Energy and the Economy–Basic Principles and Feedback Loops

Does a fish know that its nose is wet? Probably not. It swims in water, and assumes that is the only way any animal lives.

We live in an economic world. Economic models that were developed years ago were created based on observations of how the economy seemed to work at the time. As time goes on, it is becoming clear that early economists missed important connections. The most important of these is the role of energy and its connection to the economy. It takes energy to make anything, from a piece of steel to a loaf of bread. It takes energy to transport anything. Humans need energy in the form of food to continue to live. Clearly, energy should have a place in economic models.

In this post, I explain some of the basic principles as I see them:

1. Humans have evolved to be dependent on external energy.

2. Humans now supplement their own limited energy supply with external energy of various types. In general, the more external energy used, the more humans are able to control their environment.

3. Over the 1 million+ years during which humans have been able to control fire, humans have generally been in situations with favorable feedback loops, due to increasing efficiency in producing goods and services required to meet basic needs. Such loops allowed continued population growth and economic growth.

4. We are now reaching limits on these feedback loops. The result is feedback loops that are changing from favorable feedbacks to contraction.

5. Part of the change in feedback loops relates to the cost of energy sources, such as oil. A rise in the price of oil tends to reduce salaries of workers (because of layoffs) as well as reduce discretionary income (because of higher price of food and commuting), contributing to the trend toward contraction.

All of this is very concerning, because in the past, adverse feedback loops of this type seem to have led to collapse.

The Many Types of Energy

The most basic type of energy, at least from a human perspective, is human energy. This is the energy we as humans have that allows us to move our own bodies and allows us to think. Each of us is given approximately the same amount of energy, with males having somewhat more energy for lifting and pushing objects, and females having the special ability to give birth to new humans.

In order to use human energy, humans need to eat food of appropriate kinds. Most of this food is from plants and animals that we process in some way for this purpose. (This processing normally requires some type of energy.) The only food that is not from plants and animals is mother's milk. Women need to increase their own intake of food from plant and animals, in order to produce enough milk for their babies.

Humans are able to leverage their own energy with many types of external energy. One very old source of external energy is burning wood and other plant matter. Such energy is used in keeping warm, cooking food, making sharper tools, and warding off predators. Another very old source of external energy is energy from dogs, trained to help with hunting, and from draft animals, trained to help with plowing and grinding tasks.

Humans have learned to harness various other forms of other energy, such as wind, water, and geothermal energy. In the last 200 years, the use of fossil fuels (coal, natural gas, and oil) has greatly expanded the amount of external energy available to humans.

Fossil fuels are important, not just because they can be burned directly, but because they enable the use of electricity from a wide range of sources—including hydroelectric, nuclear, and solar photovoltaic. While we think of these latter sources as non-carbon fuel sources, they are today available only within a system powered by fossil fuels. It takes fossil fuels to create metals in the quantity needed for electrical transmission; it takes fossil fuels to make and transport the type of concrete used in hydroelectric dams and wind turbines; it takes fossil fuels to purify silicon and other materials used in making solar PV.

While people talk about a system that does not require fossil fuels, no one has mapped out how the world could in fact transition from a system that uses fossil fuels to capture these types of energy to a system that would work without fossil fuels. The best we can hope for within the next 100 years is to use fossil fuels more sparingly.

One specialized form of energy is embedded energy that has been stored up in goods for the long term. Examples of early embedded energy includes heat-sharpened stone ax blades, used by hunter gatherers, and clothing, whether made by hand or machine. Today, there is much embedded energy in roads, pipelines, and electrical transmission systems. The vast majority of today's embedded energy is derived from fossil fuels.

External Energy as a Human Need

Most animals seem to get along fine without external energy, other than the sun's rays. They live in the parts of the world where they are adapted. They more or less live in balance with their predators. The number of a given species may rise for a while, but if the number grows too much, the species will exhaust its food supply, leading to population decline.

Humans have moved to a different model. The change came when humans (or predecessors to humans) first learned to control fire, over 1,000,000 years ago. Being able to control fire gave humans many advantages over other animals. Humans were able to cook part of their food. This had many advantages: It greatly reduced chewing time, allowing time for other activities, such as making tools and clothing. It improved nutrition, by making food more digestible. It allowed the human body to evolve in ways that used more energy for brain development, and less for chewing and digestion. [i]
The way the natural order works is that each species gives birth to far more offspring than is needed to survive to adulthood. "Natural selection" determines which of these offspring will survive. If humans had been like apes, chimpanzees, or gorillas, total population might have reached a plateau of perhaps 3,000,000, (based on historical animal populations). This limit would be reached because of competition with other species, and because climate is less hospitable outside of a narrow range.

