied by a few remnants of a wider ranging trade. In local emergencies, such as droughts and consequent famines, produce was procured over longer distances, but these circumstances were the exception rather than the rule.

The estate-based crafts might occasionally be called upon to produce some higher-class items for the local elite, but basically they catered for essential needs and were not subject to either competition or the influx of foreign ideas. Thus the early part of the Middle Ages remained at a technical stage reached by the Romans or, if anything, declined from that achievement because of the decline of urban demand and demand by a highly organised large military machine. Only a few areas of technology showed progress, especially personal armour, swords, and some agricultural techniques.

The period of instability following the collapse of the Roman Empire began to be overcome by the end of the 10th century and a period of population growth began that lasted well into the 13th century. The worst of the aftermath of the collapse of the Roman Empire was over and the political and social situation became sufficiently calm to allow sufficient food to be grown and distributed, so that the birth rate exceeded the death rate. Because landlords, mostly large ones, owned all the fertile land and, apart from owning and tilling land, there were few other means of making a good living and becoming prosperous, the growing population was forced to search for new economic opportunities. One way of creating opportunities was to bring more land into cultivation by draining marshes or by felling trees. Indeed some men escaped from serfdom and cleared and drained previously unused land and settled on it as free peasants. The Cistercian monks often founded monasteries in the wilderness and brought new land under cultivation, creating new opportunities for the monks and

for their lay tenants. Many new villages were founded on land owned by a landlord, and the new villagers became tenant farmers rather than serfs. As commercial life revived, the landowners became interested in monetary income from rents and feudalism slowly declined.

As the land offered few opportunities for free men, there was a tendency for people to move into towns and engage either in commerce or in crafts. The 12th century saw a rise in commercial activities and a considerable growth in the merchant class. Many fortunes were made by trade. Some serfs escaped from the estates and found refuge, opportunities, and eventual freedom in the towns. The towns offered many advantages to their citizens. They had freedoms that peasants and country dwellers could only dream of. Townspeople could travel freely, make fortunes and keep them in the family, and they had opportunities to engage in trade or in a craft.

Economic activity, including the manufacture of technical artefacts, gradually shifted from the estates to the towns. In the towns technology was in the hands of artisans and was highly organised. Competition in the present sense had not entered into the thinking of the time. The belief was that the role of the guilds – the associations of artisans – was control over the quality of entrants into the professions, control over the quality of the products, and the safeguarding of fair play between all members of the group and with the consumer. The concept of fair play included the notion of a fair price for a fair product; thus price cutting and cutting of corners were equally frowned upon. Specialisation and competence were the dominant ideas, not the search for novelty. The number of trades had become quite large and the products had reached a high standard of quality, but there was little incentive for technological innovation. Markets were not saturated; the only brake on sales of technological products was lack of money, not lack of interest, need, or demand on the part of customers. The organisation of manufacture was in very small units. A master, a few journeymen, i.e. fully trained workers who had not achieved the status of master, and a few apprentices made up the full complement. To rise from journeyman to master required not only experience – often acquired by travelling from master to master – but also needed capital for the acquisition of premises, tools and materials. Apart from all that, numbers were restricted by the guilds in order to avoid a ruinous over-supply of craftsmen. One way of obtaining the status of master was, of course, for a journeyman to marry a master's daughter and take over the business. The sale of craft products to the public was direct – no large showrooms, very few, if any, middlemen. Local people bought directly from the local craftsmen, only more distant customers were served by travelling traders.

In the later Middle Ages and with a revival in trade, some goods were produced in large quantities, particularly cloth of various kinds. As the scale of operations increased and more capital was needed to invest in raw materials and equipment, manufacture became organised around merchants who were able to raise the capital. The actual production was still carried out in small units specialised in various aspects of production: carding, spinning, weaving, dyeing, and finishing. Thus trades such as fullers became established. The merchant supplied the raw materials and provided what we now would call logistics. They organised the progression of work, the transport of intermediate products, and the sale of the finished products. Various regions and towns became specialised in various products. Obviously the regional availability of raw materials and tools and the possibilities of cooperation between different producers provided many advantages that outweighed the disadvantages of local competition.

The power in the land shifted to some extent from the feudal landlords to the towns and to the artisan and merchant classes. This process continued until, by the late Middle Ages, feudalism had given way to rising capitalism.

