

Complexity: The Connection Between Fossil Fuel EROI, Human Energy EROI, and Debt

Gail Tverberg – June 27, 2016 – Biophysical Economics

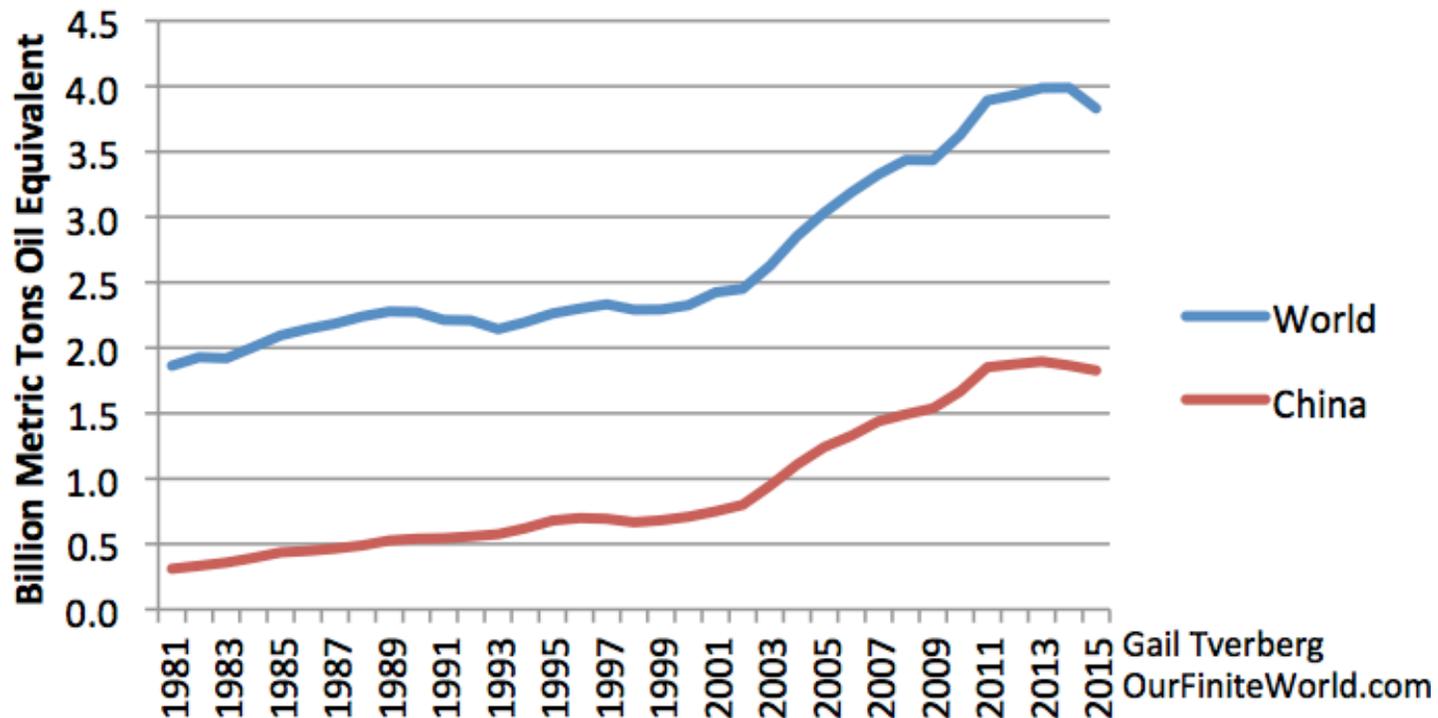
Outline

- ▶ Overview of where we are now – how complexity fits in
- ▶ Complexity (underlies “technology”)
 - ▶ Concentration of energy
 - ▶ Pure elements and compounds
 - ▶ Leveraging of human labor through hierarchy
 - ▶ Why debt is needed
- ▶ Relationship of debt to commodity prices
- ▶ What Hubbert’s model omits
 - ▶ EROI of fossil fuels based on Hubbert’s model
- ▶ EROI of human energy