With the help of external energy, such as the controlled use of fire and the use of dogs for hunting, humans were able to gain an advantage over other species and spread to all areas of the globe. This is what allowed population to grow, and continues to help it grow.

The natural order assures that far more human offspring are born than are needed to survive to adulthood. If humans are intelligent, they desire to extend their own lives and the lives of their offspring. The result of this dynamic is that there tends to be continual upward pressure on population.

There is a second dynamic as well. Because of humans' intelligence, humans have the ability to over-consume at least some of the wildlife in the areas. For example, we learned on our recent visit to Iceland that when Vikings first discovered the island, there were both walruses and the flightless bird, the auk, on the island, but both disappeared soon after humans moved to the island.

Because of these dynamics, there has been tendency to need more food, and more energy supplies of other types, over time. To meet the need for greater food supply, humans began using agriculture about 10,000 years ago. With the advent of agriculture, the amount of human food available per acre was greatly increased.

The availability of agriculture added to the two dynamics noted previously for hunter-gatherers. As before, (1) population tended to increase, because the natural order provides for far more births than are needed for replacement, and because humans, with their intelligence, now had a way to provide more food per acre. Also, (2) there was a tendency of the amount of food available from a given acre of land to degrade over time, because the methods used for agriculture were less than perfect. Erosion was a problem, especially when planting was done on slopes. If irrigation was used, salt deposits often became a problem. Rising population combined with degrading resources led to a need recurring need for additional energy, since supplemental energy could indirectly add to food supply. In situations when additional energy was not found, populations had a tendency to collapse after many years of growth.

Besides the two basic dynamics of rising population and degrading resources leading to a need for additional resources, there were other forces that tended to add to the need for increasing amounts of energy:

a. Cheapest resources used first. Soon after agriculture began, humans began to use resources of other types, such as wood from forests and metals such as iron and bronze. With any of these resources, there is a tendency to use the "cheapest" (easiest to extract, closest at hand, highest ore concentration) first. If extraction is to continue, increasing amounts of energy per unit extracted are likely to be required for later extraction.

b. Increased disease transmission when population is packed more closely together. This issue can be overcome with techniques that kill germs and that keep humans separated from waste products of other humans. The need for these techniques adds to the need for external energy.

c. Deforestation. Without fossil fuels, there was a severe tendency to overuse forests. Deforestation occurred as early as 4000 B. C. E., according to Sing Chew. HistorianNorman Cantor writes, "By 1500 Europe was on the edge of a fuel and nutritional disaster [from] which it was saved in the sixteenth century only by the burning of soft coal and the cultivation of potatoes and maize." The use of coal allowed more energy per person, and took pressure off of limited forest resources.

d. Pull of Technology. The availability of fossil fuels, starting around 1800, has allowed much of what we now call "technology." Without fossil fuels, our ability to make materials such as metals and glass is severely restricted. Without fossil fuels, we are also lacking for the basic building blocks for plastics, synthetic fabrics, and even modern medicines. Technology provided ways to use fossil fuel resources in ways that helped overcome many human limits. The desire to use more technology led to increasing use of fossil fuels in the 19th and 20th centuries.

Hunter-Gatherer Economies

There were no doubt many different types of economies in the over one million years when humans and pre-humans were hunter-gatherers. One documented approach is the gift-economy. With this approach, those who killed animals shared what they obtained with others in their group. Status was gained based on how much an individual was able to provide to others in the group. Members of the group played different roles—some were involved with caring for children, or too old to work, but what was available was shared with the group as a whole.

In the days of hunter-gatherers, the function of the economy was not too complicated. There was little need to "save for tomorrow," because it was difficult to carry anything during travels. The amount of food an individual could eat was pretty much limited by appetite, so having "more food" for one individual wasn't particularly helpful. If one person was the leader, he (or she) might have special adornment.

If population rose too high, relative to resources, this may not have been apparent in "normal" times—when weather was good, and when a particular hunter-gatherer group had an area to itself. But if there was a major weather problem or an encounter with another group needing space as well, population pressure could lead to a crisis. It seems likely that die-offs occurred from time to time, especially during natural "bottle-necks."

