

## Chapter 4

### **Natural Resources, Technology and Institutions: A Historical Perspective**

What are the driving forces of human history? What is the future of human society? Mainstream economists believe that “the performance of an economy is dependent upon its organizational structure” (North, 1981, p. 90). The gradual development of technology and increase of human population in the past ten thousand years is often interpreted as the gradual improvement of institutional structures. From this understanding, human societies will or at least would become more prosperous in the future as human institutions keep on improving. From this perspective, natural resources are not essential in economics.

Mainstream economists argued that the improvement of technology will reduce the overall consumption of resources and hence technology can substitute resources. Recently, Arrow et al. (2004) did an empirical work to conclude that “genuine investment was positive in all the rich nations of the world and in many of the poorer nations as well” (p. 160). This means that the current living standard at rich countries is sustainable, although the authors conceded that natural capital may be under priced.

Jevons, however, pointed out long ago in *The Coal Question* that, “It is wholly a confusion of ideas to suppose that the economic use of fuel is equivalent to a diminished consumption. The very contrary is the truth.” (Jevons, 1965(1865), p. 140) In the last several hundred years, the consumption of energy has increased tremendously while energy conversion has become more efficient overtime (Smil, 2003). If the

consumption level of natural resources is higher than what the nature can regenerate, mostly by energy from the sun, then this consumption level is unsustainable. Historically, all the high consumption societies collapsed because of the depletion of natural resources. When natural resources are depleted, the accumulated technology and human capital, which are really means to utilize natural resources, lose their value as well.

North noted that neoclassical economics was unable to explain the dynamics of change of the human history:

Neoclassical economics applied to economic development or economic history may account very well for the performance of an economy at a moment of time or, with comparative statistics, contrasts in the performance of an economy over time; but it does not and cannot explain the dynamics of change. (North, 1981, p. 57)

In this chapter we will show how the new theory provides a simple and coherent understanding of the co-evolution of natural resources, technology and human institutions. This theory also provides a simple description of the process of biological evolution, which includes the evolution of human societies as a special case. Finally, we will offer a detailed analysis of the process of industrialization in the last several hundred years to show this theory provides a very coherent understanding of the process. This analysis unequivocally indicates that the current high level of consumption is unsustainable.

#### **4.1. Dynamics of Change in Human Civilization**

We often associated many changes in human civilization as progress or setback. But they can be more precisely described as the changes of systems with different levels of fixed cost and variable costs. The beginning of civilization is often identified with the transformation from gathering/hunting to agriculture. We can compare agriculture and gathering activities as an example.

Gathering only needs working at harvesting time. Agriculture, however, needs working in the whole process from planting to harvesting. Hence, agriculture activity is of higher fixed costs than gathering of wild grains and fruits. Agriculture activities, as higher fixed cost systems than gathering activities, also generate higher density of resources, which support higher density of population and make

agriculture societies more powerful than gathering societies. Agriculture societies, therefore, have the incentive and power to take more land, by force if necessary, and convert it into agricultural use. The major part of human civilization is the process of expansion of agricultural activity (Diamond, 1997).

While the high concentration of resources in an agriculture society enables itself to expand, it will also attract looting from outsiders. Only when military capability of a society is strong enough related to its neighbors, agriculture becomes possible.

Therefore agriculture activities are intrinsically linked to military activities and the use of violence. Among all human activities, the application of violence often offers the highest returns. So the military industry was developed very early and like most other industries without anti-trust constraints, achieved regional monopolies in most places. Each unit of the monopoly on violence is a state. A monopoly on violence provides a more stable social environment than a free market of violence (Diamond, 1997). More equal opportunity to conduct violence is conducive to the creation of anarchy and chaos. From Formula (3.5), systems with lower uncertainty have lower variable cost in production and transaction. So state as in institutional structure is very competitive and gradually replaces all other forms of social systems as the most important form of social institutions.

Since all economic activities are ultimately regulated by the states, the history of economic development is largely shaped by the evolution of the structures of the states, which in turn is largely shaped by the development of military organizations and military technologies. (North, 1981) Better military technologies are often more expensive and better military organizations often need longer time of training, which means that the development of military capabilities is a process toward higher fixed cost, which requires the support of higher level of resource abundance and larger market size.

