CHAPTER 1

INTRODUCTION

An invention is usually considered a delightful new device or method that would make life better. Let us also look at some official definitions. The Oxford English Dictionary mentions that it could be a discovery, a fabrication, introduction of a new instrument, a design or plan, a figment of imagination, or a piece of music written by Bach.

The US Patent Office requires that for an invention to receive a patent, it should be new, inventive, and useful or industrially applicable. It is possible to be new without being inventive, such as a scientific discovery that may have no immediate practical application. The Patent Office defined four general categories of inventions: (a) a process or a method, (b) a machine, (c) a manufacture, and (d) a composition of matter. A significant improvement can be patentable, but an idea or suggestion must be accompanied with a complete description of the actual machine, and reduction to practice is often required. The patent gives the owner the exclusive right to use the invention for a number of years, such as 20 years, and can license the right to another party for considerations. The owner can also sue anyone infringing on the patent without a contract and payments. In practice, it is very easy to detect infringement on a patented product when it is sold in the market to many customers, and somewhat more difficult to detect the presence of a patented matter in a manufactured product. The most difficult to enforce is a patented machine or method that is installed in a factory not open to the public without a search warrant.

We usually think of inventions as providing the means to satisfy our material needs, such as for food, clothing, and shelter. For these purposes, we have invented the tools of agriculture, of spinning and weaving, and of beams and roofs. Our spiritual needs such as knowledge, beauty, truth, and justice are also supported by inventions and technology—including the ability to record and print words and pictures, and to communicate to people far away and to future generations. There are very few revolutionary breakthrough inventions on brand new technologies, such as penicillin and transistors. Most inventions are based on making improvements on an existing technology to make it more effective or efficient such as vulcanized rubber, or finding a new use for an old material such as using ether for painless surgery and childbirth.

What is a great invention? An invention adds to the store and power of technology, which bestows benefits (and sometimes harm) on our work, lives, society, and the environment. We value an invention according to a number of criteria including: (a) the audacity of the technology over the existing technologies, (b) the expansion of our capabilities to perform tasks that were considered impossible, and

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to open doors to exciting new possibilities, and (c) the valuable and long lasting benefits that it brings to many people.

The greatest inventions make dramatic breakthroughs, and open new eras in human history. Consider the lives of early men in East Africa about 4 million years ago without the sharp teeth of lions to tear meat. The stone axe was the first great invention that allowed our ancestors to eat the food of lions, and set us on the path of independence from our meager tools of teeth and claws bestowed by nature, as we could invent a whole arsenal of new and powerful tools. Fire led to the invention of cooking and softened tough meat and cereal as food, to ceramics and metallurgy, and to the colonization of the frozen north. Agriculture led to much greater and more secure food production, and allowed people to settle in villages and cities. The steam engine led to tireless power for manufacturing and transportation and to a burst of productivity increase and the Industrial Revolution. Modern sanitation and the germ theory lowered the rate of infant mortality, so that it is no longer necessary to have six children to ensure that two would survive to adulthood. Each generation of human society inherited a much bigger toolbox of technology from the previous generations, and can enrich it by the constant addition of ever more new inventions to benefit the next generation.

A drug that cures lung cancer would benefit millions of people, and would be considered more important than a drug for a rare disease that affects only thousands, according to the Jeremy Bentham principle of greatest happiness for the greatest numbers. Bentham also specified that happiness should be ranked by intensity, duration, and certainty. An invention that keeps us alive is more valued than an invention that improves our vanity; an invention that remains in use for many years is valued more than inventions that are quickly replaced; and a drug that always works is better than one that works only some of the time.

The direct benefits of an invention can be obvious, such as fire providing warmth and light. The unintended indirect benefits (or harm) are often slower in coming but can be far more important, such as fire leading to cooking which softened tough grains, and made possible pottery, bronze, and iron. The synthetic dye mauve was invented by William Perkin in 1856 and was used for only a short period of time before it was replaced by newer and better dyes, but its success inspired many chemists and entrepreneurs, and subsequently gave rise to many new synthetic dyes and synthetic drugs, such as sulfonamide. These new drugs became the foundation of the modern pharmaceutical industry, and saved millions of lives. Freon was a refrigerant introduced in 1920 that made possible safe home refrigerators without the hazards of fire and toxic leaks, but it accumulated in the atmosphere for many decades and led to the ozone hole and global warming, which made it no longer suitable.

1.1 INVENTORS AND INVENTIONS

Consider where and when great inventions were made, who made these inventions, what motivated them, what were their methods, and how revolutionary were their inventions?

1.1.1 Cradles of Inventions

In the past several hundred years, the most inventive places on earth were in Western Europe and later in North America as well. Is there an association between climate and inventions? Let us use the Köppen Climate Classification scheme, which is based on the distribution of temperatures and rainfall of each month in the year. Mellinger, Sachs, and Gallup observed that the temperate zones within 100 km of the ocean or a sea-navigable waterway accounts for only 8% of the world land area, but has 23% of the population, and 53% of the GDP of the world. It is also the most inventive area in the modern world, with the highest standard of living.

The most inventive places in the ancient world were in the dry climate (Mesopotamia, Egypt) and located at large rivers. The more recent inventive and economically successful places tend to be in the humid temperate zone (Athens, Rome, London, Xi'an, Philadelphia), and less often in the humid cool zone (Beijing, Boston, Berlin). The tropical humid equatorial climate of the Amazon and Congo supports a large population, but is not very inventive; the cold polar and the highland climates support little population, and are not inventive.

However, the ancient cradles of the most important inventions came from the tropics, and gradually migrated to warm subtropical climates, and later to cool temperate zones. Let us look at this migration for six great inventions: the stone axe was from Olduvai Gorge in Tanzania (latitude 5°S) 2 million years ago; fire was first mastered at Zhoukoudian in China (40°N) 500,000 years ago; agriculture began in the Fertile Crescent (33°N) 10,000 years ago; writing began in Mesopotamia (33°N) 3,500 years ago; the steam engine was established in Scotland (56°N) in 1750; and the electronic digital computer began in the United Kingdom (51°N) and the United States (41°N) around 1950–2000. They exhibit a steady northward movement with time.

The climates of Eurasia and North America were not always the same throughout human history. The world climate turned distinctly colder from Pliocene to Pleistocene 2 million years ago, perhaps by as much as 2–6°C in comparison with the year 1950, and much of Northern Europe and America were under sheets of ice. The ice age ended at the beginning of Holocene 10,000 years ago, and the world began to warm up significantly.

Why did most great inventions arise in these temperate places, and why at that moment in time? The most frequently cited requirements to support inventions include the following:

(1) *Environment.* The hunter–gatherers need a healthy and agreeable climate with warmth, rainfall, and soil, suitable for the growth of plants and animals for food. The farmers need to find local plants and animals that can be domesticated, stone and clay for construction, trees for fuel, and ores for metallurgy. The temperate climate provides the stimulus of a change of seasons and cyclonic storms, and gives the residents challenges to keep them alert with problems to solve. Arnold Toynbee proposed the Golden Means theory on the genesis of a civilization. A group of people can live in comfortable torpor for a long time, and would need a stimulus or a challenge in order to respond and move into a dynamic creative state. There are various stimuli, such as living in a hard country and environment, moving to a new habitat, external blows from enemies, internal pressures, and penalty in comparison with other groups. If the stimulus is necessary to wake one from contented torpor then would more stimuli always lead to better responses? He proposed that challenges should be large enough to be stimulating, but not too large to be overwhelming. He gave the following examples as illustration:

- The Vikings living in Scandinavia had a mild climate during the Viking Age, and were not sufficiently challenged to produce much literature; but the Vikings in Iceland were exposed to a bleak and barren environment and made greater achievements in literature; and the Vikings living in Greenland had an even more bleak and barren settlement, and were barely able to survive and had no time for literature.
- The Europeans that settled in North America at Virginia and the Carolinas had a comfortable life, and made few contributions to literature; the settlers in Massachusetts had a more harsh climate and stony soil, and were sufficiently challenged to achieve leadership in intellect and commerce; the settlers in Maine and Nova Scotia had scanty livelihoods and no time for literature.

If we rank the climate zones according to the degree of challenge, we may obtain the following from the least challenging to the most challenging, and the optimum is presumably somewhere in the middle: humid equator < humid temperate < humid cold < dry < highland < polar. Environment alone is insufficient to explain why North America was dormant before Columbus, and became a world leader after 1950.

(2) *Contacts and Heritage.* Inventors build on the stimulus of previous technologies, which they inherited from their ancestors; they also learn from neighbors and visitors that they meet. They need access to transportation in order to trade and to communicate with other people, and to learn new ideas and technology. Jared Diamond argued that the various people of temperate Eurasia can travel 13,000 km from Western Europe to East Asia without a change in climate, and can learn and adopt inventions and ideas from other people. On the other hand, the peoples of North and South America became a series of isolated communities as a similar trip of 13,000 km from the Bering Strait to Tierra del Fuego would involve crossing numerous climate zones, with the need to adapt to new food sources and enemies, and to stay warm or cool. The people of Oceania were likewise isolated from the Eurasian inventive communities. This requirement of heritage and contact does not explain why Africa did not continue to be inventive after a glorious start, or the long sleep of Rome between Justinian and the Renaissance, the sudden birth of the Islamic civilization with Mohammed, and the long silence of Mongolia after Genghis and Kublai Khan.

(3) *Soul and Leadership.* The creativity and dynamism of a civilization, as well as subsequent stagnation and decline, have many causes that are difficult to analyze and explain. One can put together a long list of influences: internal tradition, philosophy, religion, external challenges, optimism, stability and security, openness to new ideas, and willingness to adopt progressive ideas and to reward innovators. Charismatic leaders are possibly the most important requirement. Oswald Spengler believed that each great civilization has a soul, which runs through the course of a thousand years from the awakening of barbarism to growth of a new civilization, from expansion to the zenith of empire, to decline and eventual decadence. His Apollonian soul is the Greco-Roman civilization, and his Faustian soul is the Western civilization from Merovingian to now. This explanation can be viewed as an inspired oracle instead of a scientific method, as it gives no principles to predict the arrival of the future souls.

1.1.2 Creativity

We have very little knowledge of the inventors of the first stone axe, who lived in East Africa some 2–3 million years ago. After the invention of writing, we begin to have written documents and some information on the inventors. Who were the inventors, and what were their backgrounds and education; why did they become interested in inventions, and what were their methods; and how revolutionary were their inventions?

In ancient times most people toil for immediate needs, and only a few had the leisure to pursue interests that did not produce short-term benefits. Perhaps the earliest inventors known by name in history were Imhotep and Yu the Great. Imhotep dated from 2600 BCE in Egypt, and was chancellor to the pharaoh Djoser and high priest to the sun god Ra. He was also the first engineer, architect, and physician of Egypt; was credited with the invention of the papyrus scroll and the architecture columns; and was declared to be a god after his death. Yu the Great lived around 2060 BCE in China, and was the founder and first emperor of the Xia Dynasty. China was suffering from great floods, and the king Yao assigned the task of taming the flood to his minister Gun. Gun erected numerous dikes that failed, and he was executed by Yao, who turned around and assigned the same job to Gun's son Yu. Instead of erecting dikes, Yu dredged new river channels to serve as outlets to the flood, and for irrigation. Yu labored for 13 years as an inventive hydraulics engineer, tamed the flood, and was reward with the kingship by Yao. For these two inventors, the process of invention took little time in a schedule crowded with numerous important duties. No inventor since Imhotep and Yu has received as much recognition and honor as these two.

The occupations of the inventors at the time of invention can generally be divided into part-time amateurs who dabbled in inventions as a hobby or side interest, and dedicated professionals who received support to invent for wealth and fame.

Inventions require time and patience, as well as optimism from the inventors, who often must have other means of livelihood. The part-time inventors had other occupations or inherited wealth, and occasionally took time out to invent something. Archimedes (287–212 BCE) was a wealthy aristocrat, and a relative and advisor to the king of Syracuse. He was freed from the concerns of making a livelihood, and had the time to make scientific discoveries and inventions such as a method to determine the density of metals by immersion in a bath, and the Archimedes screw to raise water from a river. Other examples of amateurs as inventors include Alexander Fleming and Wilhelm Roentgen, who were professors engaged in teaching students and making scientific investigations. They also made accidental discoveries that led to great commercial success.

Independent entrepreneurs are people without the sponsorship of a government or a company, but who gave up regular occupations to dedicate themselves to inventions, hoping to gain fame and fortune. James Watt invented several much improved steam engines, and went into partnership with Matthew Bolton. Charles Goodyear gave up all other work to concentrate on finding a way to improve rubber. Alexander Graham Bell invented the telephone. Thomas Edison was among the first to take up inventions as his main occupation and source of income, when he set up his independent industrial research laboratory in Menlo Park, New Jersey in 1876 with funds from his previous inventions. The Silicon Valley is full of such independent entrepreneurs, and some of them became very wealthy at an early age.