A Simple Agricultural Economy

Thinking about a simple agricultural society gives us some insight as to how early economies must have operated.

Consider a simple economy in which some members produce barley; others produce fish. The fish can be salted and dried, so both the fish and the barley can be stored, if desired. The big issue in such a system is how efficient the barley and fish operation is. If in order to feed the group, half of the group must work full time growing barley, and half of the group must work full time catching, salting, and drying fish, then no matter what kind of economic system is in place, the result will simply be trading fish for barley. Everyone will continue to have to work at either producing fish or barley. The economic system will simply move some of the fish to the barley producers, and some of the barley to the fish producers.

Let's suppose instead that the barley and fish producers are much more efficient. Suppose that with 10% of the population working at barley production and 10% of the population working at fish production, the population can provide enough food for the full population, leaving 80% of the population (100% – 10% barley producers – 10% fish producers) to pursue other activities. How the remaining 80% of the population will spend its time will depend on resources available and the desires of the citizens. Perhaps 30% of the citizens would make goods of various types (build homes, make clothing, and make furniture) and 20% of the citizens would provide services of various types (education, health, artwork, and hair cutting). This would leave 30% for government and finance. The government portion would include pay for government officials and police and transfer payments to the elderly and disabled.

The total wealth of the community is then the sum of all of the goods and services in this community. The financial system will redistribute the goods and services produced among the members of the community, perhaps allowing some "savings" for future consumption. Those producing goods and services will expect to be included in the redistribution, but so will others, if this has been the tradition in the community.

If the economy operates without fossil fuels, the quantity produced is limited by the speed with which biomass regrows. Thus, unless the community is willing to live with deforestation, it can't use much wood each year. This puts a severe limit on the amount of goods produced. Printing more money does not change this dynamic.

In the example above, I suggested an efficient economy might need only 20% of its population for food production. In fact, the percentage of the population involved in food production varies greatly across economies. Before fossil fuels use, typically 80% of the population of a country was involved in agriculture. With so many involved in agriculture, the number who were involved in manufacturing and services of all types (including government services) was necessarily very limited, because they needed to be “squeezed into” the remaining 20% of the economy.

Per Cent of Workforce in Agriculture
Selected Countries
Based on CIA World Factbook Data

	% Agriculture	Energy/Capita*
Burundi	94%	0.47
Ethiopia	85%	1.59
Angola	85%	14.04
Afghanistan	79%	3.59
Kenya	75%	5.38
Cambodia	56%	4.23
India	53%	18.69
Armenia	44%	71.44
China	35%	75.84
Bolivia	32%	23.38
Egypt	32%	41.10
Nicaragua	28%	12.90
Kazakhstan	26%	132.00
Serbia	22%	105.46
Brazil	16%	57.70
Mexico	14%	64.76
Venezuela	7%	121.99
Australia	4%	270.10
Italy	4%	125.53
Japan	4%	170.66
USA	1%	316.95

*Million Btu per Capita, based on 2010 EIA Data

Figure 1. Percent of Workforce in Agriculture based on CIA World Factbook Data, compared to Energy Consumption Per Capita based on 2012 EIA Data.

If, in our hypothetical community, population rises because more children live to maturity, this adds a new dynamic. There is a need for more food, clothing, and housing for the growing population. Unless land area keeps increasing, there becomes a need to grow more barley per acre. In a world without fossil fuels, increasing grain yields becomes difficult. More farmers can be added to a given plot, but the additional yield for additional manual effort (perhaps picking off insects that might eat the crop) is not very high. This dynamic tends to lead to what we think of as falling wages of the common worker, when population becomes high relative to resources available. As I have mentioned in previous posts, based on the book *Secular Cycles* by Turchin and Nefedof, collapse often occurs in such situations. Governments have promised significant services, but it becomes difficult to collect enough taxes to pay for these services, with falling wages of the common worker.

The dynamic is similar if energy supplies of types other than food (such as oil and coal) does not rise as fast as population. The amount of goods produced using these energy supplies will tend to fall, unless technology advances are able to offset the decline in energy consumption per capita. Such technology is normally fossil fuel dependent. If goods per capita falls, this will be reflected in what we think of as falling inflation-adjusted wages, since it is not possible for workers to have more than what is produced.