As demand for goods increased in the later Middle Ages, some incremental – as opposed to radical – technological progress occurred. Looms grew bigger and the length of cloth woven increased. The whole of Flanders became a country of weavers and fullers. The centres of production of woollen cloth were towns such as Ghent, Bruges, Ypres, Lille, and Arras. We can see that some of the specialisations of those remote days have outlasted the centuries, and a town such as Lille is still a centre of textile production. When the industry had outgrown the local production of wool, wool was imported from England. Woollen cloth from Flanders or Brabant was superior to other regions in finish, softness, and colours. Because transport was expensive, only the highest quality goods were transported over longer distances; cheaper products were only sold locally.

Other towns and regions specialised in different products. The Meuse valley became a centre of copper working in the 11th century. The town of Tournai (in modern Belgium) became a centre of stone working and

provided baptismal fonts far and wide. Lucca in Italy became a centre for silk weaving, while Milan and the Lombardy towns produced mainly cheap fustian.

The degree of concentration of certain trades in some towns is remarkable. Thus Ghent had 4,000 weavers and 1,200 fullers out of a total population of about 50,000. Similarly, in Ypres nearly 52% of the population were engaged in the woollen trades.

The advantages of cooperation apply to this day. We still see concentrations of certain industries in certain places. Perhaps the best-known example is the so-called Silicon Valley in California, which is one of the main centres of production of modern electronics based on silicon chips. Although the very first firms established in the region may have chosen it for a variety of reasons, the founders of the later firms producing chips deliberately chose the proximity of similar manufacturers because of the possibility of sharing information, sharing suppliers and, occasionally, sharing sales contracts².

We also see remnants of former concentrations of tradesmen in street names such as Carpenter Street, Cloth Street, Fuller Street, Goldsmith Road, and so forth; but also in the name of certain neighbourhoods, such as jewellery quarter or in the continuing tradition of certain roads, such as Savile Row in London continuing the tradition of fine tailoring.

The concentration of certain trades in certain areas held advantages for both the trades-people and their customers. If you needed a pair of shoes, you simply went to Shoemaker Lane and were able to compare the shoes and the prices of different shoemakers. The craftsmen profited by being able to help each other out, and benefited from the availability of the supplies they needed and by exchange of experiences. Helping out was sometimes of crucial significance, particularly in the case of armourers, as the demand for their wares could arise very suddenly and urgently and far exceed the capacity of any one master. The reverse side of this coin was, of course, that each craftsman was able to spy on and supervise all the others, so as to eliminate malpractices.

Craftsmen not only manufactured items of ordinary consumption, they also were in charge of large enterprises, such as major buildings. The person in charge of stone buildings was a stonemason; whereas timber buildings were built by carpenters. In a big enterprise, the main contractor employed numerous sub-contractors of varying skills. Stonemasons were not all equally well qualified. Some were entrusted only with the rougher work, and only the best undertook the shaping of the elaborate stone ornaments and sculptures that we admire in many a medieval cathedral. Even the largest buildings were designed and constructed by artisans, there was no such thing as an architect or a civil engineer. Designs were based on experience and on talent, not on theory.

The 12th and 13th centuries saw a considerable increase in the circulation of money. With the rising importance of trade and of towns, and an increased availability of a variety of goods, people needed money to take advantage of the new opportunities. The land-owning aristocracy discovered the need for money to buy luxuries, where previously they were content to make do with the supplies produced on their estates. The quality and quantity of food and of dress improved, household furniture became more elaborate, and the taste for luxuries increased. The feudal landlord was happy to sell freedom to his serfs and to derive income from his tenant farmers. Agricultural production became more specialised and tenant farmers were interested in purchasing more land. Even townspeople with surplus cash invested in land – the ownership of land was suddenly seen as a profitable commercial transaction. Whereas in feudal times the ownership of land implied power over a certain region, these implications gradually ceased in the 12th and 13th centuries and land became a commodity and a source of income without too much social meaning.

The early long distance merchant travelled with his wares, often in armed caravans. As trade between countries to the North of the Alps and Italy developed, improvements were made to the land routes across the Alps. For example, Europe's (and probably the world's) first suspension bridge was built across the St. Gotthard gorge in Switzerland at the beginning of the 12th century. In the second half of the 13th century, transport became divorced from trade. The merchant became sedentary and the transport of goods was undertaken by specialists. This new division of labour was accompanied by several developments. First, transport itself developed. Not in one fell swoop with a major innovation, but gradually with improvements in roads, improvements in road ve-

² See e.g. Braun and Macdonald, *Revolution in Miniature*, (1982)

hicles and, probably, better breeding of suitable horses. Shipping improved quite radically with increasing size of ships, to about 200 to 600 tonnes, and an improved design of rudder. More importantly, the introduction of the mariner's compass freed ships from the need to follow coastlines and enabled them to take the shortest route to their port of destination. During the 14th century the compass became universal in the Mediterranean, and during the following century it came into general use in the North and Baltic Seas. The ports were equipped with wooden quays and with cranes.