The corporate employees are engaged by firms or governments to do research and inventions, and may be required to sign over future patent rights and profits to the employers. Leonardo da Vinci (1452–1519) was paid by the Duke of Milan and by Francis I as a painter and military engineer, when he invented methods of fortifications and siege engines, as well as flying machines. After the dye discovery of Perkin, the German companies such as Hoechst, Bayer, and BASF poured resources into research, hired highly educated graduates from universities to discover new dyes at lower cost or higher quality, and later branched out into pharmaceuticals with the discovery of the sulfa drugs. The DuPont Company set up a research laboratory in 1902 to diversify from their traditional business of making gunpowder, and hired Wallace Carothers who went on to invent nylon in that laboratory. Thomas Midgley invented the tetraethyl lead and the refrigerant chlorofluorocarbons (CFC) in the General Motors laboratory. The Bell Laboratory was set up in 1925 by the parent company AT&T, and one of their most famous inventions was the transistor by the team of Bardeen–Brattain–Shockley. Corporate funding has become the dominant support of inventors, where teams of specially trained scientists and engineers are housed in special buildings and laboratories, equipped with modern equipment and instruments, and are paid to do full-time discoveries and related activities.

The successes of inventors owe a great deal to the encouragement of society, for support before the inventions, and for rewards after the inventions. Public support includes education in science and technology, research grants, and patent protection, which gives the inventors a monopoly on exploiting their inventions for 17–20 years. Another form of encouragement is public honors in the form of prizes and recognitions, such as the Nobel Prize and the Inventors Hall of Fame.

Why was the inventor motivated to invent something? It is often said that necessity is the mother of inventions. This would imply that many inventions began with needy and dissatisfied customers, followed by deliberate searches to find solutions to important problems. There are many examples to these *Market-Pull* inventions, when the investigators were motivated by market applications. Raw rubber was used to make raincoats and balls, but they were brittle in cold weather and sticky in hot weather. Charles Goodyear searched for a method to improve the qualities, and to turn unsatisfactory raw rubber into a useful product. He spent 5 years doing trial-and-error experiments before he discovered that sulfur and heat could be used to vulcanize rubber. The Newcomen steam engine was used to remove water from flooded mines, but it was very inefficient and wasted a great deal of coal. James Watt made many improvements so that the steam engine became much more efficient, and this tireless and inexpensive engine started the Industrial Revolution. Home refrigerators originally operated with a number of refrigerants that have toxic and flammable properties, such as sulfur dioxide and ammonia, and posed real threats. Thomas Midgley was asked to find a nontoxic and nonflammable refrigerant, and he invented the chlorofluorocarbons. In a modern company or government agency, the quest for an invention may begin at the marketing department, reporting on customers with needs who are not satisfied, and demanding a better product.

Another mode of invention is to start from a technology, and then search for customers. The investigator may have created an improved or new technology, either by accident or while looking for something else. The investigator may also start from a "platform" technology that has proven successful in serving one market, and search for other markets that can be served by the same or slightly modified technology. These are sometimes called the *Technology-Push* inventions, since the investigators had the technical capability first. The Watt steam engine was so successful in pumping water from mines that Robert Fulton modified it to operate steamships, then George Stephenson modified it to drive trains, and even the textile industry adopted it to power textile mills. CFC is effective in refrigerators and air conditioners, due to its nonflammable and nontoxic properties, which also makes it suitable for other applications such as propelling aerosols and blowing dust off computers.

The most innovative event is created when an invention creates a new demand that did not exist before, and thus a brand new market. The vegetable and mineral dyes available in 1850 were few and drab, but since the public was not aware of the possibility for a greater and more vibrant variety of dyes, they did not clamor for them. Perkin was an 18 year old schoolboy on vacation at home, who started out looking for a way to synthesize quinine to treat malaria, but his oxidation of coal tar resulted in a brilliant dye. It led to a series of more brilliant dyes, as well as the modern chemical industry. From the beginning of history, humanity suffered, and died of infectious diseases, but the suffering public did not know that it was possible to invent miracle drugs. Alexander Fleming was working with staphylococcus bacteria in a London hospital when he found colonies in the Petri dishes in his musty and dusty laboratory. He observed that bacterial colonies do not grow in rings around areas that have been accidentally contaminated by a green mold, and he found the substance that he named penicillin. This led to its widespread use in medicine, and created the new market of antibiotics. In the same way, there were no market demands before the launching of the personal computer, the cellular telephone, or the Internet. Steven Jobs was famous for inventions that anticipated public demand: the public could not imagine such miraculous machinery as the iPad and iPhone before they were introduced, and could not live without them after they were introduced.

For the inventors of the stone axe 2 million years ago, a stone with a naturally broken sharp cleavage was found to be effective in cutting meat, and became used regularly. Probably the long process of improvements over the next 2 million years was guided by random tinkering, trial-and-error experiments, and remembering which methods produce better products. This process of empirical inventions had no scientific theory and systematic data for guidance. This method survives today in areas with insufficient scientific understanding.

Paul Ehrlich was a medical doctor searching for a drug to cure syphilis without severe side effects, and was convinced that arsenic held the answer. He reacted arsenic with other chemicals to form many new compounds, and hoped that one of them would not be overly toxic to humans but still effective on syphilis. He synthesized 606 arsenic compounds, and found the compound Salvarsan to have the desired properties. The random search of thousands of objects is a very slow and expensive undertaking, but is worthwhile when the goal is very important and no knowledge or theory exists to help. This method is sometimes called "Edisonian" as it was used by Thomas Edison in his search for a carbon filament in the incandescent lamp. It was also the method used to discover taxol, the recent drug for uterine and mammary cancer.

The modern scientific method arose in the Renaissance, and became the new source of the most productive inventions. Francis Bacon described the scientific method in 1620 as an endless cycle of the following steps:

- **(i)** Make observations of a phenomenon, note the regularity and reproducibility of the observations, and confirm by more measurements.
- **(ii)** Make hypothesis of an explanation about the cause of this phenomenon.
- **(iii)** Based on this hypothesis, make predictions of other phenomena that can be observed and measured.
- **(iv)** Perform experiments designed to test the predictions, and compare to the results to confirm or deny the validity of the hypothesis.
- **(v)** If the experiments confirm the predictions, the hypothesis receives one more vote of confidence; if the experiments deny the predictions then the hypothesis needs to be revised and we return to (iii) to repeat the cycle.

The scientific method led to a set of fundamental theories that govern the physical world, such as the Newton's law of motion, the Maxwell law of electromagnetism, and the second law of thermodynamics. Systematic experiments for many years led to a body of knowledge and databases of the properties of matter. In modern times, there is a very large body of scientific knowledge and understanding, which became the foundation of many inventions. The public support of education in science and engineering creates a larger pool of workers who have the necessary background for inventions based on science.

The modern inventors who have studied the physical and biological laws can make reliable predictions on many consequences when an action is taken. For instance when you climb a peak of 20,000 ft, what would be the boiling point of water, and how long would it take to make a hard-boiled egg? Another challenge is how you would operate a pressure cooker to control the pressure so that you can hard boil an egg in 2 min instead of 5 min. Most technology today is based on reliable science and supplemented by the less reliable intuition and hunches, based on the skill and the inspiration of the artist. The rate of inventions based solely on empiricism was painfully slow for millions of years, and became dormant in the west during the middle ages; but since the scientific method, the rate of science-based inventions has been phenomenal.

Most inventions are embedded in a long evolutionary sequence of many closely related inventions, and can be studied as a continuum over time. Each invention in such a sequence can be considered to be *incremental*, as they made small and more or less obvious improvements in the technology, or adapted a product to a slightly different market application. After many years of improvements, such technologies often become mature and do not offer further opportunities for development. Revolutionary improvements come with inventions that merit the designation of *breakthrough*, as they involve unexpected and novel ideas that spawn many applications and improvements in the future.

The following table is a matrix of inventions with rows from current technology to improved technology, and finally to revolutionary technology. The columns range from serving the current market to serving additional markets, and finally to creating brand new markets. In an incremental invention, an investigator starts from a current market served by a current technology, and looks for incremental changes that would lower costs or improve quality, or serves to find a new market. For the inventor, this is a relatively safe path that poses small challenges in getting the technology ready and a receptive market. However, the rewards in fame and fortune are likely to be modest. There are three forms of this incremental invention, which are listed as:

(i) Keeping the same market and searching for an improved technology. Salicylic acid from willow bark will cure headaches, but it is very harsh on the stomach. Felix Hoffman chemically added an acetyl group to salicylic acid, and the result was aspirin, which has the same effectiveness but is less harsh on the stomach.

(ii) The term “platform” technology is sometimes used when one takes a proven technology successfully used in one application, and looks for other applications. Botox is the deadly poison from the botulism bacteria that causes paralysis of the muscle. Many years later, it was found to be effective in removing facial wrinkles.

(iii) The steam engine was successful in pumping water from flooded mines. Robert Fulton modified the Watt engine to propel the steamboats he was operating on the Hudson River, and George Stephenson modified the engine to propel railroads.

	Serve current market	Serve additional markets	Create brand new markets
Current technology	Business as usual	(ii) Botox to remove skin wrinkles	(vi) Morton, ether for anesthesia
Improved technology	(i) Hoffman modify aspirin	(iii) Fulton and Stephenson used steam engines for trains and ships	(vii) Cellular telephone
Revolutionary technology	(iv) Midgley, CFC for refrigerators	(v) Midgley, CFC for air conditioning and aerosol	(viii) Perkin, synthetic dye for textile Fleming, penicillin as antibiotics

Occasionally, we witness the excitement of an invention that takes a revolutionary leap forward in creating a *breakthrough* technology. This is more risky, as it may be difficult to make this technology effective, safe, and economical.

(iv) Thomas Midgley was asked to come up with a refrigerant that is not flammable and not toxic, thus suitable for home refrigerators. Instead of studying the currently available refrigerants, such as sulfur dioxide and ammonia, and finding ways to improve their properties by additives or substitutions, he used the periodic table of Mendeleev to discover a new class of compounds, the CFC.

(v) Since CFC became successful in refrigerators, the same nontoxic and nonflammable properties make them useful in air conditioning and aerosols.

Sometimes we create a brand new market that did not exist before. This is also risky as customers may not embrace this unfamiliar new technology, and may refuse to use it.

(vi) Ether is a chemical used for solvent and paint removal. Morton introduced diethyl ether into surgery as an anesthetic, which reduced pain and suffering. Before ether was introduced for anesthetics, there was not a market for an effective and safe anesthetic.

(vii) Many changes were made to the traditional telephone to make the cellular phone, which is portable and not tied to the wall by a cord. It created the new market of cellular telephone.

Undoubtedly the most exciting inventions involve the simultaneous creation of a revolutionary technology and a brand new market. These inventors take a doubly risky path, as the technology may not work, and the public may not embrace this new product.

(viii) Perkin's synthesis of mauve from coal tar was a brand new technology, and created colors so brilliant and enchanting beyond what occurred in nature, which started the new field of synthetic dyes. Fleming's discovery of penicillin enabled us to save millions of lives from bacterial infections, and created the new field of antibiotics. Before Perkin and Fleming, dyes and drugs were found in plants and the earth, but these two inventions awakened the world to the realization that there is unlimited potential in synthetic chemistry. The doors that they opened are even more valuable than those two original inventions of mauve and penicillin.

1.2 INNOVATION, DEVELOPMENT, DIFFUSION

Joseph Schumpeter once said that an invention that is not widely used is irrelevant to human affairs. There are thousands of ingenious and admirable inventions that were neither carried out in large scale nor were they used by millions of people to change the world. Hero of Alexandria in the first century produced a steam engine by jet action, but it was treated as a curiosity and did not lead to benefits for society. Leonardo da Vinci invented a number of flying machines, but there is no record that they were ever built to change transportation or warfare. Crawford Long of Georgia actually used ether for anesthesia in surgery a few years before William Morton in Massachusetts, but Long did not publish his results and had no influence in subsequent medical history. Out of the many thousands of inventions in history, only a few were able to travel the long and difficult path from discovery to development, to be manufactured on a large scale, and to be sold widely in the marketplace, and effect significant change in the world.

A discovery does not become a widely used technology until it has been shaped to suit the factory where it will be manufactured, to suit the customers in the marketplace, and to find sufficient financial backing to pay the bills till revenue begins to roll in. Some argue that there are two separate acts to a successful innovation: (a) the invention, which is an original act of discovery with or without an economic motive and (b) the innovation, which is driven by entrepreneurs for economic development. In the case of the atomic bomb and radar, the innovations were driven by the government for political and military reasons.

1.2.1 Development

After a discovery, the concept needs to be shaped into one or more products to suit specific needs of the marketplace, so that it can be sold at sufficient volume and price to compete with other products. It must be possible to make the product in a factory, with a suitable manufacturing process, raw material supply, equipments and plants, and at an affordable cost. The entire innovation effort must be organized under some leadership, with access to sources of finance to pay the bills till the products can be sold in volume. This sequence of events involves many people with different talents, and must be coordinated successfully.

Wallace Carothers of DuPont discovered that he could make polymer fibers by reacting a 16-carbon diacid with a 3-carbon dialcohol, which has a melting point of below 100°C. What products could DuPont make with this technology that would earn a profit for the stockholders? DuPont decided to make nylon as a luxury stocking for women, as they already had experience making the semisynthetic rayon fiber for the textile industry, and a pair of nylon stocking requires only a few grams of polymers and can be sold for a high price. This decision set up a number of development problems of production and marketing. Nylon stockings were offered to displace silk stockings from the market, so there had to be advantages to women to wear nylon instead of silk, and the price of nylon could not be too high in comparison to silk prices. A pair of silk stockings had to be ironed, so it required a sufficiently high melting point; DuPont found a solution by replacing the dialcohol with the diamine, which resulted in a higher melting product. How could DuPont acquire enough raw materials of diacids and diamines from plentiful and cheap coal tar or petroleum? After a great deal of investigation, they decided to switch to the 6-carbon diacid and the 6-carbon diamine, which could be made from the abundant supply of 6-carbon benzene, and was named nylon 66. The polymer also had to be pulled in the molten form through diamond dies and twisted into fibers of the appropriate thickness and elasticity. The DuPont Company had enough confidence in this decision to finance the development from past earnings. Ten years passed before the first satisfactory product emerged dating from the original Carothers discovery.