Adding Fossil Fuels

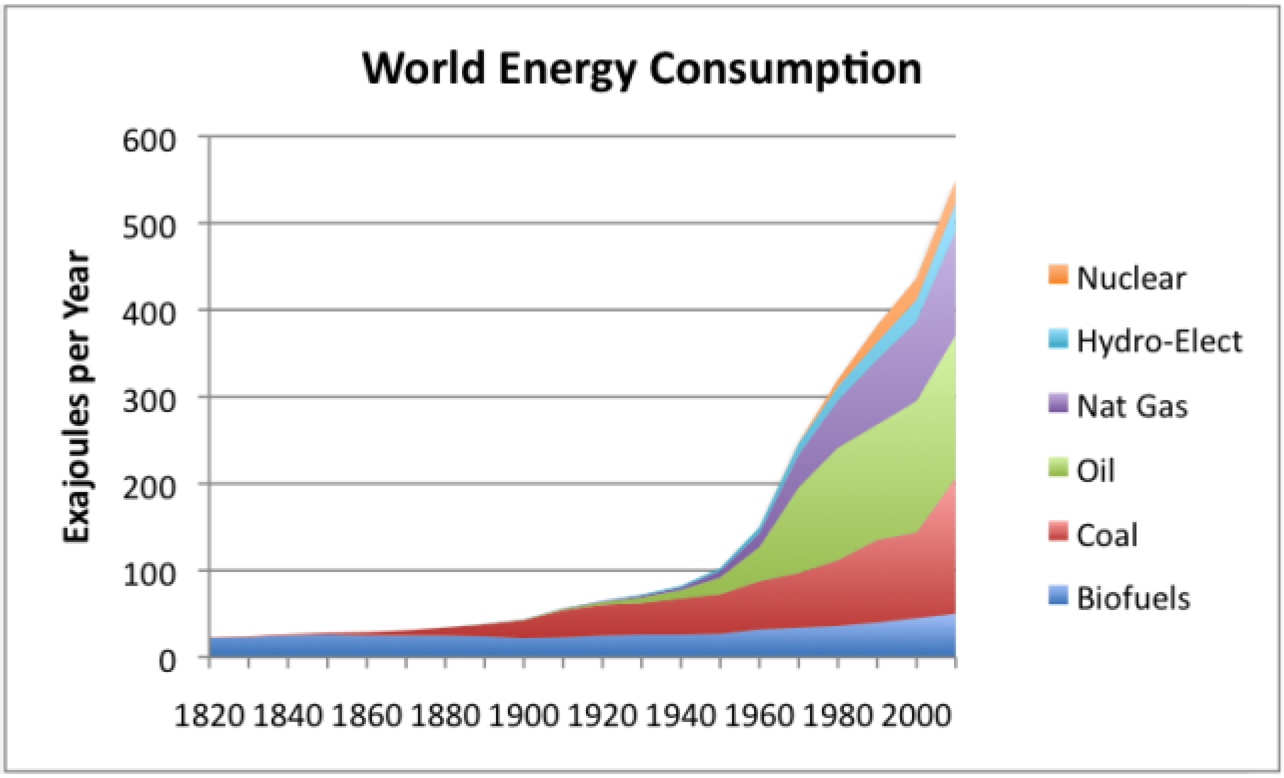

Figure 2. World Energy Consumption by Source, Based on Vaclav Smil estimates from Energy Transitions: History, Requirements and Prospects and together with BP Statistical Data on 1965 and subsequent