Historically, the emergence of new military technologies is generally associated with the new technologies on basic materials or energy use. The progress of technology is often marked by the increase of energy demand. Therefore, the emergences of new military technologies, which require higher fixed cost, often cause financial difficulties for the states (North, 1981). Higher fixed cost systems require bigger market to sustain itself. So the emergence of new military technologies, by changing the cost structure of states, makes the existing political units unstable. At the

same time, higher fixed cost systems earn higher rates of return in larger markets. When market size is large, it pays to maintain costly social structures with well defined property right that enable them to build up human and physical capital and to reduce uncertainty in exchanges. These states enjoy lower variable costs in various economic activities. They tend to expand to achieve even greater economies of scale and accumulate great wealth in the process. The stage of expansion of the empires is often associated with rising living standard and greater political freedom, at least for the citizens of the empires. This type of periods can easily be classified as progress. However, most of these wealthy states eventually collapsed. Since most theories about history and economics are intrinsically progressive, the explanations for the collapses of highly developed societies are often very colorful and imaginative. However, from a physical, or a natural resource based theory, understanding collapses becomes very simple and straightforward.

First, wealthy states are often the results of the development of new technologies with higher fixed costs, which require more resources or low entropy to sustain themselves. Economic development is largely determined by the amount of low entropy that human beings can extract from the natural environment. The agricultural revolution is a transformation of food production from collecting grains or fruits in the wild to actively managing the extraction of large quantities of low entropy from the sun through certain plants in highly concentrated manner. The industrial revolution is a transformation from collecting low entropy from living organisms to the development of technologies that systematically utilize the deposits of biological low entropy, like petroleum and coal. Biological low entropy that was deposited over hundreds of millions of years is transformed for use by human societies over the last several hundreds years. This development forms the foundation of the economic prosperity many the world over have enjoyed in recent times. Each step of progress is a step toward higher fixed cost system, which requires more resource to sustain itself. Many believe that ultimately natural resources are practically infinite. Although this could be true, there is no logical certainty that a scientific breakthrough will always occur in time to provide new ways to utilize resources when the prevailing ways of resource development and use no longer sustain the existing social structures and life styles. Historical evidence shows that

most highly developed societies collapsed before they could find new ways to utilize resources.

Mainstream economists argue that today's capital investment will always benefit future for accumulated human capital can substitute natural capital (Samuelson and Nordhaus, 1998, p. 328). However, the accumulated capital, including knowledge capital, is geared toward the current level of energy consumption and other natural conditions. If these conditions change, the assets could become liability. For example, highways can facilitate rapid movements of goods in an era of cheap fuels. However, if cheap energy supplies exhaust in the future, highways, which take vast amount of land, cannot be reverted to agriculture land easily. So today's investment could harm future's sustainable economic environment. In fact, in most sites of early civilizations, once rich and productive areas have been turned into desolate regions through over exploitation (Tainter, 1988; Ponting, 1991).

While over exploitation of natural resources is often thought to be caused by some specific mistakes, it is an intrinsic consequence from competitive pressure. If a community can develop methods to extract more natural resources faster than its neighbors, it will become stronger and gain ability to take over its neighbors resources. So competitiveness is intrinsically incompatible with sustainability.

Some of societies that Diamond (2005) described as success stories did manage to maintain sustainable lifestyle by restricting energy consumption. It will be helpful to compare the paths of development of two island states, Japan and Britain. As noted by Diamond (2005), Japan maintained a sustainable lifestyle. It even abolished the use of firearms, which require tremendous amount of energy in their manufacturing and use. By contrast, Britain actively developed its industry, with the result of complete deforestation (Jevons, 1965). Because of the unsustainability of its ecological environment, Britain adopted emigration as a systematic way to reduce ecological pressure, which was made possible with its superior military power (Colinvaux, 1980). As a result, Britain colonized North America and many other places to become the largest empire in human history. On the other hand, the Tokugawa-era Japan, being low energy intensive, was quickly defeated by America, a descendent of British Empire, which utilized high energy intensive weapons. Soon after an American fleet under Commodore Perry forced Japan to open its ports, Japan swiftly abandoned its policy to maintain a sustainable lifestyle. It quickly modernize itself with high energy intensive industries

and start conquering neighboring countries for land and other natural resources to satisfy the increasing demand for an expanding economy. This comparison explains why the policy of sustainability cannot be sustained under free competition. The subtitle of Diamond's new book is "How societies choose to fail or succeed". However, the reality is more subtle. A society that is succeeded in maintaining a sustainable lifestyle will eventually be failed by a society that is more aggressive and adventurous in developing high energy consuming technologies.