When Alexander Fleming of St. Mary's Hospital discovered penicillin in a Petri dish, more than a decade elapsed before it became a lifesaver for millions. Fleming was a bacteriologist, and had no idea how to manufacture and market a novel drug. Penicillin was produced in his Petri dish with a concentration of 30 ppm, and he did not have the knowledge and skill to extract and purify the drug for clinical tests with animals and humans. He could make a few milligrams in one Petri dish, but he could not manage a million Petri dishes to make 1 kg of penicillin. Some of the purification and testing were solved a decade later by the chemists Howard Florey and Ernst Chain of Oxford University. They lacked the industrial capability to produce penicillin in wartime England, and Florey sailed to the United States to seek help. Penicillin is a very unstable liquid, and decomposes in about 3 h, and he did not know how to store it and have it ready for clinical use. After these problems were solved, a big source of financing was needed to pay for the costly steps of building plants, buying machinery and raw material, recruiting and training labor, and developing a storage and distribution organization. The US Scientific Research Board became the entrepreneur to manage these developments and assigned different tasks to different organizations and investigators, and persuaded the US President and Defense Department to take the risk and finance this unproven venture.

Perhaps more than 99% of all the discoveries do not make it to the marketplace, either because they fail to find an entrepreneur with sufficient resources to undertake the expensive development–manufacturing–marketing processes, or because they run into obstacles in the process. There is an illness called "kala-azar" or black fever, which is spread by sand flies, and kills half a million people per year, making it the second largest parasitic killer in the world after malaria. It occurs mainly among the poor people in India, Bangladesh, Nepal, Sudan, and Brazil. The drug paromomycin was discovered in the 1960s and seemed very promising, but was abandoned due to the high cost of Phase III clinical trials and the low probability of making sufficient profit to recover the development costs. A number of private foundations, such as the Bill and Melinda Gates Foundation, are beginning to finance the development of such neglected drugs. Even after the drug has been tested and found to be effective with negligible side effects, distribution looms as the next hurdle as getting the drug to remote villages at the end of pothole-pocked roads will be difficult.

In the last two centuries, there have been several very successful models of managing development from discovery to the marketplace:

- *The Discoverer–Entrepreneur Model.* Synthetic mauve was accidentally discovered in 1856 by William Perkin when he was a schoolboy of 18, who realized that its rich purple color could be used to dye textiles. He dropped out of school, formed a partnership with his father and brothers, developed the process for manufacturing, procured the necessary raw material, visited textile manufacturers to persuade them to use his dye, built the factory, and supervised the manufacturing and shipment of dyes. Besides doing the discovery and development, he was also the entrepreneur who found financial support and managed the entire enterprise from the beginning to the end. Thomas Edison also followed his discoveries with entrepreneurial work, participated in forming companies and kept much of the profit. Alfred Nobel, the inventor of dynamite, was also a discoverer–entrepreneur. The modern equivalents of this super solo model are some of the Silicon Valley information technology start-up entrepreneurs, especially those in software who do not require large capital investments in plants and equipment.
- *The Company Acquisition Model.* Fritz Haber informed the BASF Company that he had found a way to synthesize ammonia from air and water, but Haber did not have the means or the knowledge to turn it into a process. The company purchased the rights to Haber's patents, and retained him as a consultant. Then the company proceeded to develop the process under the direction of Carl Bosch, built the plants, sold the product to the German government, and financed the effort. Many start-up companies in the Silicon Valley sold their companies to large corporations, instead of remaining independent and taking more risks for more control and a chance to make bigger profits.
- *The Central Command Model.* The DuPont Company hired Wallace Carothers to do research. After the discovery of nylon in 1935, the company decided that it should be developed for stockings. DuPont assigned many talented researchers to solve problems of manufacturing and marketing as well as financing the entire project. This model can be appropriate for a company with a strong staff and deep pockets.
- *The Consortium Model.* The development of Fleming's penicillin was first carried out by Florey and Chain, and later by numerous American industrial organizations with the chemical engineering skills to make large-scale production, purification, concentration, and stabilization of the product for storage and shipment. This process was financed by the US government as part of the efforts of fighting the World War.

1.2.2 Factory Production and Market Penetration

No invention can be manufactured in large enough quantity at reasonable cost unless a number of production factors are available. For instance, the Sahara and Greenland cannot adopt agriculture as a way of production because their climate and soil are not suitable. Diamonds are mined in South Africa, which lacks skilled diamond workers or the right marketing outlets. Consequently, the raw diamonds are shipped to the Netherlands and to Israel, to be polished into gems and sold at luxury showrooms. The principles of the atomic chain reaction was demonstrated by Enrico Fermi in Chicago, but the atomic bomb could not be manufactured till sufficient uranium-235 had been separated and enriched, and plutonium had been created by neutron bombardment.

The economists often list the "factors of production" as land, labor, capital, and technology.

- The term "land" includes the natural resources that come with the land—the bounties or paucity of climate, temperature, rainfall, animals, plants, soil, and minerals.
- The term "labor" includes considerations of the total number of workers, their age distribution, the states of health and vigor, the education and skill, and the intangible aspects of diligence and creativity. Another indispensable factor is "entrepreneurship," which is the leadership with an overall vision of the enterprise, the ability to find financial resources, and the courage to take charge and make risk decisions.
- The term "capital" includes capital investments into the technology of production machinery, tools, buildings, inventions, patents, and methods of production. It also includes society's investment in the public infrastructure for transport, so that raw material can be efficiently brought in and products brought out; for information infrastructure such as telephone and Internet; and for utilities such as dependable electric power and water.
- The term "technical knowledge" is not one of the classical factors of production, but must be available in the education and previous experience of the staff, and as patents and trade secrets.

When a product is bought steadily by a group of customers over a period of time, it must be due to the needs that are met by the product. The customer must be satisfied by the benefits from the products, and have sufficient purchasing power to cover the costs of the product at posted prices. A customer usually has a choice of other products on the market, and will do a cost/benefit analysis to determine that this product is worth buying either because it costs less or has better benefits than any other competing products. The needs and constraints of buyers are different for consumer products such as nylon stockings, for business products such as oil tankers, and for government products such as nuclear submarines. The entrepreneur tries to understand the needs, the budget, and the competition of each group of customers, and tailor the products and prices to suit these realities.

Throughout history, the global reach of an invention often followed trade, migration, and colonization. The traders were often the first visitors to an isolated community, and the first to expose the natives to new goods and methods. Marco Polo was credited with bringing back a number of inventions from China to the Western world, such as noodles. Peaceful migration and military conquests bring a larger influx of exposure, such as the appearance of horses and firearms in the New World. There are a number of consumer barriers to the diffusion of new technology, thus the process can take many years before a new technology is adopted. Besides cost/benefit and competition, there can be many social barriers to the market acceptance of new products, such as inertia, xenophobia, and religious and cultural taboos. The rate of adoption of a new technology such as the mp3 player can be compared to a parade led by the innovators for their own uses, followed closely by a few intrepid early adopters. There is a tendency for the innovators and early adopters to be risk takers who are younger, better educated, of higher socioeconomic status, and who take pride in being the trendsetters for their generation. They are followed by the majority, who join when they are encouraged by the satisfaction and recommendations of the early adopters. The trailing groups are the late adopters, who are more conservative, more inflexible, and suspicious. Finally there are the laggards who do not join this parade at all. The late adopters and laggards can be older skeptics who have an aversion to change, are less educated, and are socioeconomically lower.

The US Census Bureau provided data for 2007 on the relatively new technology of the Internet, which is used by more than 4/5 of the wealthier users with more than $100,000 in annual income and by the younger users less than 44 years old. On the opposite end, the Internet was used by less than 1/3 of the lower-income population who earn less than $20,000 and users older than 65.

The World Bank publication of World Development Indicators gave the following data on popular use of information technologies as an international comparison per 1000 population. The high-income nations use the television 10 times more often than low-income nations, and use personal computers 100 times more often. In this instance, wide usage is not simply a matter of need, but is driven by purchasing power and education as well.

Nation	Radio set	TV set	Personal computer	Internet
Low income	139	91	7.5	10
Lower middle	360	326	37.7	46
Upper middle	466	326	100.5	149
High income	1266	735	466.9	364
United States	2117	938	658.9	551

1.3 CHANGING THE WORLD

Inventions lead to technological developments and effects on society that can be either beneficial or harmful. Many people feel that new technology is basically beneficial and gives society more choices, even if it is sometimes hazardous, and people should be willing to adapt to the inevitable march of progress. Others view many technological developments as basically harmful, because they may fall into the hands of unscrupulous individuals and institutions who would misuse them. The steam engine and penicillin are generally viewed as beneficial inventions with a few unfavorable consequences, but weapons of mass destruction are more often viewed as primarily harmful. In the free market, inventors respond mostly to demands from people with strong purchasing power, and ignore the weaker signals from people with ethical concerns or weak purchasing power. Inventors can serve the needs of the poor and powerless only if there is a market demand created by governments and nongovernment organizations.

1.3.1 Transforming Work

When Adam and Eve were banished from the Garden of Eden, they were told that "By the sweat of your face you shall eat bread." Since the beginning of time, mankind has had to labor to produce the necessities of life. Human history took great leaps forward when outstanding inventions appeared to expand our capabilities so we could produce results previously thought to be impossible. However, most inventions have the more modest goal of making our work more efficient and productive. The productivity of our work largely determines how well we live, and how easy it is to produce the necessary and luxury goods and services for ourselves and our families. Our employment also affects our self-esteem, sense of accomplishment, purpose in life, and ability to help others.

There were a few truly outstanding inventions that so greatly expanded human capabilities that we could accomplish work that could never be done before. Several times in history, a new invention changed the way we work to make a living, and ushered in a new age in our history.

The *stone axe* was the first human invention that put us on the evolutionary path. To be human means that, simply by our ingenuity, we can supplement the gifts of nature. The first human invention appeared 2–3 million years ago in East Africa, marking the beginning of the Paleolithic Age. Humans are not the only animals that use natural objects as tools to supplement our teeth and claws, but only humans can design, manufacture, and constantly improve their numerous fabricated tools. Perhaps the first inventions of humans were clubs of wood or horn used in hunting and warfare, which have perished through the years. The stone axe is the oldest surviving man-made object, which was designed and manufactured for a function, and was continuously improved over millions of years. But the most important consequence of this invention is that humans no longer relied entirely on nature to provide useful tools, and began to supplement their insufficient inheritances by inventing their own tools. The stone axe is really the father of all inventions.

Before *fire* was tamed, humans had to live in warm climates and work only by daylight. Their diet consisted of easily digestible fruits and nuts, and they had difficulties with uncooked cereal grains and tough meat. Fire was tamed some 500,000 years ago, with the immediate benefit of providing heat to keep humans warm in winter, light to see and work at night, and a weapon to scare away ferocious animals. Fire also led later to many other wonderful inventions, including cooking for improved flavor and digestibility, making durable pottery, and creating metallurgy, which in turn led to the Bronze and Iron Ages (3300 and 1200 BCE in the Middle East).

Before the invention of *agriculture*, the primary human diet was obtained by gathering plants, hunting and fishing, and scavenging dead animals. This often meant a nomadic life with no fixed residence, as the availability of food was seasonal so people followed warmth and rainfall favorable to plant growth and animal grazing. Since wanderers have no place to store food for long periods of time, the bleak time in winter before the next growing season could mean hardship and starvation. About 10,000 years ago in the Fertile Crescent and Mesopotamia, agriculture appeared for the first time in the human world, which ushered in the Neolithic Age. The Agricultural Revolution introduced a method of food production far more abundant and dependable than hunting and gathering; it led to better nutrition and health, an explosive population increase, and it allowed people to abandon the nomadic life by settling down in fixed houses and villages. Agriculture became the principal source of wealth and power for the next 10,000 years. When farming became extensive on land far away from rivers and springs, artificial irrigation became necessary to feed the distant farmlands. A network of irrigation canals and ditches required organization and leadership, and led to hierarchy and government.

Before *writing* was invented, our knowledge about ancient people was based on their bones and the objects that they made. Writing began as a means of keeping track of inventories of grains and beer, and of contracts and promises. Recorded human history began in Sumer around 3500 BCE when people wrote down their histories and stories, their laws and religions, and their communications to each other. The written record is more accurate and detailed than the oral tradition of passing stories from one person to another. The earliest civilizations are known to us because we have the written records of Gilgamesh, the Code of Hammurabi, and the Bible. This led to the beginning of books and libraries, and the accumulation of human knowledge and technologies, so that each educated person can learn from the storehouse of experiences of the past. Isaac Newton said that he could see very far because he was riding on the shoulders of giants.

Energy and power are required for construction, for manufacturing, and for transportation. Initially, we learned to supplement human power with animal power. Much later, we harnessed wind power with windmills and water power with water wheels to grind corn. The coming of the *steam engine* in the 1780s was based on combustion and heat, which gave us almost unlimited power, and led to textile mills, steamships, and railroad locomotives. Since the Industrial Revolution, manufacturing became the principal source of wealth and power in the last two centuries, and led to mass migrations of people from the countryside to cities where the factories were located. Large-scale transportation and trade between continents became practical, for commodities as well as luxuries, and each region on earth could choose to work only in some specialized areas, and export the surplus to trade for other necessities.