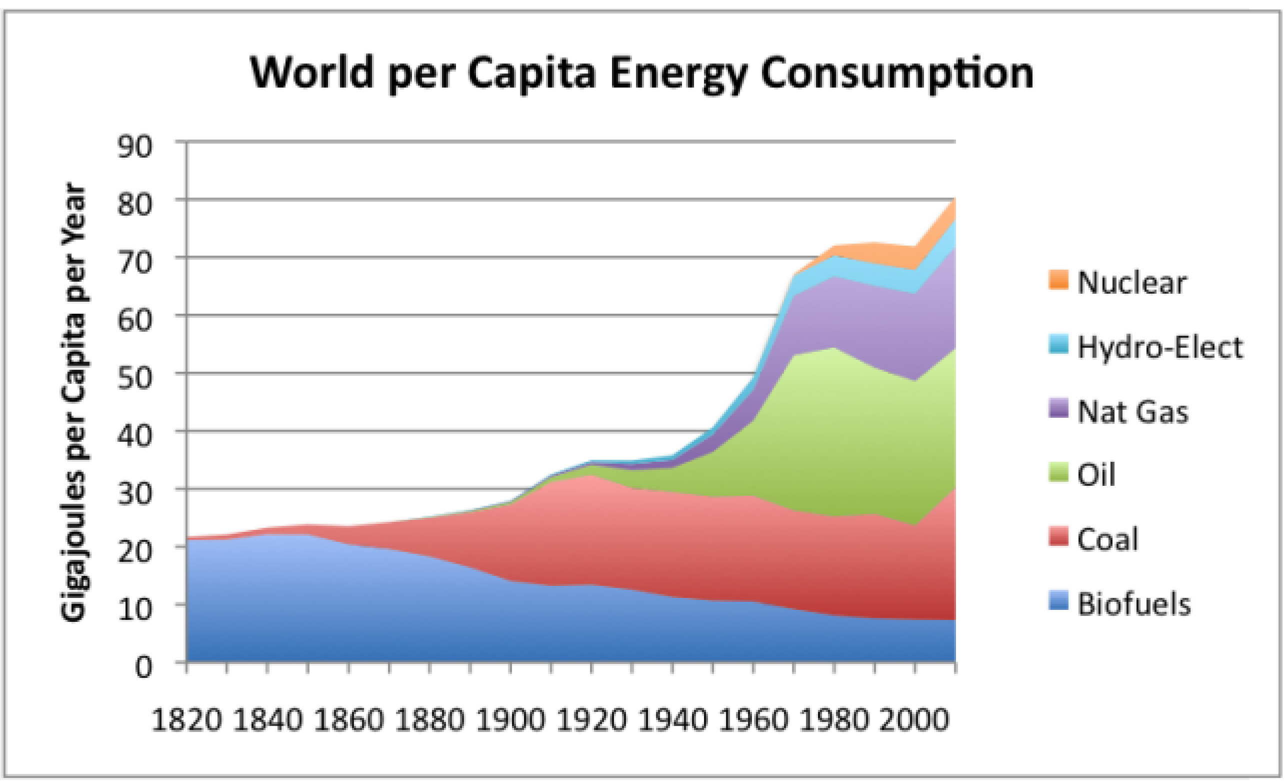

Figure 3. Per capita world energy consumption, calculated by dividing world energy consumption (based on Vaclav Smil estimates from Energy Transitions: History, Requirements and Prospects together with BP Statistical Data for 1965 and subsequent) by population estimates, based on Angus Maddison data.

If metal tools can be used—say metal plows—these metal tools can greatly ramp up efficiency of farming, allowing fewer people to work in the agricultural sector. If we think about the result in the last section, this situation allows a greater proportion of the population to be employed in producing discretionary services, and thus more wealth for the community as a whole.

The problem with making metals such as iron using renewable resources is that huge amounts of charcoal are needed to make even small amounts of iron. If one wants reasonable quantities of metal, or modern alloys such as steel used in plows and trucks, a person needs fossil fuels.

If a person wants to add fossil fuels and the things that fossil fuels can make to a community that does not have fossil fuels, the question becomes how to pay for the new goods using fossil fuels. As an extreme example, if farmers have always planted barley with a stick, the amount of barley each farmer produces is tiny, and the population is likely mostly farmers. If a farmer can use a new tractor, with the latest equipment, a single farmer can perhaps feed the whole community. The tractor will provide the improved efficiency needed to free up a whole community of workers for other purposes.

The secret to adding fossil fuels (or any kind of energy source that can improve efficiency, and allow fewer people to produce essential goods and services) is *debt*. While the farmer cannot pay for the new tractor with his earnings from growing barley using a stick, the farmer can indeed pay for the tractor with all of the goods and services that the whole community can produce, as the result of the tractor handling work that now takes many workers to do. By growing much more grain, and selling that grain to all of the workers who are now freed up to provide discretionary services, the farmer will have enough funds in the future to repay the loan for the equipment which will allow much greater efficiency. (The problem is that the tractor requires a huge amount of embedded energy from fossil fuels. Workers who have been working without fossil fuels will not be able to earn enough to pay for this embedded energy without debt.)