The second consequence of the sedentary merchant was the need for organised financial transactions. The merchant needed credit to finance large quantities of goods in transit and, a little later, he needed possibilities of paying for goods in distant lands without the need to transport large quantities of cash. Credit in medieval times was problematic because of the church's opposition to usury. Thus usury, although practised on a large scale from about the middle of the 12th century, had to be disguised and atoned. The church made sure that merchants who made profits out of loans suffered from a bad conscience and atoned for their sins by making large gifts and/or legacies to the church. There were other clever means of avoiding the charge of usury. It was possible, for example, to make a loan in one currency and obtain repayment in a different currency. A change in the exchange rate of the two currencies during the lifetime of the loan could provide the lender with a profit justified by the risk of currency fluctuations, rather than based on payment of interest.

Spices were one of the first objects of international trade. They generally came from India and could either take the land route to a Mediterranean port or could travel by sea to reach a Red Sea port, before being transported by land across Egypt to the Mediterranean coast for shipment to Europe. In 1498 Vasco da Gama found the sea route from Portugal to India by sailing round the African continent, thus justifying the name Cape of Good Hope for the southern tip of Africa. This route was developed by the Portuguese during the sixteenth century and offered considerable competition to the mainly Italian merchants using the old routes across the Mediterranean. Pepper, cinnamon, cloves, nutmeg and sugar-cane entered the diet of the wealthier Europeans. From the beginning of the 13th century imports from the East into Europe included rice, oranges, apricots, figs, raisins, perfumes, medicaments, dyestuffs such as Brazil wood from India, cotton, silk, damask from Damascus, baldachins from Baghdad, muslins from Mosul, gauzes from Gaza. This trade was balanced by exports from Europe of timber, arms, slaves, and woollen goods, particularly fustians from Italy and cloth from Flanders and Northern France.

By the 13th century there was an established market for luxury goods, such as exotic fruits, perfumes and luxury cloth. The people who were able to consume such goods belonged either to the landowning or, increasingly, to the merchant classes. The families that had made fortunes from trade soon formed a separate upper class. They built better houses for themselves, consumed luxury goods, including, no doubt, gold and silverware, and they formed into groupings that exercised considerable power in society. The guilds or hanses of the wealthy patriciate were born. Much of the governance of towns and cities became concentrated in the hands of this new urban upper class.

We mention medieval cities and imagine them as large entities. This was not the case. The only cities approaching populations close to 100,000 in the 14th and 15th centuries were Venice, Florence, Milan and Genoa. Northern European cities in the middle of the 15th century were much smaller:

Basel	about 8,000 inhabitants
Brussels	about 40,000
Frankfort	about 9,000
Nuremberg	about 20,000
Strasbourg	about 26,000

The urban populations became stratified: wealthy merchants as the upper class, artisans and small traders as the middle class, and all the rest as the lower class. Rare and luxury items were produced only in the larger towns; smaller towns produced only items of everyday consumption for the town and its rural surroundings. The rural surroundings, in their turn, produced all the food the town required. The common trades were bakers, butchers, tailors, blacksmiths, joiners, potters, pewterers, and many more. The relationship between the guilds and the authorities varied and was not always smooth. Eventually, in the course of the 14th century,

the guilds reached a position where they participated in local government and had considerable autonomy in regulating their own affairs. The guilds regulated entry into the professions and the training given to apprentices. They also regulated working hours, wages, and prices. It may be said that the guilds stifled competition and prevented innovation; on the other hand, they guaranteed the quality of workmanship and protected apprentices and journeymen from exploitation. The free artisans provided the goods required in the nearer or wider locality, whereas goods for long-range trade were often produced by craftsmen employed by the merchants. As capitalism became more mercantilistic and more aggressive, some conflicts, including strikes, between workers and their masters became inevitable.

For those modern contemporaries who believe unconditionally in the blessings of technical and scientific progress and in the power of competition to spur people to greater achievement and greater happiness, the Middle Ages are abhorrent on account of lack of competition and technological stagnation. The guilds would be anathema to contemporary neo-liberals. Their purpose was to protect their members from too much competitive pressure and to protect the public from both shoddy workmanship and excessive prices. The guilds protected the good name of the craftsmen and in this way protected the public from unreliable suppliers of goods. Considering that the *caveat emptor* (buyer beware) principle now rules almost supreme (though mitigated by some statutory regulation and by guarantees), and the buyer is often unable to beware sufficiently and falls victim to all kinds of malpractices, the security offered by the organised medieval craftsmen does not seem like something worthless. Buying goods in the certain knowledge of receiving value for money is worth a great deal. One can but wish that modern merchant bankers had been organized in guilds before causing so much trouble in the credit crisis.