The *Information Revolution* involved the convergence of many information technologies in telecommunications, computers, and the Internet. This led to a globalization of information, which made it possible to access any information from networks of libraries and databases, and to send messages to other people. In manufacturing, it is possible to unbundle a complex task into components that can be made in different parts of the world, and then transport and assemble the parts at one place. This outsourcing also applies to many service activities, such as the reading and diagnosis of X-ray photos by physicians, and the reservation of airplane tickets by clerks in remote locations such as India. It is no longer necessary for an educated person to leave her or his country to take up residence in another country in order to participate in high paying and satisfying careers. These are all profound changes brought about by inventions and technologies, affecting how we make a living, how well we live, and how our society is organized.

Years ago	Invention	Transformation
2,000,000	Stone axe	Human progress
500,000	Fire	Migration to Asia and Europe, cooking, pottery, bronze, iron
10,000	Agriculture	Secure abundant food, villages, population and density increase
3,500	Writing	Record keeping, history, documents, communication, trade, contract
250	Steam engine	Textile mills, steamship, railroad
20	Information revolution	Information access, analysis, storage, communications, globalization

For a given state of technology, a wilderness area may be regarded as barren and useless, but inventions can create new resources out of the wilderness. Early men in East Africa looked at their forests and grasslands and recognized food items in fruits, nuts, small animals, and decaying carcasses; but the rest of their world was not edible to them. Then came the stone axes which enabled them to move into the ecological niche of lions as they could now cut up meat from fresh carcasses, of hyenas as they now had the tools to crush bones to extract bone marrows, and of warthogs as they were now able to dig for roots. Fire enabled humans to cook and soften grains, so that they expanded their diet into the niche of horses and cattle for grain. Fire also enabled the conversion of clay into ceramic material for food and containers, as well as the extraction of ores into metals for tools and weapons.

Fertilizers are essential for the growth of food, and there is a limited supply in nature. It was clear by 1900 that the earth could not provide food for much more than 1.5 billion people, as there was a limit to naturally available fixed nitrogen for the growth of plants. Fritz Haber and Carl Bosch changed all that by converting water, air, and energy into synthetic ammonia, so that we now have enough fertilizers to support more than 6.5 billion people. The burning Arabian Desert is one of the most barren places on earth, but oil drilling changed it into one of the wealthiest communities on earth. Flat low land is ideal for growing rice in flooded paddies, but not the mountainous regions of Asia. New flat lands were created by the construction of terrace farms that march up the steep mountains. Holland did not have enough land to support its growing population, so they turned to the sea, and expanded agricultural territory and living space with landfill in areas of the North Sea.

Inventions in technologies for work have made labor much more productive and less onerous, and produced higher quality goods and services. When a farm tractor can plow land 10 times faster than a horse can, the farmer can cultivate much more land and become much richer, as well as have time left over for recreation and leisure. When the Watt steam engine required much less coal than the Newcomen engine, the coal that was not wasted could then be used for other valuable tasks.

Our ancestors in the Paleolithic Age lived in isolated communities, which may be comparable to the modern-day aborigines in New Guinea. Each tribe had to be totally self-sufficient, and live entirely by the local resources. Small bands of hunter–gatherers tended to be nonhierarchical and egalitarian, except for the sexual division of labor where men do most of the hunting, and women do most of the gathering. When the stone axe became widely used, some bands may have had the luxury of a part-time artisan who made and repaired stone axes for others in return for a share of successful hunting and gathering expeditions. When the superior quality of stones at distant quarries became known, the new occupations of transportation and trade would have become involved in acquiring these stones. When agriculture created sufficient food surplus, there was enough to support specialists in tool making, health care, trade, priesthood, art, war, and leadership. Since the copper and tin ores were seldom found locally, the Bronze Age brought even more specialization in the transportation of ores and the fabrication of tools and weapons. Today in villages and small towns with a low population density, there is enough demand to support specialized health care providers and doctors; in small cities, the health providers can specialize further to internal medicine and surgery; and in a great metropolis, the surgeons can specialize even further into brain surgery and plastic surgery. The diversity of occupations increases with market size; when two communities trade, the effective market size is increased, as is occupational diversity. In the modern world, we can all be specialists who make or do a few things very well, and buy everything else.

The gainful occupations of the modern world are traditionally divided into three groups:

(1) *Primary Activities.* Farming, forestry, fishing, hunting, mineral extraction.

(2) *Secondary Activities.* Manufacturing of goods, construction, public utilities.

(3) *Tertiary Activities.* Trade, transportation, information, finance, insurance, real estate, education, health, art, entertainment, recreation, restaurant, hotel, government.

In the history of more developed nations, there was a steady shift from agriculture to industry and then to services, together with enormous increases in productivity and the standard of living. This pattern changed for developing nations: when the low productivity farm labor poured into cities for industry jobs, their productivity increased as well as the economy of the entire society. The following table lists the wealth of Ethiopia, Indonesia, Brazil, and United States today, together with their labor distribution among agriculture, industry, and services. The values of gross national product per capita ($GNP/capita) are according to the official rates of currency exchange, and the $GNP/capita purchasing power parity (PPP) are based on purchasing power, which is more relevant for buying local products and services. The poor nations mostly work on low efficiency farms; it is evident that improvements in wealth involve the shift of occupation from agriculture to industry and services.

	$GNP/capita	$GNP/capita PPP	Labor in agriculture (%)		Labor in industry (%)		Labor in services (%)	
			M	F	M	F	M	F
Ethiopia	204	630	84	76	5	8	10	18
Indonesia	1,420	3,310	43	41	20	15	37	44
Brazil	8,515	8,700	25	16	27	13	48	71
USA	44,710	44,070	2	1	30	10	68	90

Since these four nations have different climates and resources, it would be more instructive to consider the influence of occupation shifts within a single country. The relative productivity of these three sectors in China in 2007 can be seen in the following table. Since 43% of the labor in agriculture produced only 11% of the GNP, but 25% of the labor in industry produced 49% of wealth, clearly everyone gained when some of the farm labor migrated to the cities to enter industry or services. This migration will continue to be profitable for many more years to come, till the percentage of labor involved is roughly the same as the % GNP generated for all sectors.

	Agriculture	Industry	Services
% GNP generated	11	49	40
% Labor involved	43	25	32
Relative productivity	0.26	1.94	1.25

The new technologies of information and transportation are helping to narrow the gap between rich and poor nations. When world trade became more liberal, and shipping by ocean liners and air cargo planes became more affordable, the high-income nations began to outsource much of its low-tech manufacturing overseas to nations with lower wages, and to keep only the most proprietary and critical manufacturing at home. The world GNP is 48.7 trillion dollars and growing at 4.6% each year, but the world merchandise export is 12.1 trillion dollars and growing at 8.0% each year. Food, fuel, and ores take up 27% of merchandise export, and manufactured goods take up 73%. The United States is steadily losing low-tech manufacturing jobs, and Wal-Mart is piling up with imported low-tech goods. In the last decade, the economy of China was growing at an average rate of 10.6% per year, and India was growing at 5.9%, principally fueled by this shift of migrating surplus farm labor into more productive manufacturing and service occupations.

While goods can be outsourced, some services still require that the provider is in front of the client, such as for haircuts and baby-sitting. However, with the emergence of information technology, especially rapid and inexpensive telephone and Internet, it is now possible to outsource many service works to other countries, such as the preparation of tax returns, tutoring of school children, and examination of X-ray photos to India. Banks and financial investment firms traditionally divide their jobs into the "front office," where officers and agents talk to the investors and Wall Street analysts, and the "back office," where the staff collects information, does data analysis and makes reports. Fast and cheap telephone and Internet made it unnecessary for the back office support staff to be on site, so they can now live where they want to and still participate in high level professions and good pay. World export of services is now 7.8 trillion dollars, and growing at 7.8% each year. The major items of service export are transport, travel, insurance and finance, and information.

1.3.2 Transforming Lives

Humans were descended from East African tropical fruit eaters. We have already seen that the invention of tools enabled humans to eat the food of other animals and invade their ecological niches. An equally impressive expansion was their ability to live in the habitat of any animal, and to colonize the entire globe. Humans have proven that they can even live in research stations in the Antarctica and space stations, where no animal has ever lived before.

How do we measure the well-being of an individual, so that we can make comparisons among nations, and measure progress with the help of inventions through the years? It is easier to measure material well-being using economic purchasing power to acquire desired consumer goods such as food and clothing, and consumer services such as health care and travel. It is more difficult to quantify many intangible measures such as the pleasures of family, friends, community, freedom, justice, beauty, and truth. Besides purchasing power, individual well-being also depends on the rate of business investments on production machinery and plants; on transportation and utilities; and on government expenditure on schools, police, and national defense.

Some of the most dramatic episodes in human history took place when a large population migrated to new habitats, which were either uninhabited or home to indigenous people, which the newcomers then colonized permanently. The early hominids had developed a set of technologies to cope with life in the highland savannah of East Africa, then some of them decided to leave for other lands. Perhaps the reasons for migration were *Push* to escape dangers from human enemies in war or persecution, or from nature's wrath in disease or disaster; or *Pull* to benefit from the opportunity of better climate, health, resources, and land. The first great wave was the migration of *Homo erectus* from Africa to the Middle East, and then to Asia and Europe around 1.5 million years ago, and the second great wave was by the *Homo sapiens* out of Africa some 75,000 years ago. These were heroic journeys that required solving many problems encountered en route. It is particularly difficult to cross from one climate zone into another, which involved adaptations: dealing with unfamiliar climate and terrain, identifying food among new plants and animals, seeking shelter, finding material to make tools and weapons, and facing new enemies.

Each animal in nature is usually best adapted to one habitat or biome, where their bodies have the nature-provided tools to obtain resources and to avoid hazards. A Bengal tiger would not trade places with a Gobi camel, as neither one has the tools to cope with the swapped habitats. When the season changes, some animals migrate a great distance each year to favored habitats, such as the annual arctic tern flight from the Arctic to the Antarctic and back. The fable of the Hedgehog and the Fox describes two animals with different strategies: the single-minded hedgehog has one big idea to cope with any problem, by rolling up into a ball; but the versatile fox has many small ideas, by studying each situation and arriving at a tailored solution. Humans are the most versatile in adaptations, as the clever fox that can live anywhere.

A climate zone is defined by the parameters of temperature, rainfall, soil, vegetation, and animal life. Let us consider the Köppen climate classification system, the environment, resources, and people that live there now.

Climate	Environment	Resources	People
A. Tropical	Rainforest	Banana, yam, sugar, coconut, grass	Masai—Africa
	Monsoon	Zebra	Polynesian—Hawaii
	Savanna		
B. Dry	Steppe	Cactus, date palm	Tuareg—Sahara
	Desert	Lizard	Zuni—Arizona
			Australia Aboriginal
C. Template Warm	Broadleaf forest	Rice	China
	Long grass	Chicken, pigs	Italy
			Cherokee—SE US
D. Template Cold	Evergreen forest	Wheat, grass	Scandinavians
	Short grass	Sheep	Russian
E. Polar	Boreal forest	Lichen, moss	Eskimo
	Tundra	Reindeer	Laplander
	Ice sheet	Seal, fish	Chukchi—Siberia
F. Highland	Short grass	Potato, corn	Inca—Peru
	Ice and snow	Goat, yak	Tibetan

The *Homo habilis* (handy man) was inventor of the stone axe, and lived in East Africa in A. Tropical Climate. The *Homo erectus* (upright man) migrated from East Africa during the Early Pleistocene 2 million years ago. They journeyed first to the Middle East, and went through B. Dry and C. Template Warm zones. Possibly it was during a period of time when the Sahara was wet and supported vegetation. The journeys to Mediterranean Europe and to Java were in warm and tropical climates. Their journey and final settlement in northern China would seem very difficult without the invention of fire to keep them warm.

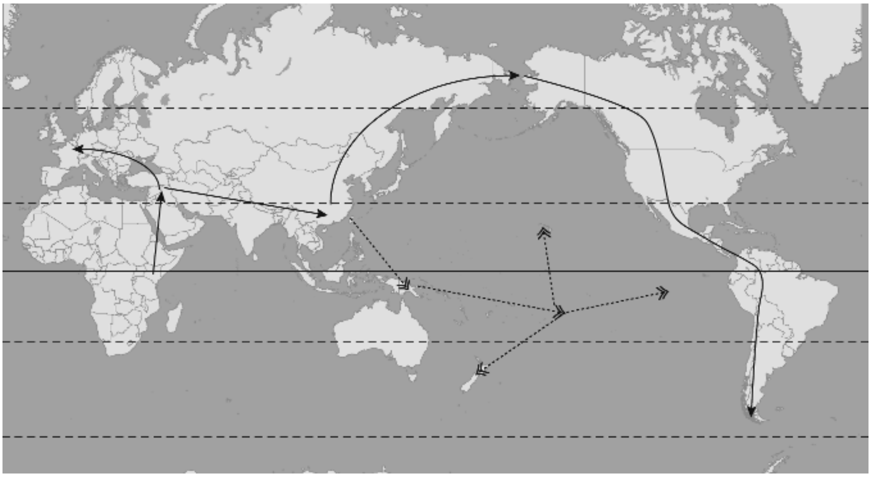

FIGURE 1.1 World human migration before history.