Salaries of Workers

In my imaginary simplified economy, there is only one country. In such a country, the amount of salaries that workers receive then is closely related to the amount of goods and services that the economy produces. There will be part of the production that goes to the owners of factories, farms, and other sources of production, but they cannot eat any more than anyone else, or sleep in more than one place at a time. If they get paid much more than others, some of it must be in the form of “paper income” that they can theoretically use at some time in the future, but does not involve current consumption.

In general, the more goods and services produced relative to the population, the more workers will receive in inflation-adjusted salary. If the economy is so distorted that most of the goods are made with machines, the government must play a much bigger role, providing transfer payments to those who cannot find employment (unless the government is prepared to handle uprisings by citizens). If workers are not receiving adequate wages to pay the taxes, taxes will need to come from some other source-possibly from the owners of the sources of production.

To see how a rise in oil prices will affect the economy, lets consider what can be expected to happen to a manufacturing company. Suppose that for a particular manufacturer, costs are distributed as follows (the actual percentages aren’t important-just the point that wages tend to be a big piece of the total):

- Wages 40%
- Oil products 10%
- Electricity 5%
- Raw Materials other than Oil 20%
- Rent 15%
- Profit 10%

If the cost of oil doubles and the manufacturer is not able to raise prices, the higher cost will wipe out profits. In fact, the cost of other raw materials is likely to rise as well, because oil is used in extracting and transporting raw materials. This will make the impact on profit even worse than the oil-only comparison would suggest.

To “fix” the problem, the manufacturer has to make some sort of adjustment, and the adjustment will almost certainly lead to less dollars being paid for wages. One such approach is to “make a smaller batch,” with the amount produced equal to what can be sold at the higher price. If this is done, the manufacturer will employ fewer workers. It will also cut back on oil consumption, other raw materials, electricity consumption, and rent. The result will look like recession.

Thus, a rise in oil prices, such has happened since the early 2000s, can be expected to affect feedback loops for countries that use very much oil.