The 14th century generally saw a halt to economic progress and a stop to population growth. Disasters struck Europe in the form of famine and the notorious Black Death that killed about a third of the population of Europe between 1346 and 1369. Armed struggles between neighbouring states added to the calamities. Italian cities fought each other and Germany sank into anarchy. The Hundred Years War (1338 – 1453) between England and France very nearly ruined both. As times became harder, towns made it more difficult for “foreigners” to become citizens. They also made it harder, indeed illegal, to carry out trades outside the city walls. Only spinning was allowed in the countryside, the rest of the textile manufacturing operations had to be carried out within the cities. It all sounds rather familiar: a mixture of protectionism and immigration controls as a response to a harsher economic climate. It did not always work and, in any case, it did not at this stage apply to large cities and to states. By the beginning of the 15th century, competition from English textile manufacture became very strong and Flanders lost its predominant position.

Despite all these problems, the 14th and 15th centuries saw the growth of large commercial companies that engaged in long-distance trade and in banking. The first such companies started in Italy, but soon found competitors north of the Alps. Probably the first major modern bank, Casa di S. Giorgio, was founded in Genoa in 1407. This was also the period when protectionism gradually shifted from the towns to larger entities. Economic power shifted from municipalities to states. In England, Henry VII (1485 – 1509) pursued vigorously mercantilistic and protectionist policies started by his predecessors. The importance of industry grew rapidly and became a prime object of state economic policy. The state attempted to protect English production from foreign competition, to protect and enhance English shipping and English exports, and to reduce imports. Whereas previously Flanders used some English wool to supplement its own sources for its textile industry, by now English cloth producers consumed all the homegrown wool and exported cloth.

We have excellent contemporary descriptions of some of the technologies current in the middle of the sixteenth century and early seventeenth century AD. Although strictly speaking this period belongs to the Modern Age, rather than the Middle Ages, I shall take the liberty of describing these technologies as medieval because we may safely assume that they were current in the late Middle Ages. The pace of technological change was not as rapid as in later centuries and what was described in a standard text in 1550, or even 1620, may safely be considered late medieval technology.

Our knowledge of the state of metallurgy and mining of this period is based mainly on the famous text by Georgius Agricola, *De Re Metallica*, first published in 1556. The German Georg Bauer was a man of his time and used the Latin translation of his name as a nom de plume. His book is a product of his time in that it con-

tains detailed technical information alongside expressions of piety and general wholesome advice. When he describes the desirable character of an owner of a mine, he mentions piety as the first requirement and prudence, in the sense of spreading risks between several mines rather than owning a single one, as the second most important characteristic. On the other hand, Agricola does not believe in the power of divining rods to find ores, but instead puts his faith in the power of geological knowledge and observation. He sings the praises of metals and is convinced that their use is a blessing for humanity. By way of good advice, Agricola suggests that "It is necessary that the assayer who is testing ore or metals should be prepared and instructed in all things necessary in assaying, and that he should close the doors of the room in which the assay furnace stands, lest anyone coming at an inopportune moment might disturb his thoughts when they are intent on the work."³

He provides a detailed description of underground mines, presumably for various metallic ores. Underground mines are constructed by drilling vertical shafts connected to horizontal tunnels. The miners reach the tunnels on ladders and the ore is lifted in buckets by winches. The winches are mostly operated by hand, though some are powered by horses moving in a circle or working a treadmill. Water has to be pumped out of the mine and a variety of pumps may be used for the purpose. Some pumps consist of a chain of buckets; others use the principle of a piston operating in a cylinder. The cylinder might be constructed by boring out a log with an auger drill. The number of different designs of pumps used from antiquity and right into the modern age is amazing. From the simple single bucket pulled on a rope, with or without a pulley, or lifted by a lever construction, right up to elaborate piston pumps. An entirely different design principle was the Archimedes screw, where water is transported and lifted by a metallic or wooden rotating spiral. Some piston pumps were operated by a screw and toothed rod, which turned rotary motion into the to-and-fro motion of the piston.

There was an acute awareness of the dangers of gas formation in mines and the need to ventilate the tunnels. Various devices were used to suck out, or drive out, the pestilential air. Ventilation could be achieved either by diverting wind into the shaft, or by using fans that could be driven by a water wheel, or by bellows. The latter could also be driven by water or by horses or other animals working a treadmill. Miners were aware of the disease afflicting their lungs, quite apart from the dangers they faced through collapses of tunnels or explosions of methane gas.