The modern men *Homo sapiens* originated in East Africa. That was the start of the last ice age, which lasted 60,000 years and reached its maximum 20,000 years ago. During the height of the Last Glacial Maximum, ice sheets covered North America and Western Europe, and mountain glaciers covered the Alps, Himalaya, and Andes. The frozen sheets tied up so much water that the ocean was as much as 600 ft lower than today. Land bridges were formed between Siberia and Alaska, and from Southeast Asia to Java and Borneo. The modern men traveled and colonized the Near East about 70,000 years ago, shown in Figure 1.1. These were incredible journeys of courage and resourcefulness, overcoming tremendous obstacles with very primitive tools. This audacious conquest and colonization began from the tropical grassland of Kenya. They had to cross the Red Sea either in the south near Yemen, or at the north near Suez. In either case, there were more than 1000 miles of desert before reaching the temperate grassland of the Fertile Crescent. What were their motivations to undertake such a journey, leaving comfortable grasslands to enter hostile deserts, meeting the challenge of finding food and water, shelter from the scorching sun, and avoiding new and unfamiliar dangers? How would they know that after 1200 miles of hardship, they would find temperate grassland that may be no better than their original home?

The next journey took them into the temperate forests of Europe and Asia, arriving at Southeast Asia 50,000 years ago, and Europe 40,000 years ago. Some of them turned north into the frozen taiga and tundra of Siberia before they reached the polar desert of the Bering Strait. Then they crossed over to Alaska 12,000 years ago, and went south all the way to Tierra del Fuego at the tip of South America in approximately 1500 years! In this process, they repeatedly crossed from one climate zone into another, with the need to adapt and adjust from keeping warm in the frozen lands to keeping cool in the steamy jungles, and back to frozen land again.

The conquest and colonization of Oceania by the Polynesians was completed by the year 1000, and depended totally on the inventions of the sailing canoes and celestial navigation. The Polynesians started from Southeast Asia for Fiji, and reached New Guinea (5°S), which formed their base to reach Samoa around 1600 BCE, then Tahiti (18°S) around 300 BCE, Hawaii (20°N) around 500, New Zealand (40°S) in 850, and Easter Island (27°S) between 500 and 1200. The distance from Tahiti to Hawaii is 4500 km, and they traveled in the sailing outrigger canoes that were open to wind and storms. We do not know how they navigated without charts or compasses in an alien ocean. There are not even any fixed stars in that area to serve as reference points, as Polaris is not visible south of the equator and the Southern Cross is not visible north of the equator.

These pioneers were followed by the subsequent voyages of discovery and conquest of Christopher Columbus (1492), Vasco da Gama (1497), and Magellan–Elcano (1519–1522). These later voyages were made possible by the invention and development of ships in the form of carracks and caravels that are deep ocean-going vessels with great cargo spaces to carry food and water for the journey, as well as spices to pay for the journey.

In the future, if we run out of living space on earth, there is the moon beyond as well as the planets and the cosmos. Perhaps there are life forms beyond our planet in this solar system, or out in the galaxies. There are many science fiction stories about the conquest of space, such as the "Martian Chronicles" of Isaac Asimov. Rockets and spaceships are our technology for such grand conquest and colonization, if we are desperate enough about the future of the earth to take this very risky adventure. The challenges of living on the moon or Mars would be very great indeed, but we have the tradition of 2 million years of inventions, and we are the descendants of resourceful pioneers.

What is the ideal life? The gardens of Eden and Paradise were thought of as walled orchards or gardens in simpler times, when men live off God's bounty and had no need to toil for a living. The climate would be sunny and mild, and the gardens always well watered. However, Thomas Hobbes believed that in the state of nature, human lives used to be "poor, nasty, brutish, and short." The moving description by Charles Darwin about the naked natives shivering in the frozen Tierra del Fuego would suggest that Hobbes was not far off the mark. We would like to know how our lives today compare with our ancestors 2 million years ago in East Africa. Historical comparisons are usually very qualitative, as such economic records were not a high priority among historians. A proxy is to make comparisons of the welfare among various groups of contemporary people, on their technologies and their lives.

What are the most important human needs and desires, and how do we measure the quality of life? Survival is usually the prime objective, so the most basic needs are food, clothing, and shelter, followed by health and security. When survival is no longer the issue, we can tend to more advanced and less urgent needs. How do we put together and sort out a list of economic and noneconomic needs? Abraham Maslow proposed a hierarchy that starts from the lowest level of basic needs for everyone to the highest level of self-actuation for the elite.

- *Basic Needs:* Food, drink, shelter, clothing
- *Safety:* Security, health, freedom, stability
- *Love/Belonging:* Family, friendship, community
- *Esteem:* Recognition, fame, social standing
- *Self-Actuation:* Fulfillment for prophets and saviors

Maslow suggested that after the most basic needs for survival have been satisfied, one would move up to the next level of safety and love, then to the next levels of esteem and self-actuation. In this view of sequential climbing of a pyramid, we consider love and friendship only after our stomachs are full and we are safe from wild animals. But we also know about selfless acts that put the welfare of loved ones ahead of oneself. The notion of a family budget suggests that there is actually a parallel as well as sequential distribution of attention. People with few resources would assign larger amounts on the lower levels of needs, but people with more resources could assign more to the higher levels. Inventions and technologies play a large role in satisfying the basic needs of the first level, such as food production that requires plows, fertilizers, irrigation, harvesting, and storage. As one travels up the levels, the role of technology becomes less obvious and less direct, but still very important. Fame is difficult to achieve without the printed word in books and journals, and the media of radio, television, and the Internet.

There are many methods to measure the wealth of a nation, including the GDP, the GNP, and the GNI. They are used to measure different things, but their differences are small. The official GNI of a nation in US dollars is computed by conversion of the national currency by the official currency exchange rate. An important variant is the PPP, based on the local cost of food and labor instead of the official exchange rate. The GNI is given in two different forms by *income* or how it is earned in the farms, factories, or office towers and by *expenditure* or where it is spent on food, housing, health care, and investments. The GNI per capita of the nations currently vary from a high of $68,440 in Norway to a low of $170 and $130 in Ethiopia and Congo; the PPP would compress this disparity from a high of $50,070 in Norway to a low of $630 in Ethiopia and $270 in Congo.

For an approximate idea of the relative importance of the components of the national expenditure, the percentage of US expenditure during 2000 can serve as a guide, shown in Figure 1.2. About 2/3 of US expenditures are controlled by households, 1/6 are controlled by business investments in production and administration tools and facilities, and 1/6 are controlled by government expenditures, particularly in health, security, transportation, and education.

The Human Development Index (HDI) of the United Nations is a more comprehensive measure, which rates the well-being of a group of people by three indexes: life expectancy at birth, adult literacy plus years of schooling, and standard of living. Out of 177 nations ranked in 1993, Norway was the first and Niger ranked the last, and the breakdown of a few nations in 2003 is shown in the following table.

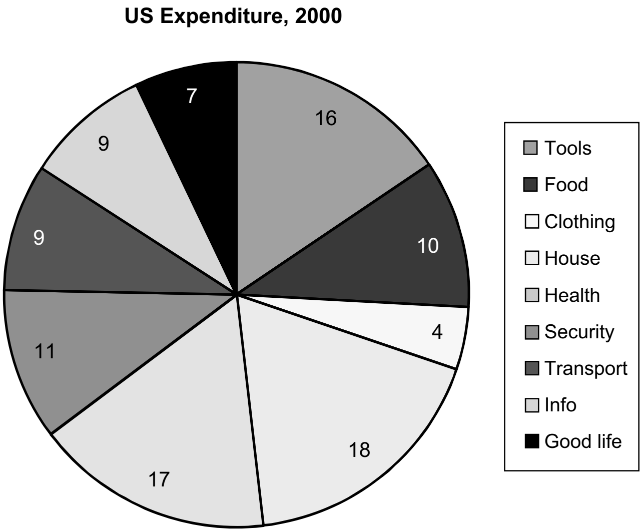

FIGURE 1.2 US National Expenditures in 2000.

Nation	HDI	Life expectancy at birth	Adult literacy (%)	School enrollment (%)	GDP (US$/cap PPP)
Norway	0.963	79.4	100.0	100	37,670
US	0.944	77.4	100.0	93	37,562
Russia	0.795	65.3	99.4	90	9,230
China	0.755	71.6	90.9	69	5,003
India	0.602	63.3	61.0	90	2,892
Niger	0.281	44.4	14.4	21	835

This table shows that the rich live longer and with better education. Between the lowest Niger and the highest Norway, the standard of living is increased 45 times, the educational opportunities are increased by a factor of 5, and the life expectancy is almost doubled. Perhaps the residents of Niger have something that those of Norway do not have, but it would be difficult to find many envious Norwegians. Many factors contribute to this disparity in the quality of life; however, inventions and the use of technologies are essential.

1.3.3 Transforming Society

The enjoyment in life of average people is better correlated with the productivity of their society than with their individual abilities and efforts. An average teacher of arithmetic in Ethiopia or Haiti has a much lower life expectancy or income than his or her counterpart in the United States or Norway, even if they all have similar training and dedication. Great civilizations have dynamic cycles of growth and expansion associated with new inventions, followed by maturity and decay. As societies become more complex, hierarchy, and inequality usually follow.

Inventions have always been an aspect of the creativity of a dynamic civilization and a prosperous society. The people of central Italy slumbered for a long time, and then awakened during the Roman Republic and Empire by making creative and triumphant solutions in organizations, sciences, inventions, arts, which led to prosperity, power, influence, admiration, and imitation. After a span of time in the sun, Italy returned to slumber and stagnation till a second awakening during the Renaissance. What is behind this transition from the static YIN to the dynamic YANG, followed by a return to YIN again? What nations are the leaders on earth today, how long have they held leadership, and how long will it be before they surrender to newcomers?

Spengler and Toynbee discussed the evolutions of great civilizations in history, such as Mesopotamia, Egypt, Greco-Roman, China, India, Arabia, and Western. They all went through periods of awakening in springtime, growth in summer, maturity in autumn, and decline in winter—measured by their creativity and influence in philosophy, religion, mathematics, art, music, and politics. Did great inventions in technology play significant roles in their evolution? According to Spengler, Western civilization began around 900, when there was an awakening in the pace of technology. The first great invention of printing by movable type was in 1454 by Johannes Gutenberg, at the beginning of summer, and the other great invention of the steam engine in 1764 by James Watt in the middle of autumn. Other inventions sparked the beginning of Western civilization, and these two great inventions were instrumental in its growth and glory.

Inventions have been an integral part of civilizations. A prosperous society has the optimism and ability to support the explorations of a few creative members, which can lead to inventions that benefit the whole society. New inventions have been the engines of growth in wealth and power, and have provided resources for contributions in the arts and sciences. The scientific contributions of Pythagoras, Archimedes, Newton, and Darwin were made by prosperous people whose lives were not totally consumed by the necessity of earning a living. All of their inventions took place during the golden age of their respective civilizations, not during the early periods of struggle with subsistence living nor during the later periods of indolence with decadence.

There are no reliable estimates of the size of human population in prehistory. It was probably stable during the long period of hunter–gatherers according to the carrying capacity of the land, but the Agricultural Revolution brought about a rapid increase. Better and more dependable nutrition led to a great improvement of health and longevity, increase in fertility and decrease in death by disease and starvation. The sedentary habit of life was also more favorable for family formation, as there was no need to carry dependent children in a nomadic lifestyle, so that the spacing between babies could be shorter and birth rates could soar.

A UN report in 2004 made estimates on the world population since the Agricultural Revolution, which showed three periods of rapid growth that occurred around 10,000 BCE, 800 BCE, and since 1800. The first and third of the growth

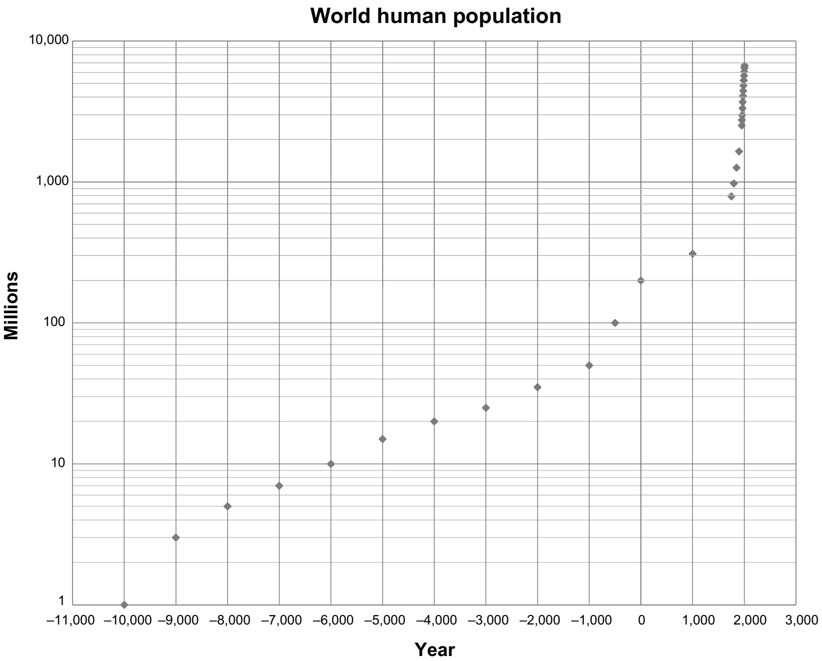

FIGURE 1.3 World population from 10,000 years ago to now.

spurts can be associated with the Agricultural and the Industrial Revolutions, shown in Figure 1.3.