Second, economic development is usually achieved by more concentration of resources or wealth. For example, compared with grains in the wild, grains of cultivated plants are much more concentrated, which provides great incentive for looting. The concentration of wealth makes it necessary and profitable to create and enforce property rights of exclusion. At the same time, the concentration of wealth by only a small number of people or states increases the incentives for others to extract wealth from them. Externally, as the wealth of a state accumulates, it becomes more and more profitable for other states to extract wealth from it. Internally, as the level of wealth increases, the demand of redistribution increases as well. Most wealthy states evolve into a system to provide safety net for the poor to reduce this incentive. The decline of the Roman Empire offers a classical example. "The prospering economy faces ever-growing costs of either bribing the invaders or making increased military expenditures. ... Not only were larger and larger payments in gold made to barbarian groups to bribe them not to invade, but the expenses of the legions rose.... At the same time, Rome was feeding 120,000 of its citizens free." (North, 1981, p. 115, 122) In a word, the cost of maintaining a wealthy system increases with the level of wealth.

Third, the accumulation of wealth increases the size of market. It encourages higher fixed cost investment, which is mainly achieved through division of labor and specialization of knowledge. While specialization increases the depth of knowledge of a person, it also reduces the breadth of knowledge and makes one less able to determine the value of others' work, which increases uncertainty in exchanges and hence increases transaction costs (Barzel, 1982; Wallis and North, 1986). Highly complex formal and informal constraints are developed to reduce uncertainty and transaction costs (North, 1990). But the constraints often restrict the path of future development of the system as well and make it less responsive to changes in the environment.

Human history demonstrates that social systems become more and more sensitive to uncertainties when the level of fixed costs and living standards increase. In the end, exhaustion of natural resources or changes in the environment sparked the inevitable decline of the old systems. Frequently, this dynamics was often accompanied by the rise of simpler structured and lower fixed costs systems on the periphery (Colinvaux, 1980; Tainter, 1988).

Along with a repeated cycle of rise and fall of states and civilizations, the higher fixed cost systems, with greater scale economies, gradually diffuse and replace the lower fixed cost systems. But will this trend last forever? Will human societies ever evolve to an optimal equilibrium state?

All living organisms are characterized by the struggle to extract low entropy from the environment. Since biological data contain much richer samples over a much longer time horizon than data on the human species, in the next section, we will investigate the general patterns in biological evolution in order to gain deeper insights into the evolution of human societies.

#### **4.2. General Patterns in Biological Evolution**

Biological species are sometimes classified, according to their relative level of fixed and variable costs, into two categories, the *r*-strategists and the *K*-strategists. Organisms with low fixed costs are termed *r*-strategists. They are usually of small size, produce abundant offspring and invest very little in each one. They are the species that prosper in a volatile environment for low fixed costs make them flexible. But they cannot compete well with other species in a stable environment for their marginal costs are high. In contrast, fixed costs are high for the *K*-strategists. They are usually large in size, produce fewer offspring but invest much more in each one. They are conservative species that are able to out-compete the *r*-strategists in stable environments, for their marginal costs are low. But they cannot adjust quickly when environment changes. Between the extreme *r*-strategists such as bacteria and the extreme *K*-strategists such as elephants, there lies the *r* and *K* continuum (MacArthur and Wilson, 1967).

Over geologic time, stable periods with relatively uniform environment were punctuated with sudden changes from time to time, such as a huge asteroid hitting the earth or the quick emergence of a

dominant species, such as human beings. During short periods of volatile change, large size *K*-strategy species are more prone to extinction since it is more difficult for the high fixed cost systems to adjust to the changing environment. Specifically there are three reasons. First, large species need more resources to survive and are often more severely affected by changes in the environment (Withers, 1992; Gould, 1996). Second, large species often contain big concentration of low entropy sources and become the prime targets of other species. For example, improvement in the hunting skills of human beings quickly leads to the extinction of most large mammal species. Third, large species usually have more complex structures than small species, which make it more difficult for large species to develop variations that are well coordinated internally. So large species usually have much lower genetic diversity than small species. For example, two species of fruit flies may only have about 25 percent of their DNA sequences in common while humans and chimpanzees have over 98 percent in common, even though they belong to different genera (Stebbins, 1982). There are more than five hundred species of fruit flies in Hawaii (Stebbins, 1982). But there is only one species in the genus *Homo*. The ultimate in genetic diversity and reproductive speed can be found in micro-organisms, such as bacteria (Margulis, 1998). This lack of genetic diversity among large species makes them much more vulnerable to sudden environmental changes. The mass extinction of species, especially the dominant species, during periods of volatile environmental changes, clears the ground for a new round of evolutionary competition. During long periods of relative stability, the small size and less specialized *r*-strategy species tend to branch into new species. Among these new species, those larger or more specialized, which incur higher fixed costs but are more efficient with lower marginal costs, have a competitive advantage in a stable environment and gradually dominate the ecosystem (Brown and Maurer, 1986; Colinvaux, 1986; Gould and Eldredge, 1993).