The book contains much detailed information on metal smelting. The metallic ores are first broken up, sometimes using mechanical hammers driven by water or animal power, and then ground and heated (roasted) below the melting point and calcinated. After all this preparatory work, the actual smelting process is carried out. We describe here the smelting of iron. A crucible is placed in the hearth inside a closed furnace. The hearth is made of powdered charcoal mixed with powdered clay. The furnace is filled with the prepared ore, charcoal and unslaked lime. Air is blown into the furnace by bellows and the slag is allowed to run off. After about 8 to 10 hours the molten iron is poured out and when it had cooled a little, it is compacted with a hammer to drive out remaining slag. A higher class of iron, we might term it steel, is made by melting iron over a long period in a crucible with the addition of charcoal. It is then again treated by hammering it and eventually tempered in cold water.

By this time a whole array of flourmills had been invented. Some were driven by men, some by animals, some by water and others by wind. They came in all shapes and sizes; some were even portable and could be operated by a single man. Power-driven saws for cutting timber and even some for cutting stone were available. Any number of different designs of lifting gear: cranes, multiple pulleys and various combinations thereof for loading and unloading ships or carts, were in use.

Much ingenuity was spent on siege machines. Some were designed to bridge ditches; others provided an artificial steep slope to enable troops to move up the incline to the top of a fortification. Other machines were designed to ram gates or walls, and yet others to sling missiles over great distances into fortified towns or castles. It was a time when fortifications of all kinds were built and ever further refined. Virtually all towns had walls, and large numbers of castles were built. As fortifications became more refined, so siege machines were improved in the usual manner of offensive and defensive weapons developing in parallel and keeping some sort

³ Agricola, Georgius (1912). *De Re Metallica*, translated from the first Latin edition of 1556 by Herbert Clark Hoover and Lou Henry Hoover. London: The Mining Magazine, page 223

of balance. The difference between then and now – apart from the complexity of the weapons themselves – was that defensive and offensive weapons systems could be clearly distinguished, at least as far as fortifications were concerned. A siege machine is clearly offensive, a fortress clearly defensive. Similarly, a shield is defensive and a sword offensive – though the distinction breaks down here because a sword could be used for defence as much as for offence.

Some devices of the time must be regarded as toys rather than useful machines, though the production of toys and ornaments has always been one of the lesser goals of technology. Ornamental water fountains of some complexity were built as the art of the stonemason combined with the arts of producing water pipes and pumps. A machine was invented for holding several books open for the reader, who could rotate the machine to access different books.⁴ We do not know whether anybody ever used this weird contraption.

The Romans had a well-defined system of measurements. Medieval Europe more or less continued with the Roman system, but it was less uniform because there was no overall authority as there had been in Roman times. The main units of measurement were the ell, a unit of length used extensively for measuring cloth. The great trade fairs of the 12th and 13th century kept their own standard ell. The ell of Champagne was based on an iron standard kept by the Keeper of the Fair. It measured about 76cm (30inches) and was accepted by many important centres of the woollen trade, such as Ypres, Ghent, and Arras. The ell in other towns was slightly different. The Roman unit of weight, the libra, survived into the Middle Ages, as did the mile, though the pace, on which the mile was based, disappeared and gave way to feet and yards. Liquids were generally measured by the pint, which was roughly equal to the modern litre⁵.

The metal industries developed gradually through many parts of Europe. One aspect of this development was increased use of waterpower for driving bellows, hammers, and stamping mills. The scale of production of iron increased, the knowledge and skill of metal workers improved both with experience and with the slowly growing availability of specialised literature. The temperature and size of smelting furnaces increased. Cast iron became an important part of iron production and the smelting furnace developed into the blast furnace. The production of other metals also increased and improved. For example, tin mining in Cornwall rose steadily from the 10th century. Coal mining also increased. Iron smelting still required charcoal, which became increasingly scarce with large-scale deforestation and the demands on land made by agriculture, especially in the Mediterranean region. Coal was used for preliminary operations and for lime burning and, of course, in forges. Coal mining centred particularly on Liege from the end of the 12th century, and Newcastle from the 13th century. Coal was shipped from Newcastle to London (so-called sea-coal) and was used there for domestic heating, with consequential problems with, and complaints about, smoke and smell.