Overview of where we are now

- ▶ We seem to be at peak coal production

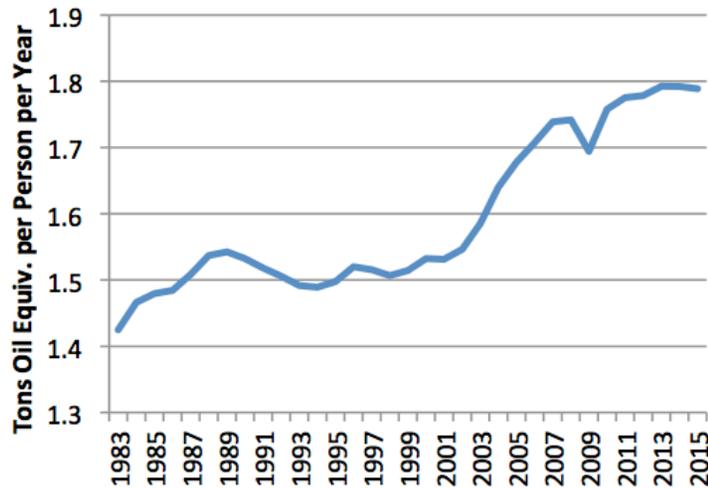
World and China Coal Production



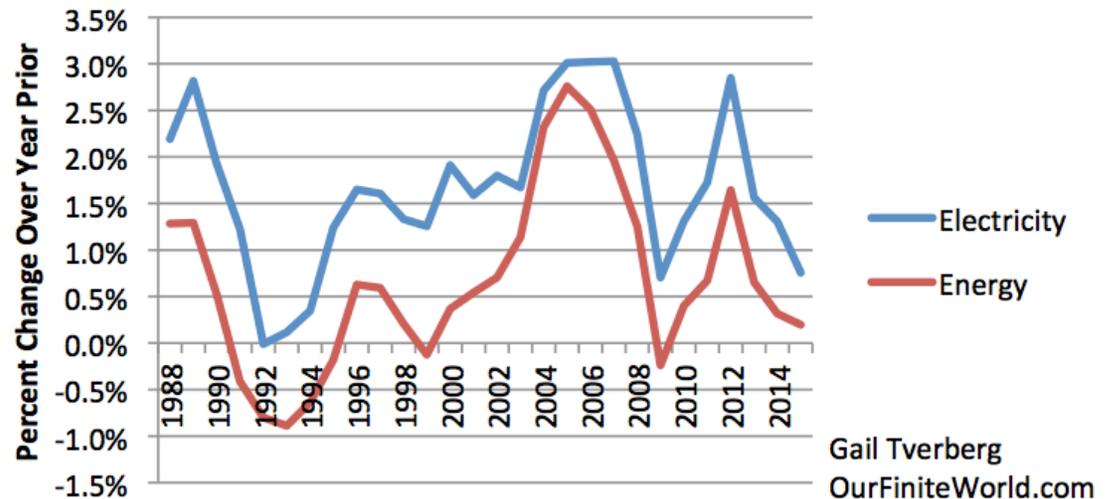
Based on BP 2016 Statistical Review of World Energy

World per capita energy consumption may have reached a peak in 2013

World Per Capita Energy Consumption



World Per Capita Increase in Electricity and in Total Energy Consumption - 3 Yr Ave



Both charts based on BP 2016 Statistical Review of World Energy and UN 2015 population data.