Simpson (1944) was the first biologist to apply careful statistical methods for interpreting pattern of evolution (Stebbins, 1982). He summarized his findings as the following:

Liability to extinction tends to be directly proportional to rate of evolution. Bradytelic (*slow evolving*) lines are almost immortal. The majority of tachytelic (*fast evolving*) lines quickly become extinct and those that survive cease to be tachytelic (*fast evolving*). ...When

related phyla die out in the order of their rates of evolution or in the reverse order of their times of origin, it follows that this order is also usually that of degrees of specialization and that more specialized phyla tend to become extinct before less specialized. This phenomenon is also far from universal, but it is so common that it does deserve recognition as a rule or principle in evolutionary studies: the rule of the survival of the relatively unspecialized. (Simpson, 1944, p. 143)

The statistical results show that the fast evolving and highly specialized species, which are often more efficient and tend to dominate ecological systems, are more prone to extinction than the slow evolving and unspecialized species, which are less efficient, less competitive but more flexible.

Biologists have not found a universally applicable measure of fitness. (Stearns, 1992) From the analytical thermodynamic theory, such measure doesn't exist. Our analysis shows that the main theme of economic and biological evolution is the tradeoff between competitiveness of high fixed cost systems in a stable and resource rich environment and flexibility of low fixed cost systems in a volatile or resource poor environment. Since there is no dominant strategy in all environments, the beautiful and diverse ecological system does not reach an equilibrium state, even after four billion years of biological evolution. For the same reason, economic organizations and systems will not converge to an equilibrium state.

The tradeoff in performance of organic systems ultimately rests on the tradeoff in performance of inorganic systems, which Wiener observed more than fifty years ago:

While the prediction apparatus which we had at first designed could be made to anticipate an extremely smooth curve to any desired degree of approximation, this refinement of behavior was always attained at the cost of an increasing sensitivity. The better the apparatus was for smooth waves, the more it would be set into oscillation by small departures from smoothness, and the longer it would be before such oscillations would die out. Thus the good prediction of a smooth wave seemed to require a more delicate and sensitive apparatus than the best possible prediction of a rough curve, and the choice of the particular apparatus to be used in a specific case

was dependent on the statistical nature of the phenomenon to be predicted. (Wiener, 1948, p. 9)

Wiener believed that the problems “centered not around the technique of electrical engineering but around the much more fundamental notion of the message, whether this should be transmitted by electrical, mechanical, or nervous means” and thought they had something in common with Heisenberg’s Principle of Uncertainty, which itself is a tradeoff between two factors.

The following passage from Atkins (1995) may shed further light about some basic properties of biological and social evolution:

The region of sulfur was also explored by nature --- in nature’s serendipitous, purposeless, but effective way --- in an early investigation of the opportunities for life. Nature discovered that in some respects hydrogen sulfide ( $H_2S$ ), the analog of water ( $H_2O$ ), can be used by organisms in much the same way as water is used in the process of photosynthesis --- as a source of hydrogen. The great difference to note is that when hydrogen is removed from a water molecule by a green plant, the excrement is gaseous oxygen, which then mingles with the globally distributed atmosphere. However, when hydrogen is removed from hydrogen sulfide in the interior of a bacterium, the excrement is sulfur. Sulfur, being a solid, does not waft away, so the colony of organisms has to develop a mode of survival based on a gradually accumulating mound of its own sewage. We still mine those ancient mound of sulfur excrement from beneath the Gulf of Mexico. Sulfur’s northern neighbor, oxygen, turned out to be a much more viable alternative to sulfur in nature’s blind efforts to generate the transmittal and accumulation of information, and sulfur is now used only by primitive species that occupy a minor niche of nature. (Atkins, 1995, p. 22)

Several basic properties in biological and social evolution may be observed. First, technology development is usually achieved with a higher fixed cost methodology. The chemical bond between hydrogen and oxygen is stronger than the chemical bond between hydrogen and sulfur. Therefore it is more difficult to obtain hydrogen from water than from hydrogen sulfide. Human evolution is often divided into the Stone, Bronze, and Iron Ages. Each age is characterized by the ability of human