The so-called *Stückofen* (lump furnace) provides a good example of production gradually improving with experience. This type of furnace produced a solid lump (bloom) of metal that was extracted from the top of the shaft at the end of the smelting operation. The weight of the bloom produced in a single smelting operation increased from about 10 kg in the earliest days of the Iron Age to 370 kg in 1430, to 400 kg by 1470 and to 500 to 600 kg by about 1600. By then, however, the method of producing iron in bloomeries was obsolescent. The *Stückofen* had been largely replaced by the 15th century development of the blast furnace, a shaft furnace that used somewhat more charcoal, but allowed the molten iron to run off through a tap hole. This iron could be used directly as cast iron or could be turned into malleable wrought iron by treating it in a separate hearth, the so-called finery hearth. The iron from the blast furnace was often initially cast into shapes reminiscent of suckling pigs and became known as pig iron. The initial impetus for the production of cast iron came from its use for the casting of cannon. Cast iron cannon was much stronger than cast bronze cannon and much easier to manufacture than forged iron cannon.

Blacksmiths became highly specialised. Some made wire, others made needles; some made swords, others made scythes; some made anchors, others made horseshoes. Up to the end of the 10th century wire was made by forging. The draw-plate for wire, which allowed wire to be produced by drawing hot iron through a suitable hole, was invented at this time and drawn wire soon replaced forged wire. Early iron needles had a hook,

⁴ Ramelli, Agostino. (1976). *Various and Ingenious Machines*.

⁵ One litre is approximately two modern British pints; now largely obsolete.

rather than an eye, and were produced by hand by members of the guild of needle-smiths in Nuremberg in about 1370. The first needles with an eye were made in the Netherlands in the 15th century. Swords were made in many centres, eminently in Milan, Brescia and Passau. The craft came to Solingen as a result of the Italian campaigns of emperor Frederick I Barbarossa (1152 – 1190). Scythes were made primarily in Styria, the birthplace of iron manufacture and a rich source of iron ore.

By far the greatest numbers of medieval people were engaged in agricultural pursuits and this division of occupations hardly changed up to the time of the Industrial Revolution. Yields were small, productivity was low, agriculture was extremely labour intensive. It thus required the largest part of the working population to work the land in order to feed the population as a whole. We have seen that Roman agricultural implements had made considerable progress in comparison to earlier times. The Middle Ages saw some further advances, though no radical change. The process of land reclamation continued to some extent into the 13th and even the 14th centuries.

It is interesting to compare yields of agricultural crops during the Middle Ages with modern yields by way of illustration of gradual technological advance. The average yield of wheat on modern fields is in the region of 40 to 50 bushels of wheat per acre⁶. When a field was left experimentally without manure from 1843 to 1967, the yield declined to about 12 bushels per acre. This is still twice or three times higher than the average yield of a well managed and manured field in the 13th century. The difference lies in better methods of cultivation and in plant breeding having provided better varieties of wheat, rather than in any dramatic change in technology. The combine harvester and the tractor have drastically reduced the need for manpower and for hard physical work, and have increased the energy consumption of farms, but have not changed the yields all that much.

One of the problems of English agriculture was the balance between pasture and arable land. In the days before artificial fertilizers, the fertility of the soil had to be maintained by rotation between different crops and fallow, and by animal manure. Hence arable land could not be expanded indefinitely at the expense of pasture, because a sufficient number of animals were needed to maintain the fertility of the arable land. At times, the balance between pasture and arable land became precarious and the price of pasture rose to levels above those for arable land. In addition, pasture was needed for the production of wool and wool was one of the chief exports of England. In earlier times, much of the raw wool was exported to Flanders, where Europe's foremost woollen industry was established. In the course of the 14th century, however, the export price of English wool rose considerably because of large profit margins of the merchants and high taxation imposed by the crown. The high price of the raw material forced the Flemish industry to concentrate on high quality products, thus limiting its markets to the luxury end. The high price of the raw material also became a contributing factor to reducing the wages of Flemish workers. Social unrest resulted, which led to an urban revolution in 1320 and to the emigration of many Flemish textile workers to the Brabant, to North Holland and to England. To some extent because of the influx of skilled Flemish workers, but also because of the realisation that more profit could be made and more employment provided by substituting the export of cloth for the export of wool, English textile production rose sharply in the course of the 14th century. There were some half-hearted attempts by the English crown to force this process by forbidding the export of raw wool, but the prohibitions did not last long and had no substantial effect. Even so, the attempt to direct the economy away from the export of raw material and toward greater industrial production, half-hearted as it may have been, must be seen as a rudimentary effort by the state to introduce economic and technology policies.