Two views of peak energy per capita

- ▶ (1) Peak oil / Fossil Fuel EROI view
 - ▶ Peak energy doesn't matter too much
 - ▶ Energy production by fuel will continue
 - ▶ Future production will depend on geology; net energy

- ▶ (2) Complexity analysis (which will follow)
 - ▶ Economy requires a very definite hierarchical structure
 - ▶ Sends disproportionate share of energy consumption to favored portions of the economy
 - ▶ Economy also needs growing debt
 - ▶ Servicing this debt demands a share of energy output
 - ▶ Danger is that un-favored segments will not get enough
 - ▶ Non-elite workers; international organizations such as Eurozone

Complexity

- ▶ Joseph Tainter

- ▶ Complexity is the way that economies that are in danger of reaching limits solve their problems



- ▶ Complexity seems to be what underlies “technology”

Source: <http://b-i.forbesimg.com/siimonreynolds/files/2013/04/complexity1.jpg>

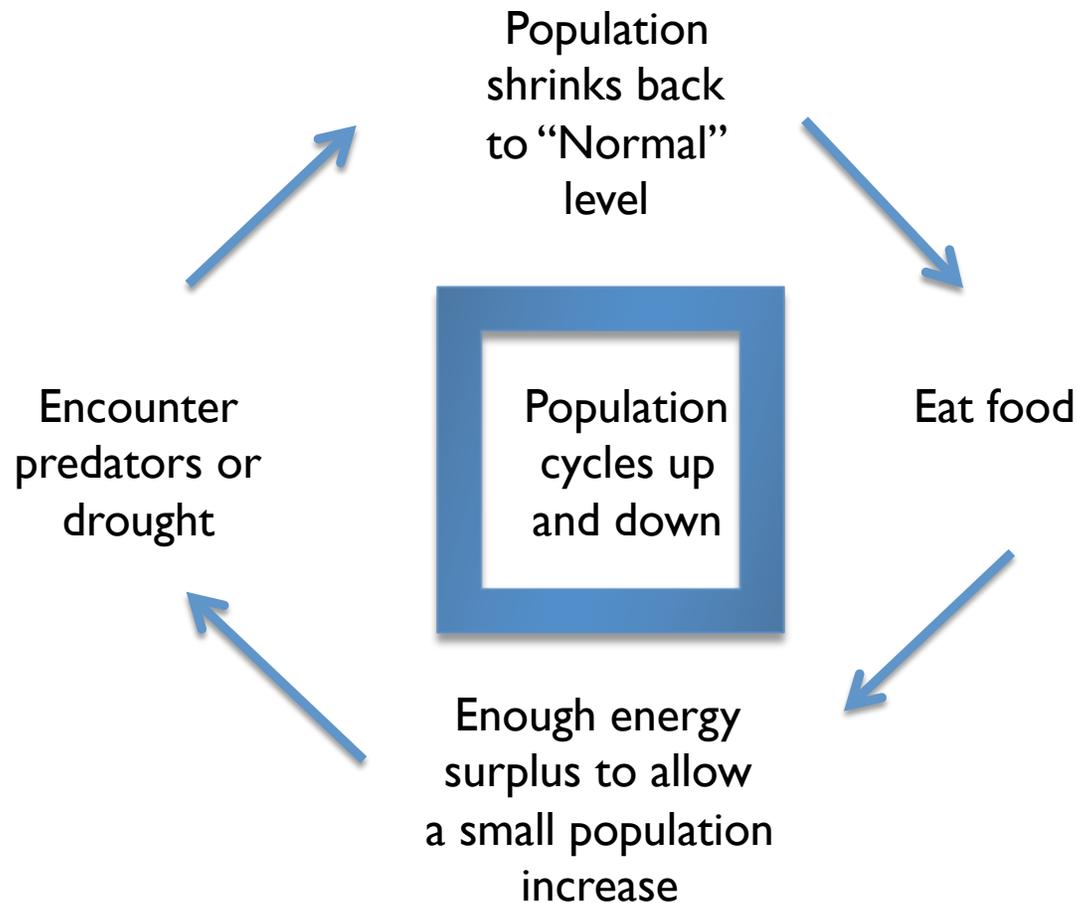
Basic Elements of Complexity

1. Concentration of energy works better than diffuse energy
2. Pure elements and pure compounds offer advantages over mixtures found in nature
3. Human energy can be leveraged by giving some people special advantages or powers (education, technical expertise, administrative roles)
4. Debt has almost miraculous powers (time shifting, imagined payback which may/may not appear)