beings to utilize energy more intensively. The melting point of bronze is 232 °C and the melting point of iron is 1535 °C, which is much higher. The substitution of bronze by iron is a long-drawn process that required much higher intensity of energy use, or much higher fixed cost (Smil, 1999). Second, new technologies are often accompanied by wider diffusion of waste and can be very harmful to general community. “When hydrogen is removed from a water molecule by a green plant, the excrement is gaseous oxygen, which then mingles with the globally distributed atmosphere.” The release of oxygen as waste into the atmosphere killed most of the living organisms at that time. Early industrial sites are often built by rivers or lakes so industrial wastes are diffused to wider communities while profits from products are retained by the producers. Today, the advance of telecommunication enables the production facilities with harmful side effects to be located in poor countries. Third, organisms, including human beings, often find extraordinary ways to adapt to the new environment. Initially, oxygen was deadly to most organisms. Gradually, some surviving organisms evolved mechanisms to resist the poisoning of oxygen. Eventually, oxygen, which permeates in air, becomes the vital source of energy that enables the evolution of highly mobile animals. Major evolutions in human societies, such as agriculture revolution and industrial revolution, are successful responses to resource depletions. The ability for organisms to adapt to new environment makes the timing of resource constraint highly unpredictable.

In the next section, we will apply the insights gained to understand the origin and future of our industrial civilization.

### **4.3. Industrialization: Origin and its Sustainability**

#### ***4.3.1. The origin of the Industrial Revolution***

The steady state of the Middle Ages was punctuated by the introduction of guns.

Once better confined and directed, the force of exploding gunpowder begun propelling increasingly heavier projectiles at larger distances. Manufacture of such guns begun in China just before the year 1200, and the true guns were cast in Europe only a few decades later. (Smil, 1999, p. 129)

Since China was a unified country and Europe was comprised of many small states, the competition among European states was much more intense, which led to continuous improvement in the techniques of gun making in Europe.

The combination of more maneuverable vessels with more accurate guns (made possible by advances in the smelting of copper and iron and by the invention of gunpowder) produced an energy converter of unprecedented speed, range, and destructive power that helped to usher a new era of world history. (Smil, 1999, p. 106)

Because of the unprecedented destructive power of guns, “casting of field guns became one of the first mass-production industries of the early modern world” (Smil, 1999, p. 128). Manufacture and use of guns, however, is very energy intensive and financially expensive.

Survival now required not only a larger army, but a trained, disciplined fighting force supported by costly equipment in the forms of cannon and muskets, ... Warfare on land and at the sea (where the size and armament of naval ships increases dramatically) had dramatically altered the size of the financial and resources necessary for survival. (North, 1981, p. 138)

The high cost of new military technology led to the growth of the size of viable states, which was often achieved by wars. It also forced rulers to make political concession in exchange for financial contribution from broader spectrum of society (North, 1981).

While North clearly recognized the direction of causality from technology to institutions in many individual historical events, he reversed the direction when he tried to interpret general patterns of social changes, such as the Industrial Revolution:

While gunpowder, the compass, better shipdesigns, printing and paper all played a part in the expansion of western Europe, the results were widely divergent. The technological changes associated with the Industrial Revolution required the prior development of a set of property rights, which raised the private rate of return on invention and innovation. (North, 1981, p. 147)

We shall briefly review the process of the Industrial Revolution, which will show that a resource based explanation offers a much simpler understanding. A resource based understanding explains why the economic performances of different states, especially neighboring states, can diverge significantly, although states can learn from each other's institutional and technical innovations.

Iron was the essential material in modern warfare. Since the making of iron needs tremendous amount of energy, by the middle of eighteenth century, whole England was deforested as wood was the main source of energy in iron making. Because of the depletion of wood, the substitution of coal for charcoal became a necessity (Jevons, 1965). The first successful experiment to process iron with coal was around 1750, the time that is generally considered as the starting point of the Industrial Revolution. Hence the Industrial Revolution is a successful technology response to a resource crisis by vastly increasing the use of coal in iron making and steam engine. Of course, many institutional measures were adopted to respond the resource and technology conditions of the time. But the fundamental reason of the Industrial Revolution is the inventions that enable the use of the vast amount of coal as a reliable energy source.

	1860	1875	1889	1903
Great Britain	80,043	133,306	176,917	230,334
United States	14,334	46,686	126,098	319,068
Germany	12,000	47,756	83,614	159,846
France	7,900	16,686	23,915	34,345

Table 4.1: The annual production of coal in thousands of tons in some coal-producing countries. Adapted from Jevons (1965).