The population density of the number of people per area of land is limited by the "carrying capacity" of the land. In the world today, population density varies from 2 persons/km^2 in Mongolia and Namibia, to 6500 in Hong Kong and Singapore. In the United States, population density varies from less than 0.4 persons/km^2 in Alaska, to more than 3065 in the District of Columbia. Since half the population of Alaska lives in cities such as Anchorage, the population density in the countryside is actually only 0.08 person/km^2.

In a society of hunter–gatherers, the amount of food that can be found in a given area is quite limited. Modern agricultural land in North Dakota and South Dakota currently produces enough food to feed 2800 persons/km^2. Ancient cities existed for political administration, trade, education, and culture. The Industrial Revolution accelerated the process of urbanization, so that more people relocated from the countryside to cities to do manufacturing. The highest population densities today are found in urban high-rise office towers and apartment buildings. It is impossible to live in such concentration without an efficient system of roads, mass transit, electricity, water, sewage, and elevators in high-rise towers.

Urbanization is a worldwide phenomenon. The United Nations projected that world population was 13% urban in 1900, but grew to 49% in 2005, and will increase further to 60% in 2030. The principal reason for the migration of rural populations to the cities is economic opportunity, better prospects for education, diversity of occupations, as well as diversity of consumer goods and services. When one lives on a small and isolated family farm, there are few opportunities to improve the standard of living beyond basic sustenance. Cities offer many opportunities to increase wealth, social mobility, job opportunities, education and access to health care, and quality services such as restaurants and a variety of entertainment venues. The dark side of urban life includes noise, overcrowding, crime, and social stratification. Since the prevailing wind in North America tends to blow from west to east, and the pollutants tend to move downwind, so many urban areas are divided between the good "west" neighborhoods and the bad "east" sections of town.

The advantages of free trade were explained by David Ricardo (1772–1823), due to comparative advantages in factors of production. England had a strong textile industry and India had a good supply of raw material; so when they specialized on producing what they were best suited for and traded for the rest, both nations benefited from the exchange. We are all familiar with life in small towns where the stores carry only basic necessities, and one needs to visit a bigger city in order to get specialized products, and to a metropolis for fancy luxury goods. A corollary to this theme is that trade would also increase career options and encourage job specialization. A village can barely support a single part-time health worker, and it takes a small city to support a doctor who is a general practitioner; a bigger city can support a surgeon and a clinic, and it takes a metropolis to support brain surgeons and surgery centers with the latest medical diagnostic equipment.

New inventions and technology can have long-term consequences in shifting power among groups within a society, and also among nations. In an economic activity such as sowing wheat to make bread, the intended consequence is to satisfy the hunger of the farmer and his customers; but there are also long-term unintended consequences for other parties that did not participate in this transaction, such as the society and the environment.

Some of the important tasks in our lives can be carried out by small independent units, such as gathering fruits and nuts, and growing corn and chicken. The production group may be organized around a family or a closely knit clan, where there may be little concern for rank and distribution of duties. There are other important tasks that can only be carried out by a large assembly of people, such as warfare and building an irrigation network. Such work is divided among numerous subgroups of people with specialized skills, and led by a hierarchy of leaders. Farmers on land without adequate rainfall in the growing season need irrigation from a river or oasis, which may be far away. Large-scale irrigation requires the cooperation and coordination of many people, who need organization and rulers to compel all participants to make required contributions. A group of prosperous farmers living near subsistence nomads creates the danger of invasions and pillage, such as what happened with the Mongols and the Vikings. This brought about the rise of governments to establish hydraulics and armies, and eventually the rise of kings.

An invention can have a profound impact on the relative welfare of different groups within a society. Products of a technology are sold by the producers to a group of users to enhance their lives, which can place nonusers at a relative disadvantage since they do not experience a similar enhancement. Some technologies are egalitarian, so that early users obtain a temporary advantage over later users, but equality returns after the adoption rates become substantially equal. Other technologies are exclusive, where the users have to possess special qualities that are not widely shared, so the advantage of those users may become long lasting if not permanent.

- *Exclusive technology* can be used only by the elites who have access to required resources, and have the aptitude and means to benefit from special training. Agriculture requires warmth, rainfall, and soil, which are not available for people living on high mountains and dry deserts. The invention of writing led to the formation of a class of scribes and elites, who had the necessary time and means to learn writing, and had access to books that were hand copied and kept in libraries away from the general population. This led to a division of the population into the literate lords and priests with knowledge and power, who ruled over the illiterate common people. When a technology is new, it tends to be used only by the elite to increase inequality; as the years go by and the cost keeps falling, it becomes more affordable for everyone and thereby more egalitarian. An example is the Internet use in the United States in 2009 for groups with different educational levels as shown in Figure 1.4. It shows that for those with less than a high school education, only one fourth would use the Internet; but for those with a bachelors degree or higher, 90% were users.
- *Egalitarian technology* can be used by every person as it does not require special resources, or special ability and training. The stone axe required fieldstone and fire required combustible plants, neither of which are difficult to obtain. The invention of printing made books cheaper and more easily

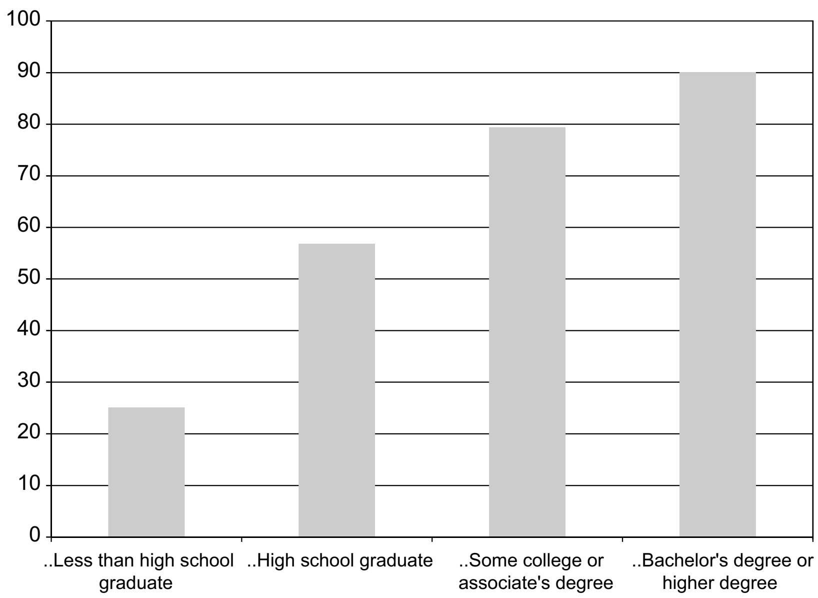

FIGURE 1.4 US Internet use by education level in 2009.

available, leading to increased literacy and decreased dominance of priests and scribes. Today, the common person can own and read books on every subject, from the most sacred scriptures and technical manuals to the tabloids. An ordinary parishioner can read the Bible without interpretation from a priest, and a student can read a classic and challenge the interpretations of a professor. Watching television also uses a technology that does not require special knowledge and education, and can be enjoyed by all.

The relative importance of the two sexes can be changed by an invention. In the days of hunter–gatherers, hunting was likely dominated by a few fit and skillful males. Meat can be more satisfying, as well as being more dangerous and difficult to acquire, which made it a more prestigious food than fruits. An invention such as the bow and arrow increased the ability and power of the hunters and helped them to be even more productive, and increased the social inequality between men and women. Conversely, gathering is more egalitarian and gives women equal status.

Lynn White proposed the theory that the stirrup for horse riding was responsible for the rise of chivalry and aristocracy in medieval history. The Greek warriors in the Iliad rode on their chariots to the sites of battles, and then jumped off to fight with spears and swords on foot. The Roman cavalry have neither stirrups on their saddles to steady their feet nor the pommel and cantle at the front and back of a saddle to prevent being thrown forward or backward, and could not deliver a lance thrust against foot soldiers without being thrown off their horses. Thus, the infantry could stand up to the cavalry.

The stirrup changed all this and kept the medieval cavalry steady on their saddles, which was augmented by their plate armor. So the mounted knights became invincible to foot soldiers, which began to diminish in importance during the time of Charlemagne. Cavalry became the main force of the army, which was expensive to maintain, and necessitated the granting of land and serfs in feudalism to ensure that the cavaliers had the means to support horses and the required armor. The castle with walls and moats also increased the power of the feudal lords over peasants, who had no means to challenge them. These inventions contributed to the rise of chivalry and feudalism, by dividing the population into aristocratic knights with stirrups and common peasants on foot.

Eventually, power shifted back to the infantry with the invention of the English longbow that decimated the French cavalry during the battles of Crecy and Poitiers during the Hundred Years' War. Then came gunpowder that made the foot soldiers with muskets the equal of the cavaliers. The cannon could rapidly throw metal and stone balls against the strongest castles to bring them down. The city walls of Constantinople withstood numerous assaults for a thousand years, but fell to the Ottoman Turkish cannons in 1493, which ended the Byzantine Empire of Eastern Rome. Gunpowder helped to end feudalism, and led to the rise of the modern age of common men.

In peacetime, a successful invention can create many winners and losers in economic and cultural wars. The first satisfied lady customers of synthetic mauve could make a fashion statement to other women, and the early users of these expensive new colorful garments included Empress Eugenie of France and Queen Victoria of England. The initial beneficiaries of this invention were the inventor, William Perkin, and his financial backers—his father and brother. The other immediate beneficiaries were the employees in his factory, the suppliers of raw material and machinery, and the textile manufacturers who had a product that their competitors did not have. The next level of winners includes the merchants who sell groceries and real estate to the primary winners, as well as the teachers of their children, the keepers of their taverns, and the tax collectors.

The immediate victims of this invention were the manufacturers of old-fashioned vegetable and mineral dyes, whose goods looked drab and unfashionable by comparison, and the envious women who did not have the means to buy mauve. As time went by, mauve became much less expensive, and other dyes were developed to displace mauve, so that almost everyone could afford colorful and inexpensive synthetic dyes. The displaced workers in old dye factories could find employment in the growing new dye industry, or move on to other occupations.

Globalization today often means moving manufacturing from developed nations to emerging nations. In the book *Winners and Losers of Globalization* by de la Dehesa (2006), and the book *The World is Flat* by Friedman (2006), it is suggested that if capital and technology can freely move, the winners and losers of globalization are as follows.

Countries	Winners	Losers
More developed countries (MDC): US, Western Europe, Japan, Australia	Consumers, capitalists, professionals, high-skilled labor	Low-skilled labor
Less developed countries (LDC): China, India	Consumers, capitalists as partners with internationals, professionals, high-skilled labor, low-skilled labor	Capitalists as independents

Consumers everywhere will benefit from a wider choice of goods and services at lower prices. The capitalists from the MDC can build factories in the LDC, sometimes in partnership with local capitalists, and employ the low-skilled labor there, which displaces the less resourceful local capitalists. The younger high-skilled labor in MDC can learn rapidly, and adjust to new job requirements with better benefits. All the low-tech manufacturing in MDC would be closed, resulting in unemployment of the MDC low skill labor. In the LDC, the most conspicuous losers are the native capitalists who remain independent. Would this trend march on without arousing contrary forces?

Jeremy Bentham concentrated on more happiness for the most people, but did not consider the important roles of fairness and justice. Is it appropriate to increase the happiness of very many and sacrifice the happiness of a few, or should they be compensated? The manufacturing process may create problems of safety and health for factory workers, and the waste streams may cause community pollution and environmental problems. Ultimately, many parameters are needed to measure the various aspects of human well-being.

The inequality of wealth or income within a society can be measured by the Gini coefficient, which measures the degree of departure of a society from perfect uniform distribution. First we rank everyone by income from the lowest to the highest. In a nation with perfect equality, the bottom 10% and the top 10% of the households both enjoy 10% of the national income; but in any real nation, the top 10% owns much more than the bottom 10%. The Lorenz curve is a graphical representation of income distribution, where the vertical axis shows the percentage (y) of total national income enjoyed by the percentage (x) of households with income equal to or up to this value, shown on the horizontal axis. For a nation with perfect equality, the Lorenz curve is the 45° line, and the Gini coefficient is 0. For a nation with perfect inequality, where one person owns all the wealth, the Gini coefficient is 100. For an actual nation, the Lorenz curve hangs below the 45° line, and the area between these two lines is proportional to the Gini coefficient. In the United States of 2000, the degree of inequality can be seen in the following table.

Families by income (%)	Wealth owned (%)
20	4.1
40	13.7
60	29.2
80	52.4
95	79.6
100	100.0

The poorest 20% of all the US families own only 4.1% of the wealth in the nation, and the next 20% own 13.7–4.1 = 9.6% of the wealth, and so on. Figure 1.5a shows the Lorenz curve of four nations. For the United States, the area between the Lorenz curve and the 45° line is 39% of the area of the triangle, so that the Gini coefficient is 39. It is also instructive to divide the families into five groups by rising income, called the quintiles. The bottom quintile is the families with incomes in the lowest 20% and the top quintile is the families with incomes in the highest 20%. Figure 1.5b shows that in the United States, the top quintile gets 46% of all the income and the bottom quintile gets 6%. Denmark is currently the most egalitarian society with a coefficient of 24.7, and Namibia is the least equal society with a value of 70.7. Even for egalitarian Denmark, the top 10% has an income 8.2 times that of the bottom 10%; in the United States the ratio is higher at 15.7 times, and in Namibia the ratio is much higher at 129 times.