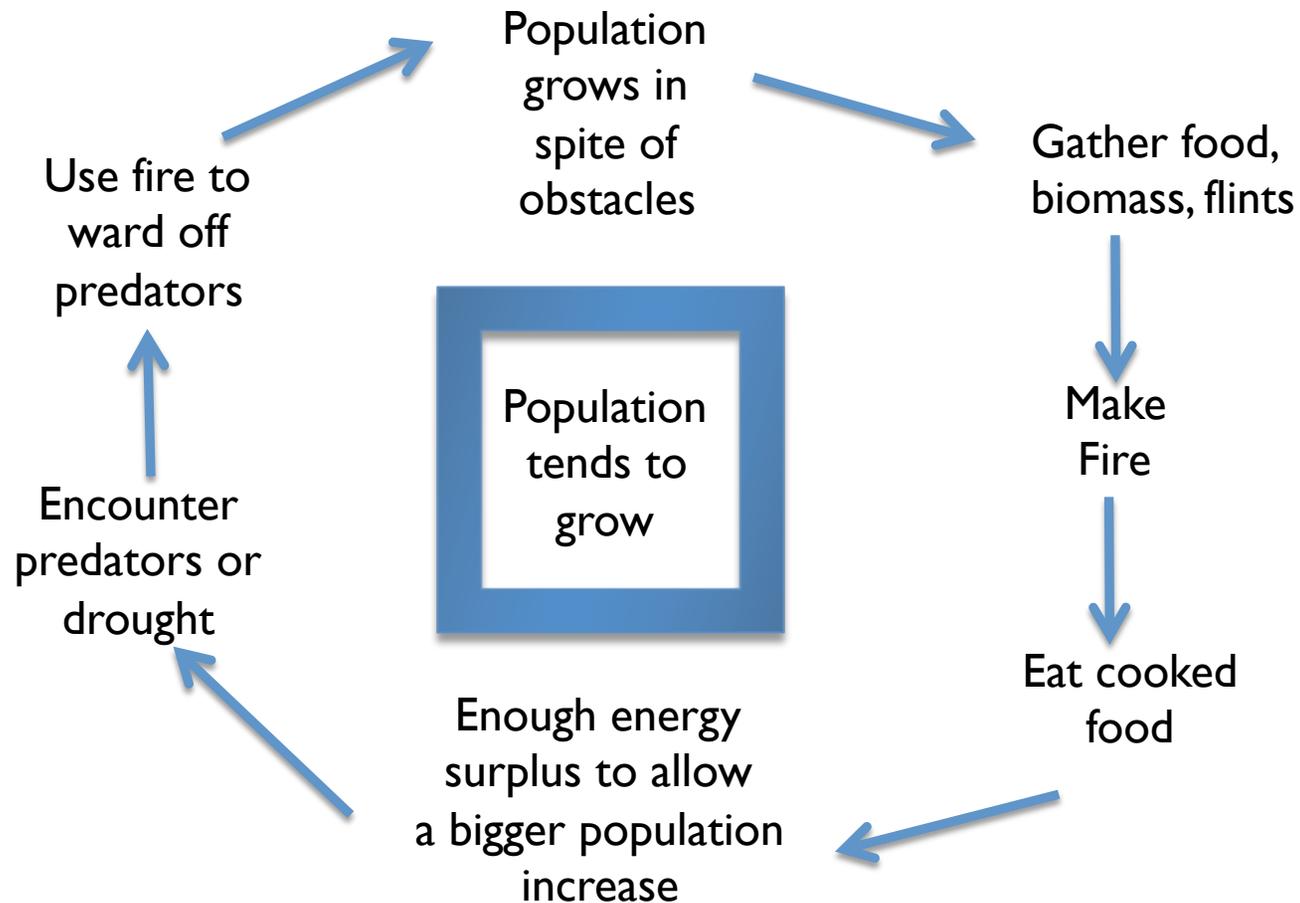
Concentration of energy

- ▶ Energy of the sun is diffuse
 - ▶ Most human physical energy is similar to that of other humans
- ▶ First use of concentrated energy
 - ▶ Taming of fire, over one million years ago
 - ▶ Didn't have to depend only on food for energy
- ▶ Use of fire allowed humans many advantages
 - ▶ Cooked food very important
 - ▶ Bigger brains; smaller jaw and gut
 - ▶ Less time chewing; more time for crafts
 - ▶ Scare predators
 - ▶ Keep warm; light in evening

Economy of a group of chimpanzees is very simple



Adding fire added a little complexity



More recent concentrations of energy

- ▶ (I) Capital goods
 - ▶ Bow and arrow; stone tools
 - ▶ Machines
 - ▶ Vehicles
 - ▶ Houses, stores, schools

Important

- ▶ Adds question of “how to pay for” capital goods
 - ▶ Workers are employed to create these capital goods
 - ▶ Need to be paid now
 - ▶ Benefit of these capital goods is spread over many years in the future
 - ▶ How can the future benefit of these capital goods be “pulled back” to today, so that these workers can be paid?

More recent concentrations of energy (continued)

- ▶ (2) Businesses and bigger businesses
- ▶ Enable more use of capital goods
 - ▶ Also allow use of cheap labor around the world
 - ▶ Allow many other services, such as trading
- ▶ Businesses have value, beyond capital goods they use
 - ▶ Example, Research and Development departments
- ▶ Have same time-shifting problem as for capital goods:
 - ▶ How can businesses get funding for their businesses, before this benefit is actually present?
 - ▶ Can't pay wages, or buy needed materials, without time shifting

More recent concentrations of energy (continued)

- ▶ (3) Governments
- ▶ Governments are similar to very large businesses
 - ▶ Main difference: ability to raise money through taxes
 - ▶ Allows governments to promise benefits based on future taxes
 - ▶ Medicare, Social Security, Unemployment Insurance
 - ▶ Programs don't appear as "debt" for government—can stop the programs "tomorrow"
- ▶ Even with taxation, governments need debt for other purposes
 - ▶ Capital goods such as roads, schools
 - ▶ Fighting wars
 - ▶ Compensate for inadequate tax revenue
 - ▶ "Stimulate the economy"

More recent concentrations of energy (continued)

- ▶ (4) Organizations combining many countries
- ▶ Examples
 - ▶ Eurozone
 - ▶ International Monetary Fund
 - ▶ World Trade Organization
- ▶ Goal: encourage globalization
- ▶ Another goal: maintain world financial system