Coal had been the main source of energy before the widespread use of petroleum. Table 4.1 records the annual production of coals in the chief coal-producing countries from 1860 to 1903. Several observations can be made from the table. First, in 1860, by far the largest producer of coal was Great Britain, which was also the most powerful country. By 1903, United States became the largest coal producer, which soon demonstrated its unparallel economic and military might. Second, among European countries, the share of coal production from Germany rose sharply from 1860 to 1903, which gradually but decisively changed the balance of economic and military power in Europe. Third, France entered

nineteenth century as the strongest continental power. However, as Europe became more industrialized, the paucity of coal mine on its territory, relative to Britain and Germany, greatly inhibits its economic development. France tried its best to increase its coal supply. For example, after World War I, France demanded repatriation of coal from German mines. But the fact that the mines were on German territory made it difficult to enforce the treaty for long times. The lack of energy resources explains why France, facing German emergence, was always on the defensive. The above discussion shows that ultimately, it is the amount of energy and other natural resources a country can control that determines the economic wealth and military power of a nation.

In the following, we will further discuss the institutional view of historical development expressed by North:

It was the reduction of transaction costs due to the establishment of private property rights of and competition in trade and commerce that allowed England to escape the Malthusian check that both France and Spain suffered during the seventeenth century. (North, 1981, p. 157)

From Table 4.2 we can found that English population was declining in the early eighteenth century, when the resource depletion caused by iron making industry lowered the carrying capacity of the country. This means that Britain, like France and Spain, suffered from Malthusian check at that time. British population started to grow steadily after 1750, which coincides with the large scale production of iron with coal and Watt's improvement on steam engines. It is the technology breakthrough

Year	Population	Numerical increase for ten years	Percentage increase for ten years
1570	4,160,321		
1600	4,811,718	217,132	5
1630	5,600,718	262,933	5
1670	5,773,646	43,282	1
1700	6,045,008	90,454	2
1701	6,121,525		
1711	6,252,105	130,580	2
1721	6,252,750	645	0
1731	6,182,972	-69,778	-1
1741	6,153,227	-29,745	0
1751	6,335,840	182,613	3

1761	6,720,547	384,707	6
1771	7,153,494	432,947	6
1781	7,573,787	420,293	6
1791	8,255,617	681,830	9
1801	8,892,536	636,919	11
1811	10,164,256	1,271,720	14
1821	12,000,236	1,835,980	18
1831	13,896,797	1,896,561	16
1841	15,914,148	2,007,351	14
1851	17,914,148	2,007,351	14
1861	20,066,224	2,138,615	12
1871	22,712,266	2,646,042	13
1881	25,974,439	3,262,173	14
1891	29,002,525	3,028,086	12
1901	32,527,843	3,525,318	12

Table 4.2 Population of England and Wales from 1570 to 1901. Reproduced from Jevons (1965).

which allowed coal to be used in producing iron and other commodities, which can be used to trade for food and other necessities that allowed British population to grow steadily. In Jevons' own words, "The nation, as a whole, has rapidly grown more numerous from the time when the steam-engine and other inventions involving the consumption of coal came into use" (Jevons, 1965, p. 9). However, France was a much smaller coal producer than Britain and Spain's coal output was negligible even compared with France (Jevons, 1965). Therefore, it is the differences in resources, which cannot be changed easily, and not the differences in institutional structures, which can be changed, that determined the long run social performances.

It is often claimed that in today's high tech society, natural resource plays an insignificant role for a nation's economic wealth. Japan, which doesn't possess many natural resources, is often cited as an example. While Japan does achieve very high living standard, during this process, its fertility rate has dropped to 1.38, which is among the lowest in the world and far below the replacement level. This means that high living standard without the support of natural resources is unsustainable. Next chapter will provide more detailed discussion about natural resource, living standard and fertility.

Ultimately, it is the resource endowment, which cannot be copied from country to country, that determines nations' power. However, when resources are discovered in poor or weak countries, it often take long

time before people in these countries can take effective control over resources on their land. For example, oil rich developing countries are often the targets of political and military actions from major powers and political reforms in resource rich countries, such as Iran, were often suppressed. While resource endowment determines long term economic performance, internal and external institutional structures determine short term fortunes, which leaves the impression that institutional structures, instead of natural resources are the decisive factor in economic performance.

We have shown that the resource based theory of human history offers a simpler and more consistent understanding than the institutional theory. In the following subsection, we will consider the future of our fossil fuel based civilization from the resource theory.

#### ***4.3.2. The future of our fossil fuel based civilization***

While it is difficult to predict the pace of technology advance and its consequence to resource exploitation in the near future, the collapses of all past highly developed civilizations due to resource depletion offer a clear understanding of long term patterns, which should make us prepare for a soft landing when resources become very scarce. Instead, our human society keeps on increasing consumption whenever it is possible. Why this is the case? We will analyze from individual and institutional levels.