Among nations on earth, there is a strong correlation between high income and low Gini coefficient, indicating that all things considered, the more developed nations tend to be more equal. Denmark has a mostly homogeneous population of race and educational attainment; Namibia has a small white minority who owns most of the material wealth, and a big black majority that lives by subsistence farming in very dry soil. However, increasing wealth does not always bring more

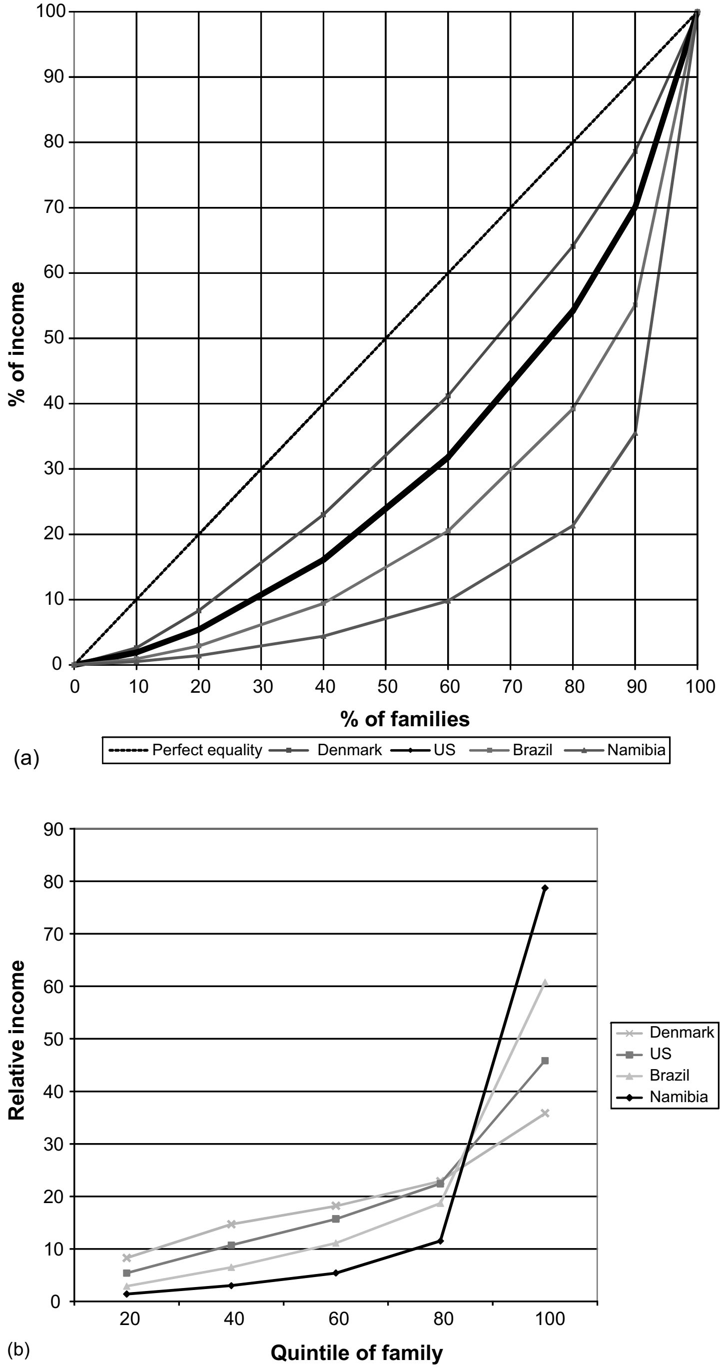

FIGURE 1.5 Gini coefficient of income inequality in four nations.

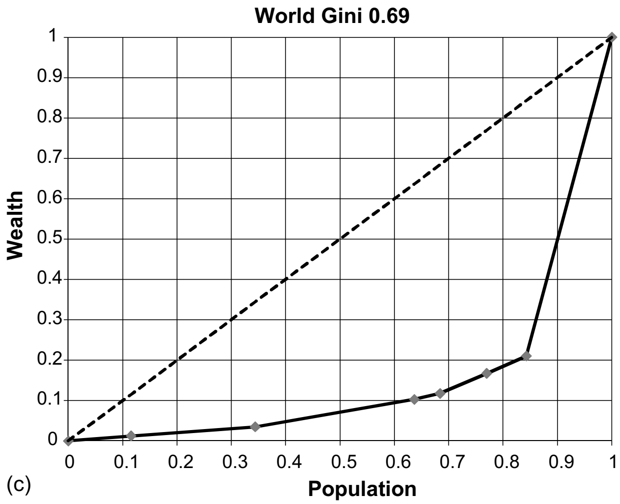

FIGURE 1.5 (*Continued*)

equality: the income of the United States has been steadily rising in the past decade, yet the value of the US Gini coefficient has also been increasing, so the United States is becoming more unequal as she becomes richer.

Besides these inequalities among families within a single nation, it is also possible to compile an international inequality comparison among nations or regions. We use the World Bank classification to divide the world into seven regions:

High Income: Australia, Germany, Japan, UK, US, Hong Kong, Saudi Arabia, and so on

Europe and Central Asia: Hungary, Russia, Turkey

Latin America: Argentina, Brazil, Mexico, Venezuela

Middle East and North Africa: Egypt, Iran, Lebanon, Libya

East Asia and Pacific: China, Indonesia, Philippines, Thailand

South Africa: India, Bangladesh, Pakistan

Sub-Sahara Africa: Congo, Ethiopia, Kenya, Namibia, South Africa

In 2006, the world population was 6,438 million, and the GNI was 45,135 billion dollars, for an average of $7,011 per person. When we prepare a Lorenz curve using these world regions as units, the result is shown in Figure 1.5c. This curve can be used to calculate the world Gini coefficient by these world regions to have a value of 69. Of course, if we break down the world regions into separate nations, and even further into individual families, the Gini coefficient would increase to much higher values.

Societies with the most extreme inequality are those who practice colonialism, imperialism, and slavery. The power of one people over another is greatly increased when one group has more powerful technologies than the other. The advent of nautical travel and navigation led to easier access to many foreign lands from Western Europe, and gunpowder plus cannons added unprecedented military power to conquer and enslave the less developed people of the world. Western Europeans created colonial empires in North and South America, Africa, India, and Australia. They deprived the Native Americans of their lands, and they captured and shipped Africans to be their slaves. In 1462, the Russians expanded their land all the way from Muscovy to Siberia and Alaska, and later into Central Asia, as they had the technology to easily overcome the tundra and nomadic people.

The conquering nation acquired a monopoly on political and military power, controlled the best jobs with high income and prestige, and retained the best living conditions. The subject people provided the raw material for manufacturing, the low-skilled labor for menial jobs, and lived in subsistence conditions and even slavery. This dominance can be relatively benign, but can also be very cruel, such as the Spartans who harassed and killed their subject people without cause.

There are many factors that lead to winning wars, particularly leadership and organization, but technology has often played a critical role. In ancient Mesopotamia and Egypt, the horse-drawn chariot was one of the most depicted images in paintings. Such chariots were superb technology that provided the top commanders with speed, the ability to observe the battle conditions, and a high platform from which to shoot arrows and throw javelins at enemies. The rapid mobility of horses often gave the less numerous nomadic archers a decided advantage in warfare over the plentiful farmers as foot soldiers. This is exemplified in the Mongol conquest from China to Eastern Europe, as they overwhelmed many nations that had much larger populations and longer histories of intellectual achievements. The Manchu conquest of China placed a small group of nomads in charge of a huge and civilized population. The Viking conquest of the more civilized states of Normandy and Sicily can be attributed to the same rapid mobility, bestowed by their dragon ships, which could be navigated through narrow rivers and sailed in broad seas. The conquistador Cortez had only 257 soldiers when he entered Mexico, but he defeated the Aztec Emperor Atahualpa's army of several hundred thousand. Cortez's superior technology consisted of guns, steel armor, and horses. The British Empire attained colonies with superior technology in rifles and cannons, transported over the ocean by ships that could enter harbors and point cannons at the palaces of rulers. The Russian conquest of Siberia and Central Asia depended principally on the Trans-Siberian railroad of 1891–1902.

It is very fortunate that there is a general world consensus that such invasion and enslavement is immoral and will not be tolerated in the world today. This enlightened view is strongest among the most advanced nations that practiced imperialism and colonialism in the past. Today the superpowers have far more terrible weapons of mass destruction, of biological warfare with deadly viruses, and of nuclear warfare with atomic and thermonuclear bombs. But as a consequence of this modern humane view, the superpowers have lost the ability to dictate their terms to the smaller and less powerful nations, as well as to pirates and terrorist groups that are not represented by governments.

1.3.4 Transforming Environment

When the human population was low and equipped with primitive tools, there was very little disturbance to nature and the environment, as people were content to live off the land and had neither the motive nor the power to do harm. As they grew in number and in power, they began to transform the environment in profound and sometimes disturbing ways. Fire gave people the power to clear large tracts of weeds and forests. Agriculture propagated the plants that are economically useful, displacing those that were less useful to humans. It became feasible to create new land by draining swamps, filling in the shallow shores of a lake or sea, and building terraces on steep hillsides, to the detriment of native plants and animals. The need for water also led to irrigation with ditches and canals, and building dams on rivers. The parallel development in animal husbandry also led to the cultivation and multiplication of economically useful species such as dogs, pigs, chickens, and cattle, and their needs displaced the natural habit of wild or unnecessary animal species—especially predators that posed a danger to humans and their possessions.

The coming of industrialization bestowed even more changes to the environment, as there were now demands for minerals as sources of metals, ceramics, and fuel. Some of the most obvious changes on earth are due to the cities which house the vastly increased human population at much higher density. Urbanization and trade also led to transportation infrastructure of roads and other pavements for urban commerce and residential needs. Often it takes many years and decades after a technology has been introduced and widely used, before serious environmental consequences are recognized, such as the ozone hole from refrigerants and global warming from burning fossil fuels. This has made people more suspicious of new inventions that may lead to unpredictable and sometimes irreversible consequences.

The human activities that have the greatest environmental impact are the heavy physical projects that manufacture goods and move them around such as agriculture, mining, construction, manufacturing, and transportation. Most of the knowledge-based service industries involve office work, and have less environmental impact per dollar produced. Consider for example the emission of CO_2 from the use of fossil fuels in generating heat and power. Low-income countries use very little energy and have low emissions per capita; many middle-income countries play a catch up game in rapid industrialization, and are very heavy in emissions per capita; and the high-income countries have moved on to service industries and outsourced a lot of manufacturing, and have returned to low emissions per capita. This rainbow curve of emission per $GDP versus income per capita is sometimes call the Kuznets curve, shown in Figure 1.6. It can be seen that low-income countries are relatively clean; but when they industrialize and become middle income, they become heavy emitters; and the high-income countries become cleaner again. It

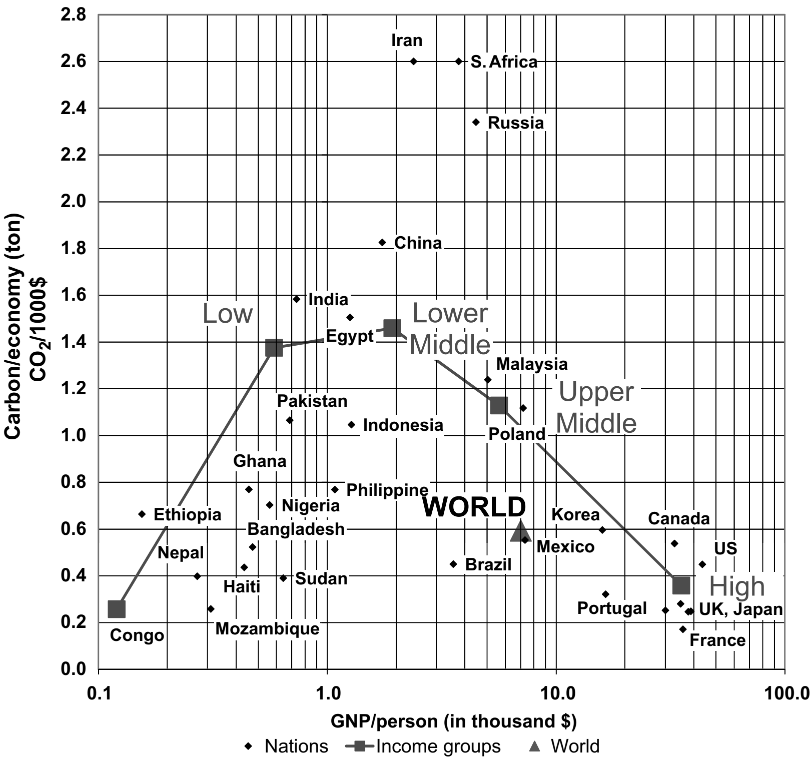

FIGURE 1.6 National carbon/GNP versus GNP/capita.

should also be remembered that the middle-income nations are the workshops for the world, and emit not only for their own consumption but also for world consumption.