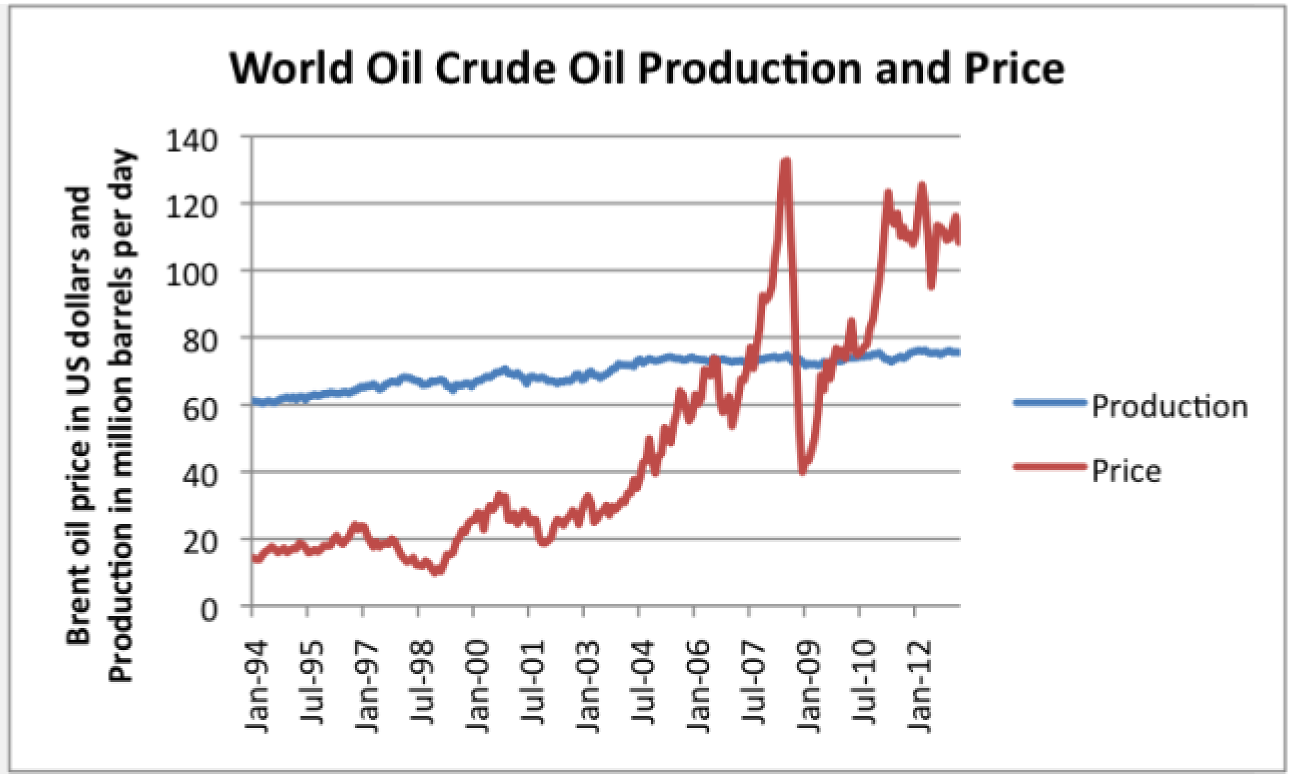

Figure 4. World crude oil production and Brent spot oil price, both based on EIA data.

The Positive-Feedback Loop

When can an economy grow? If an economy can grow in efficiency—that is, fewer and fewer people employed creating the basic requirements for life, then more of the population can be employed in providing discretionary services. In total, the wealth of the economy will grow. Historically, this has happened as increasing amounts of fossil fuel energy is added to supplement human energy.

If an economy can increase its debt, and that debt can finance equipment or infrastructure that will allow greater efficiency in producing basic services, this will also allow an economy to grow.

In economic analyses, increases in population are counted as part of economic growth. The problem with population growth is that it leads to more population per acre available for cultivation, and more population relative to external energy sources of all types. This sets up a competition: can enough external energy be added to maintain (and even increase) goods and services per capita?

Economies of scale are also important as producing positive feedback loops. Once an energy investment, such as a road, is made, it can be used for an increasingly large population, often without much additional cost. Businesses also find growth beneficial, since they can build a factory, and operate it more hours, with little additional cost.

The combination of all of these favorable feedbacks leads to the pattern of growth that economists seem to think always occurs.

What Can Go Wrong?

The big "oops" that takes place happens when we start hitting natural limits:

1. The cost of oil extraction goes up, because we pulled the easy-to-extract oil out first. This means that workers start having less discretionary income, rather than more, because they now needed to spend more on commuting to work and on food. Wages tend to stagnate or decline, for reasons described above. A larger percentage of the population needs to work in oil extraction, and more fossil fuels of various types must be used in oil extraction, leaving fewer workers and less energy supplies for other purposes.

2. The economies of countries consuming large amounts of oil are disproportionately affected by rising prices, and oil consumption begins to drop in these countries, even though world oil consumption in total is still rising.