At individual level, as we have explained in Chapter 1, the only credible signal of attractiveness is the possession and consumption of low entropy resources. All other signals of attractiveness, which require less effort, can be copied easily and hence lose credibility. Therefore, in a consumer society, maximizing consumption becomes the standard way in social communication. For example, legislations often require high fuel efficiency for cars to reduce oil consumption. However, SUVs, which consume much more energy than ordinary cars, are not classified as cars, “although they are clearly used as passenger cars”(Smil, 2003, p. 96). SUVs become very popular for the exact reason that they are costly to buy and operate, which signals the wealth and status of SUV owners.

At the institutional level, institutions, such as firms, have fixed and variable costs. From Figure 3.2, higher output generally means higher rate of return. Therefore higher level of consumptions is encouraged at institutional levels. This is why saving is often called private virtue but

public vice. Mainstream economic theory, which is a religion that justifies the modern lifestyle, often advocates the high consumption strategy (Nelson, 2001). Samuelson and Nordhaus argued:

The substitutability of natural capital and other kinds of capital is shown by the production indifference curve ... That output can be produced ... with a conservationist policy that emphasizes reducing energy use today, leaving much oil and gas and relatively little human capital for the future. Or it might be produced with a low-energy-price and high-education strategy ... Either of these is feasible, and the more desirable one would be the one that has a higher consumption both now and in the future. (Samuelson and Nordhaus, 1998, p. 328)

What will be the consequence when the fossil energy is no more available at low cost? Will it only affect our lifestyle, such as extensive traveling by cars and airplanes? In fact, not only industry depends utterly on fossil energy, but also agriculture, our very food source, depends very much on the fossil energy.

The next cause of cheapness in food came from applying the new cheap energy to agriculture. Tractors, harvesting and planting machines and, above all, chemical fertilizers lowered the costs of growing food even as they increased the total supply. ... There then came yet one further push to cheap food. This was the development of crops such as hybrid corn, a new agriculture that goes by the name of the "green revolution" in the contemporary press. This agriculture is completely and inextricably dependent on a large flux of cheap energy. ... We have taken over many of the functions that a wild plant had to do for itself, and have done it for the plant ourselves, in factories. We do not let plant hunt out scarce minerals with its roots, we give it super abundant supplies of fertilizer so that it does not have to work for its nutrients. We take away plant's ability to protect itself against disease and pests, because the plants used to spend part of the energy reserves of its grain to do the job itself. Instead we protect the plant with chemicals. In other words we keep alive, with fertilizers and chemicals, a plant that would have no chance of hacking it alone, and the energy that its ancestor would have spent in fighting its own battles is then freed for the plant to make more grain. This extra grain,

therefore, is entirely dependent on cheap fuels supplied to our chemical industries; indeed, in a real sense the energy of this extra grain is some of the energy from the chemical industry. (Colinvaux, 1980, p. 335)

Smil (1999) put it in a more quantitative scale.

Between 1950 and 1995, global synthesis of fertilizer ammonia rose from less than five million to about eighty million tones, ...perhaps already two out of every five people, gets the protein in his or her diet from synthetic nitrogenous fertilizers. (Smil, 1999, p. 171)

Therefore our very survival depends on the continuing flow of fossil energy. The discussion by Colinvaux and Smil also shows that the main function of knowledge is to utilize energy and other natural resources. This is distinctly different from the mainstream theory that knowledge is used to substitute natural resources (Johnson, 2000). Since knowledge is used to utilize natural resources instead of substitute them, it is easy to understand in most sites of highly developed early civilizations, once rich and productive areas have been turned into desolate regions through over exploitation while in primitive human societies, environmental quality does not deteriorate as much for people there had less knowledge to extract as much resources from nature.

Will the progress of science resolve the resource problem in the future? Jovons made the following observation.

It is credibly stated, too, that a manufacturer often spends no more in fuel where it is dear than where it is cheap. But persons will commit a great oversight here if they overlook the cost of improved and complicated engine, is higher than that of a simple one. The question is one of capital against current expenditure. ... It is wholly a confusion of ideas to suppose that the economic use of fuel is equivalent to the diminished consumption. The very contrary is the truth. As a rule, new modes of economy will lead to an increase of consumption according to a principle recognized in many parallel instances. (Jevons, 1965, p. xxxv and p. 140)