One of the reasons why the feudal system began to give way to a more market oriented society, though perhaps not the main reason, was the obsolescence of the armoured knight. The armoured knight was too heavy and too clumsy to be very mobile and became helpless if unseated. More lightly armoured cavalry on faster mounts proved, in the end, more effective. The death knell to the knight was sounded by two technological innovations: the crossbow and the longbow. The crossbow was very effective in disposing of even heavily armoured cavalry and infantrymen could easily learn to use it. The famous English longbow was an even more effective weapon, but the acquisition of the required skills to use it effectively was a lengthy process. At the bat-

⁶ This corresponds roughly to four cubic metres per hectare.

tle of Agincourt (1415), the more numerous French army proved no match to the well-trained English long-bowmen.

The more important factor that spelt the end of feudalism was the development of trade and the rise of towns. Between the 11th and the early 13th century numerous towns were founded, largely as trading and market centres, but also as centres for pre-industrial craft production. The citizens of the towns, the burgesses, were freemen and the towns soon developed their own systems of self-government. If a serf managed to escape and enter into a town, which was not easy, he eventually acquired his freedom. Much technology developed in the towns. Town walls were built, and the crafts developed. In England, the walls were built not so much as protection against armed attack by armies, but mainly against the infiltration of undesirable elements into the town. The towns jealously guarded their right to choose who shall and who shall not be allowed to dwell in them, or even spend the night in them. In many other countries warfare between neighbouring rulers was common and city walls did serve to protect the towns against major armed conflict. In Germany and Italy major cities became the centres of states and the small city-states remained, in one form or another, right into the 19th century, when both Italy and Germany were unified.

The main function of the towns was, of course, their role as trading and market centres. The towns had to be supplied by the surrounding countryside with food and other necessities, such as firewood, and these goods were sold in markets. Only salt and a few spices were brought from further afield. As more burgesses became affluent, more imported goods appeared in the towns. Wine, more exotic spices, medicines, ornaments, fine cloths, and so forth. Some traders who were in business selling goods that originated in distant places, or even overseas, settled in the towns. The towns provided not only safety, but also the infrastructure needed by traders. They often needed mutual support, they needed rudimentary financial services, they needed transport services, legal services, schools for their children, housing and business premises. With expanding trade and increased prosperity, the towns expanded to provide the services required. The towns also became centres of craft production, with all kinds of artisans settling in them to produce and sell their wares.

The Middle Ages were a period of strict hierarchical order and strict adherence to the teachings of the Church. Science made virtually no progress, as experiment and observation were regarded as superfluous. The doctrine of the Church and abstract theories, based on church doctrine, sufficed as explanations for all phenomena requiring an explanation. Thus medicine was based on abstract theory and it was firmly believed that both sickness and health could only come from God. Hence medical practice was always reinforced with prayer and the intervention of various saints was regarded as essential in warding off sickness and restoring health. Astronomy was based on Aristotelian principles that had the approval of the Church.

On the other hand, much activity was based on pure empiricism. Surgery, as opposed to medicine, was based on practical experience, with theory counting for little. All the trades, the manufacture of textiles, building, furniture making, and the rest were based on practical knowledge passed from generation to generation without too much development, experimentation, or innovation. The emphasis was on good sound practice, not on novelty. This is not to say that there was no technological development, but development was slow and was not deliberately sought as it is today. There was no premium on novelty. Perhaps one remarkable medieval invention ought to be singled out for mention: spectacles. The first known spectacles were invented in Italy in the 13th century. The Bishop of Exeter acquired a pair in 1326. The spectacles consisted of bone eyepieces, held together by a domed iron rivet. It has been argued that spectacles lengthened the working life of craftsmen and were thus of considerable economic significance.⁷ We do not know of developments in labour saving devices. Labour was cheap and plentiful – except after the period of the Black Death – and the idea of replacing labour by machinery had not been mooted yet.

The main role of technology was, as ever, to support needs, rather than to create or stimulate new demands. The mechanism of stimulating demand by technological innovation was still in its infancy and applied only to a few luxury goods; most stimulation came from trade. The affluent citizen, and certainly the higher clergy and manorial owners and officials, acquired a taste for luxuries, including a better class of furniture and more luxurious accommodation. As in all generations and periods, weapons were high on the agenda of needs. Perverse-

⁷ David Landes. (1998). *The Wealth and Poverty of Nations*. London: Little, Brown & Co., pp 46–47

ly, weapons were also used as fashion accessories. Large and small wars raged throughout the Middle Ages, including the crusades, the Hundred Year War between England and France (1338 to 1453) and many wars between rival city-states in Italy. Warfare, as always, led to constant improvements in weapons. Castles and fortresses were built and siege machinery was further developed. In Britain, the Normans established their rule with a series of castles that offered safety to garrisons that controlled the countryside.