Household consumption has also had a significant impact. In the opinion of the European Environmental Agency, the aspects of modern household consumption that cause the greatest problems are as follows:

- *Food and Drink.* Consumers upgrade from basic grains and vegetables to choice meats and milk.
- *Housing.* From basic shelters to spacious and power-hungry residences with heating, air conditioning, and electric appliances.
- *Personal Travel.* Commuting to work, school, leisure, shopping, visits.
- *Tourism.* Long distance travel.

Some of the greatest impacts fall on

- *Air Quality.* Urban and regional air pollution, dust, carbon monoxide, and hydrocarbons.

- *Water Quality.* Domestic water discharges, industrial and mining discharges, pollution in ponds, rivers and lakes, estuaries, drinking and groundwater contaminations.
- *Water Scarcity.* Decline in mid-latitude and in semiarid low altitude water supply, increased drought, glacial melt in the Himalayas and Andes.
- *Agricultural Productivity.* Decrease due to drought and variations in rainfall.
- *Health Risks.* Malaria in Sub-Saharan Africa, malnutrition, diarrhea, infectious diseases.
- *Ecosystems.* Harm to coral systems, biodiversity, deforestation, desertification.
- *Biodiversity.* Changing climate and disappearance of species that are unable to adapt; the practice of monoculture in agriculture incurs the risk from disease attack, which was illustrated by the Irish potato famine of 1846.
- *Nature Disaster.* Floods and droughts.
- *Climate Change.* Global warming, ozone hole, shift in rainfall pattern, ocean level rising.

An example of a society that has collapsed due to environmental degradation concerns the remote and isolated Easter Island in the Pacific Ocean, which is 3700 km from Chile and 2090 km from the Pitcairn Island. A group of Polynesians arrived around 900, and found a forest of tall trees. They divided into tribes, and the population rose to some 30,000 people. They cut down the forest to create agricultural land, and built their famous stone statues in competition with other tribes. When Dutch ships arrived in 1722, they found no trees and a much smaller and impoverished population. Anthropologists surmised that they had no wood left to sustain their civilization or to build canoes and escape from the island.

For any given invention, we cannot predict all the consequences, and we do not have a consensus on how to assess the impact, and how to balance the negative and the positive consequences. Some changes are irreversible, such as the loss of the carrier pigeons and the dodo birds. The prevailing attitude is that nature before the industrial revolution was perfect, and that any change in the environment by human intervention in any direction is considered harmful by definition. Global warming would have beneficiaries who remain silent, but would harm others who protest and try to influence the political process. A decrease in temperature would have the opposite effect, but the silent and the protesting parties would be reversed. The unattainable goal, or nirvana, would be to launch a new invention to the satisfaction of all the producers, users, and nonusers, but to leave the environment untouched, just as it was before.

REFERENCES

Adams, R. M. "Paths of Fire", Princeton University Press, Princeton, New Jersey, 1996.

Alexander, J. "Economic Geography", Prentice-Hall, Englewood Cliff, New Jersey, 1963.

Asimov, I. "Asimov's Chronology of Science & Discovery", HarperCollins Publishers, New York, 1989.

Ausubel, J. H. and H. E. Sladovich, editors, "Technology and Environment", National Academy Press, Washington DC, 1989.

Basalla, G. "The Evolution of Technology", Cambridge University Press, Cambridge, 1988.

"Beowulf", translated by William Alfred in "Medieval Epics", Modern Library, New York, 1963.

Billington, D. P. "The Innovators: The Engineering Pioneers who Made America Modern", John Wiley, New York, 1996.

Boesch, H. "A Geography of World Economy", John Wiley, New York, 1974.

Bogucki, P. "The Origins of Human Society", Blackwell Publishing, Malden, Massachusetts, 1999.

Boorstin, D. J. "The Republic of Technology", Harper & Row, New York, 1978.

Bugliarello, G. and D. B. Doner, editors, "The History and Philosophy of Technology", University of Illinois Press, Urbana, 1979.

Cardwell, D. "Fontana History of Technology", Fontana Press, London, 1994.

Carlisle, R. "Inventions and Discoveries: Scientific American", John Wiley, New York, 2004.

Constable, G. and B. Somerville, editors, "A Century of Innovation", Joseph Henry Press, Washington DC, 2003.

Cossons, N. editor, "Making of the Modern World", John Murray, London, 1992.

Darwin, C. "The Voyage of the Beagle", Doubleday Anchor, New York, 1962.

Daumas, M. editor, "A History of Technology and Invention", Presses Universitaires de France 1962, translated by E. Hennessy, Crown Publisher, New York, 1969.

Vol. I: The Origins of Technological Civilization.
Vol. II: The First Stages of Mechanization.
Vol. III: The Expansion of Mechanization, 1725–1960.

Sprague de Camp, L. "The Ancient Engineers: Technology and Invention from the Earliest Times to the Renaissance", Barnes & Noble Books, New York, 1960.

de la Dehesa, G. "Winners and Losers in Globalization", Blackwell Publishing, Malden, Massachusetts, 2006.

Derry, T. K. and T. I. Williams. "A Short History of Technology: From the Earliest Times to AD 1900", Dover Publications, New York, 1960.

Diamond, J. "Guns, Germs, and Steel: The Fate of Human Societies", W. W. Norton, New York, 1997.

Diamond, J. "Collapse: How Societies Choose to Fail or Succeed", Viking, New York, 2005.

Eco, U. and G. B. Zorzoli. "Picture History of Inventions: From Plough to Polaris", Macmillan, New York, 1963.

Ehrlich, P. R., A. H. Ehrlich, and J. P. Holdren. "Ecoscience: Population, Resources, Environment", W. E. Freeman and Company, San Francisco, 1977.

Evans, L. T. "Feeding the Ten Billion: Plants and Population Growth", Cambridge University Press, Cambridge, UK, 1998.

Fagles, R. Translation of "Iliad" and "Odyssey", Viking, New York, 1990, 1996.

Fellmann, J., A. Getis, and J. Getis. "Human Geography", William C. Brown, Dubuque, Iowa, 1990.

Finniston, M. editor, "Oxford Illustrated Encyclopedia of Inventions and Technology", Oxford University Press, Oxford, 1992.

Friedman, T. "The World is Flat", Farrar, Strauss and Giroux, New York, 2006.

Goudsblon, J. "Mappae Mundi: Humans and Their Habitats in a Long-Term Socio-Ecological Perspective, Myths, Maps and Models", Amsterdam University Press, Holland, 2002.

Grant, P. R. and B. R. Grant. "Evolution of Character Displacement in Darwin's Finches". *Science* 313, 224–226, 2006.

Grun, B. "The Timetables of History", Simon and Schuster, New York, 1963.

Hagen, E. E. "The Economics of Development", Richard Irwin, Homewood, Illinois, 1968.

Heilbroner, R. L. "The Worldly Philosophers: The Lives, Times, and Ideas of the Great Economic Thinkers", Simon & Schuster, New York, 1992.

Highsmith, R. M. Jr. and R. M. Northam. "World Economic Activities: A Geographic Analysis", Harcourt, Brace & World, New York, 1968.

Hodges, H. "Technology in the Ancient World", Barnes and Noble Books, New York, 1970.

Hounshell, D. A. and J. K. Smith. "Science and Corporate Strategy", Cambridge University Press, New York, 1988.

Hughes, T. F. "Human-Built World: How to Think About Technology and Culture", University of Chicago Press, Chicago, 2004.

"Human Development Report 2005", United Nations Development Program, New York, 2005.

James, I. "Remarkable Mathematicians: From Euler to von Neumann", Cambridge University Press, Cambridge, 2006.

James, P. and T. Nick. "Ancient Inventions", Ballantine Books, New York, 1995.

Kahn, H. "World Economic Development", Morrow Quill Paperbacks, New York, 1979.

Knauer, K. "Great Inventions: Geniuses and Gizmos, Innovation in Our Time", Time Inc. New York, 2003.

Kranzberg, M. and W. H. Davenport, editors, "Technology and Culture: An Anthology", Schocken Books, New York, 1972.

Leakey, R. E. "The Origin of Mankind", Basic Books, New York, 1994.

Lewin, R. "In the Age of Mankind: A Smithsonian Book of Human Evolution", Smithsonian Books, Washington DC, 1988.

Li, N. "Shi Jing 诗经" (in Chinese) Da Xian Publishing, Taipei, Taiwan, 1994.

Lonnrot, E. "Kalevala", translated by Keith Bosley, Oxford University Press, Oxford, 1989.

McClellan J. E. and H. Dorn. "Science and Technology in World History", Johns Hopkins University Press, Baltimore, 1999.

McNeil, I. editor, "An Encyclopedia of the History of Technology", Routledge, London, 1990.

McQuarrie, D. A. and P. A. Rock. "General Chemistry", W. H. Freeman, New York, 1987.

Mellinger, A. D., J. D. Sachs, and J. L. Gallup. "Climate, coastal proximity, and development", in "The Oxford Handbook of Economic Geography", G. L. Clark, M. P. Feldman, and M. S. Gertler, editors, Oxford University Press, Oxford, 2000.

Messadie, G. "Great Inventions through History", Chambers, Edinburgh, 1988.

Misa, T. "From Leonardo to the Internet", Johns Hopkins University Press, Baltimore, 2004.

Mitchell, S. "Gilgamesh: A New English Translation", Free Press, New York, 2004.

Needham, J. "Science and Civilisation in China", Cambridge University Press, 1954.
Vol. I: Introductory Orientations.
Vol. II: History of Scientific Thoughts.

Vol. III: Mathematics and the Sciences of Heaven and Earth.
Vol. IV: Physics and Physical Technology, 3 parts.
Vol. V: Chemistry and Chemical Technology, 13 parts.
Vol. VI: Biology and Biological Technology, 6 parts.
Vol. VII: Language and Logic, 2 parts.

Nicolaou, K. C. and T. Montagnon. "Molecules that Changed the World", Wiley-VCH, Weinheim, Germany, 2008.

OECD Factbook 2009. "Economic, Environmental and Social Statistics", OECD Publishing, 2009. www.oecd.org/publishing

Ostlick, V. J. and D. J. Bord. "Inquiry into Physics", West Publishing, Minneapolis, 1995.

Pacey, A. "Technology in World Civilization: A Thousand-Year History", Basil Blackwell, Oxford, UK, 1990.

Peel, M. C., B. L. Finlayson, and T. A. McMahon. "Updated world map of the Koppen-Geiger climate classification". *Hydrology and Earth System Sciences* 11, 1633–1644, 2007.

Perpillou, A. V. "Human Geography", translated by E. D. Laborde. Longmans, London, 1966.

Polenske, K. R. editor, "The Economic Geography of Innovation", Cambridge University Press, 2007.

Schon, D. A. "Technology and Change: The Impact of Invention and Innovation on American Social and Economic Development", Dell Publishing, New York, 1967.

Schumpeter, J. A. "The Theory of Economic Development", Harvard University Press, Cambridge, Massachusetts, 1934.

Singer, C. et al., editors, "A History of Technology", Clarendon Press, 1954.
Vol. 1: From Earliest Times to Fall of Ancient Empires.
Vol. 2: Mediterranean Civilizations, Middle Ages, 700 BC to 1500 AD.
Vol. 3: From the Renaissance to the Industrial Revolution, 1500 to 1750.
Vol. 4: The Industrial Revolution, 1750 to 1850.
Vol. 5: The Late Nineteenth Century, 1850 to 1900.
Vols. 6–7: The Twentieth Century, 1900 to 1950.

Song, Y.-X. "Tian Gong Kai Wu: Chinese Technology in the Seventeenth Century", translated by E-tu Zen Sun and Shiou-chuan Sun. Pennsylvania State University Press, University Park and London, 1966.

Spengler, O. "The Decline of the West", Vol. 1: Form and Actuality, Vol. 2: Perspectives of World-History, 1922, translated by C. F. Atkinson, Alfred A. Knopf, New York, 1928.

"Statistical Abstract of the US", US Census Bureau, Washington DC, 2007.

Strahler, A. N. and A. H. Strahler. "Elements of Physical Geology", John Wiley, New York, 1989.

Thornton, A. and K. McAuliffe, "Teaching in World Meerkats". *Science* 313, 227–229, 2006.

Tignor, R., J. Adelman, S. Aron, S. Kotkin, S. Marchand, G. Prakash, and M. Tsin. "Worlds Together, Worlds Apart", W. W. Norton, New York, 2002.

Toynbee, A. "A Study of History", Oxford University Press, London and New York, 1947.

Travers, Bridget, editor, "World of Invention: history's most significant inventions and the people behind them", Gale Research, Detroit, 1994.

Tybout, R. A. editor, "Economics of Research and Development", Ohio State University Press, Columbus, 1965.

United Nations Development Programme, “Human Development Report”, New York, 2007.

Waley, A., translator “Shih Ching: The Book of Songs”, Grove Press, New York, 1996.

White, A., P. Handler, and E. L. Smith. “Principles of Biochemistry”, McGraw-Hill, New York, 1964.

White, L. T. “Medieval Technology and Social Change”, Oxford University Press, London and New York, 1963.

Wiener, N. “Invention: The Care and Feeding of Ideas”, MIT Press, Cambridge, Massachusetts, 1993.

Williams, T. I. “A History of Invention: From Stone Axes to Silicon Chips”, Checkmark Books, New York, 2000.

“World Development Indicators”, The World Bank, Washington, DC, 2008.

Web Sources

Nobel Foundation, http:\\www.nobelmuseum.org