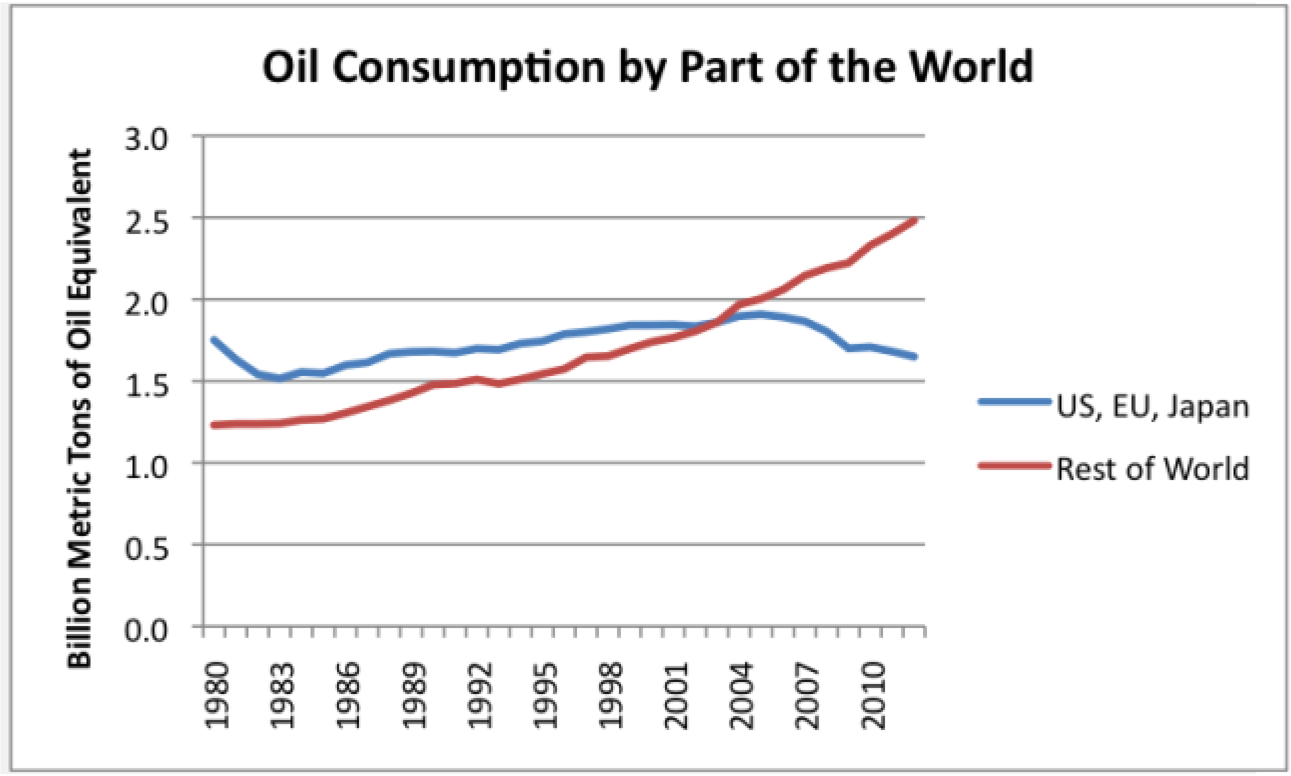

Figure 5. Oil consumption based on BP's 2013 Statistical Review of World Energy.

3. Debt added to produce oil tends to produce fewer and fewer barrels of oil per dollar invested, as the cost of oil extraction rises. With fewer barrels of oil produced per dollar of investment, less goods are transported per dollar invested. If other energy products also rise in cost of extraction, or if the cost of making metals increases, we reach a situation where increasing debt, in general, starts adding a smaller and smaller quantity of goods per dollar of investment. (Substituting a different high-cost source of energy does not fix the situation.) Eventually, so little benefit is gained from additional debt that huge defaults occur. These huge defaults are likely to lead to higher interest rates and more layoffs.

Of course, during favorable feedback loops, the economic growth that comes with increasing energy consumption plays a major role in permitting debt to be paid back with interest. If energy consumption, in fact, starts contracting, this contraction will contribute to debt defaults.

4. As the economies of individual countries got richer and richer, the natural tendency was to add more government services. Pensions and health care were promised, based on what looked possible when the economy was growing rapidly. Now, the economy is not growing as rapidly, and increasing wage disparity is occurring. There is no way to

tax the common people enough to pay for the benefits promised to people. People become very unhappy when told that the government cannot pay promised pension benefits. The tendency is toward increasing unhappiness with government status quo, perhaps even leading to new (cheaper) forms of government.

5. Because of energy limits, we find a need to conserve, but in the process discover that we are inadvertently hitting “diseconomies of lack of scale” instead of “economies of scale”. Instead of continually adding new jobs based on construction of new infrastructure, job opportunities for young people start to disappear. This adds to the dynamic of contraction, even if changes are planned.

6. All the time, natural forces are eroding the huge amount of infrastructure that has been built. Hurricanes and earthquakes cause destruction that must be fixed, if the current system is to be maintained. Lesser forces, such as freezing and thawing and roots of trees growing tend to ruin roads over time, and cause buildings to need repairs. While this has always happened, if the government is poorer, the cost becomes an increasing burden.

As a result of these influences, the natural feedback loop is now changing to contraction, instead of continually adding a positive increment. This is an unknown situation relative to what we are used to. There is no “reverse gear” on the economy.

We know that in the past, economies that have hit these adverse feedback loops have tended to collapse. The situation is indeed worrisome.

Despite evolving in the direction of requiring external energy, there is still a possibility that a few individuals in particularly advantageous parts of the world might be able to “get along” without external energy. These individuals would probably live in areas where raw fish is available for food, and where predators are not particularly a problem. If these individuals are able to use stored energy in the form of modern knives, shoes, and clothing, such stored energy may take the place of other external energy that ancient people normally required.

Source: http://ourfiniteworld.com/2013/07/22/energy-and-the-economy-basic-principles-and-feedback-loops-2/