Of more lasting importance was, of course, the introduction of firearms into Europe in the 14th century. The first cannon fabricated from forged iron was made in Germany in 1325. In 1350 the cast bronze cannon came into production and by the end of the century this was replaced by the cast iron cannon. Though the older types of artillery, consisting of a variety of catapults, was not immediately replaced by cannon, nevertheless the eventual victory of cannon over catapult was inevitable. The early cannon was difficult to load, difficult to fire, and often exploded in the face of its own crew. The range and accuracy also left a lot to be desired and it took a great deal of theoretical and practical development work to make the cannon into the devastating weapon of the 20th century. A variety of smaller firearms, the harquebus, the musket and the pistol followed in the 15th century.

It is not possible to summarise a long historic period, even from the point of view of the interactions between technology and society. In the earlier part of the Middle Ages wealth was very clearly defined as the ownership of land and power and wealth were, as always, inextricably connected. Those who owned land virtually owned all the people who lived on their land and all the labour they could provide. As the people were extremely poor, their needs could be fulfilled by relatively simple technology. All that was required were the means to till the heavy soil and to clear forests and dry marshes to gain more agricultural land. The heavy plough that was gradually developed from Roman ploughs, and better methods of breeding and harnessing draught animals, were almost all the technology that was required. Labour was cheap, so there was no incentive to develop labour saving devices. Housing and food were minimal and required little or no technological development. Only the building of large manor houses and of churches required more sophisticated building methods and their interiors demanded some good quality carpentry and other competent tradesmen. Most needs were provided locally and the total volume of trade was, initially, very small. War was a constant feature. Most neighbouring kingdoms, principalities, and dukedoms were involved in territorial or other disputes. The armoured knight was a development from Roman cavalry and required highly skilled armourers, good quality steel, good saddlers, and the breeding of heavy horses. The ownership of land became closely associated with military service. This is not surprising. As the ownership of land was the source of power, and power inevitably was involved in power struggles. Theoretically, all power and all land was in the hands of the king or other ruler, but the ruler had to devolve power and handed over land to his followers and associates who, in their turn, provided him with the armies he needed and even with the administration that was required to keep the country running. The feudal lords and their immediate entourage and family were the knights who provided the cavalry and the military leadership of either conscripted serfs or mercenaries.

Technology was entirely pragmatic. No theories were involved. All technologies were developed by trial and error, and all skills and knowledge were passed on from master to apprentice or from father to son. All theoretical thinking was dominated by church dogma or by folklore and prejudice. All formal thought and formal learning was in the hands of the clergy and the monastic orders. Dogmatic theory lends itself to speculation, but does not encourage systematic observation and the construction of theories based on such observation. A mind that is trained in dogma and speculation cannot possibly pursue what we now regard as science. Science is based on careful observation and deliberate experimentation and on the construction of theories designed to explain the observations and results of experiments in the simplest and most logical way. No theory is raised to the status of an article of faith; all scientific theories can, and often are, falsified by further experiment or observation and may be discarded and replaced by a better theory. By better we mean in better agreement with observed facts, simpler, more general, and more capable of predicting the results of future observations. In complete contrast with religious truth, scientific truth is always on probation, valid only until falsified.

In the later Middle Ages, trade developed and trade led to major changes. First, trade needed centres to operate from, and thus towns and cities grew and multiplied. Secondly, trade became an alternative source of wealth. Successful merchants could become very rich and kept their riches in cash, gold, houses, jewellery, and other luxuries. To some extent, they also invested in land and became a new class of non-feudal landowner.

Trade was not, initially, driven by technological developments. It was driven by the realisation of enterprising and ambitious men that money could be made by buying short and selling long. Perhaps the ultimate reason for the development of trade was that land clearance reached its natural limits and thus the need for more agricultural labour diminished. A growing population needed new sources of employment and income. No doubt the efficiency of agriculture increased by gradually improved methods, and the land became capable of feeding more mouths that did not contribute directly to the production of food. This provided an opportunity for more men to leave the land and engage in trade, professions or crafts. As wealth increased, more people required not only food, but also products of technology, such as houses, furniture, clothing, bedding, pottery and other domestic equipment. Traders naturally required transport for themselves and, more importantly, for their goods. Cities required not only dwellings, but also city walls, water supplies, streets, shops, public houses, and a whole range of administrative and other services. All these activities required technology but did not call for much technological innovation. Technology developed slowly and gradually to fulfil the demands made upon it; it did not stimulate many, if any, new demands.

The most visible and lasting heritage of the Middle Ages are the splendid cathedrals built during that period. They are marvellous feats of technology and a testimonial to the ingenuity and skill of medieval stonemasons. Cathedrals were not, however, a demand stimulated by technology, but an expression and technological embodiment of the power of the church and the piety of the people.

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