Put it in another way, the improvement of technology is to achieve lower variable cost at the expense of higher fixed cost. Since it takes

larger output for higher fixed cost systems to breakeven, to earn a positive return for higher fixed cost systems, the total use of energy has to be higher than before. That is, technology advancement in energy efficiency will increase the total energy consumption. Jevons' statement has stood the test of time. Indeed, the total consumption of energy has kept growing, almost uninterrupted decades after decades, in the last several centuries, along with the continuous efficiency gain of the energy conversion (Smil, 2003). Figure 4.1 displays the total primary energy consumption world wide from 1965 to 2003, a period of rapid technology progress. During this period, energy consumption grew steadily, with only two brief interruptions. The first is from 1979 to 1982, a period of Iranian Revolution. Oil price jumped from 13.60 US dollars per barrel in 1978 to 35.69 in 1980. The second is from 1997 to 1998, a period of Asian financial crisis. Oil price dropped from 19.09 US dollars per barrel in 1997 to 12.72 in 1998. Figure 4.2 displayed the oil price change from 1965 to 2003. The drops of energy consumption in both periods were not related to technology progress.

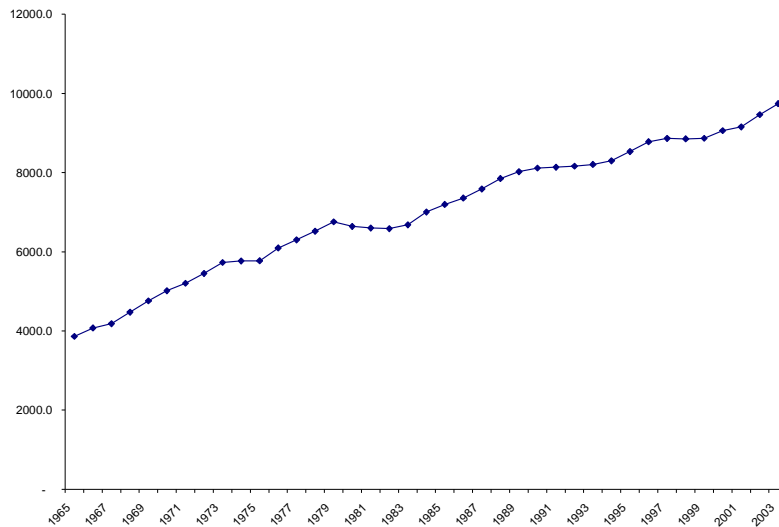


Figure 4.1: Global energy consumption (Million ton oil equivalent) from 1965 to 2003. Source: BP.

At the crest of every civilization, it is difficult to imagine its ultimate demise. But are there clear signs of unsustainability of our civilization at this moment? Yes. The fertility rates in most developed countries are already far below replacement level, a clear indication that the current living standard in most developed countries are not adequately supported by the available resources. In the next chapter, we will make a detailed discussion of fertility problem.

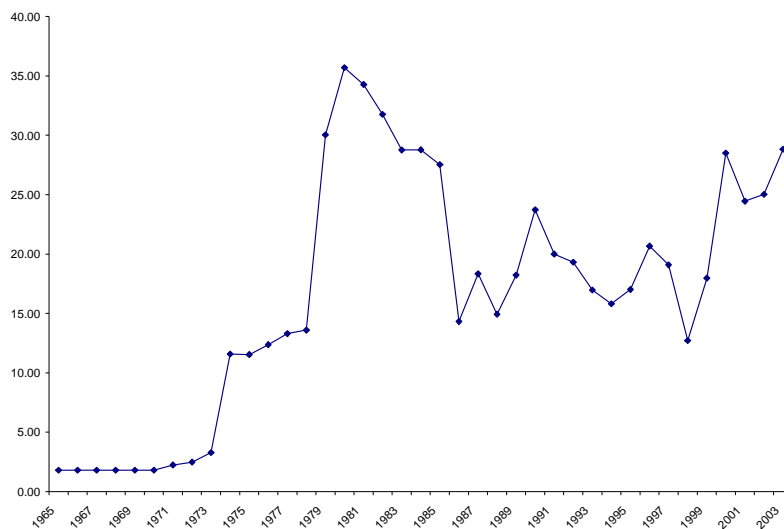


Figure 4.2. Oil price (US dollars per barrel) from 1965 to 2003. Source: BP.

#### 4.4. Concluding Remarks

The world history is an interaction between natural resources and technology, which is the ability to utilize natural resources. Institutional

structures are evolutionary adaptations to the level of technology and resources. Because of the existence of fixed assets accumulated over time, the adaptations are gradual and are constrained by existing structures. The progresses we observe are really the increase of fixed costs that bring down the variable costs. Since higher fixed costs systems need large amount of resources to maintain themselves, the grand systems of civilizations all collapsed spectacularly when resources are depleted.