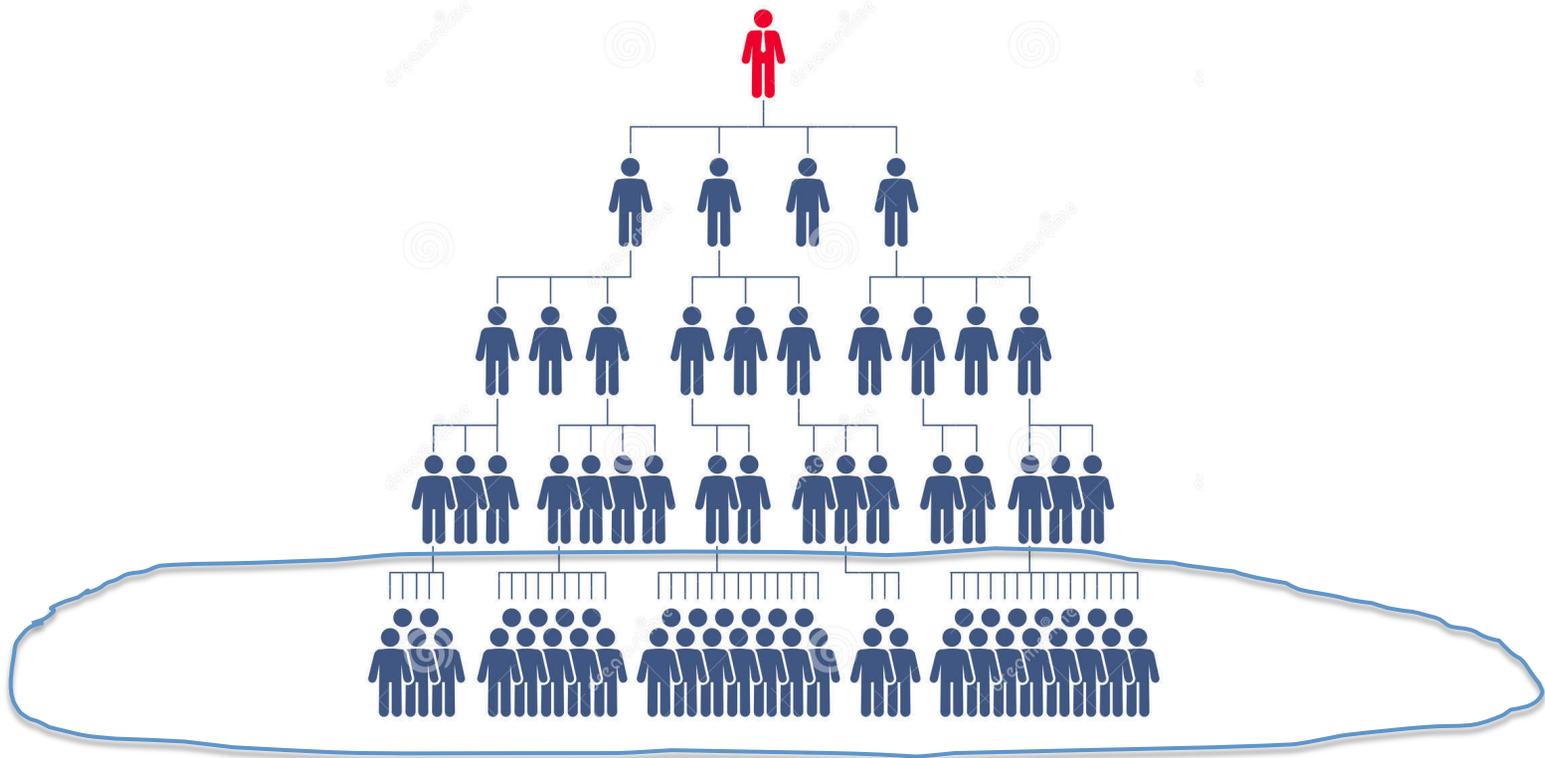
Pure elements and compounds

- ▶ Technology only “works” if it can reliably be replicated
 - ▶ Need pure resources to work with
- ▶ Related issues
 - ▶ Depletion
 - ▶ Need deeper mines; desalination of water
 - ▶ Pollution
 - ▶ Puts unwanted materials where they should not be
 - ▶ Usually very dispersed—opposite of what we want
 - ▶ Recycling
 - ▶ Tends to be very energy-intensive
 - ▶ Problem is dispersion of materials to be recycled

Leveraging of human energy through hierarchical organization

- ▶ Hunter-gatherers were all close to equal
 - ▶ Little hierarchical organization
 - ▶ Groups hunted, gathered, and burned biomass
 - ▶ Shared what they caught or made
- ▶ Settled life brought more income disparities
 - ▶ Some owned land; some did not
 - ▶ Different occupations led to different wealth
- ▶ Education is one way of giving an advantage to some workers
 - ▶ Represents a concentration of energy resources
 - ▶ Books, teachers' time, students' time are available because energy consumption allows fewer to be farmers
- ▶ Growing sizes of businesses and governments led to increased hierarchy

When population outgrows resources, people at bottom of hierarchy are most vulnerable



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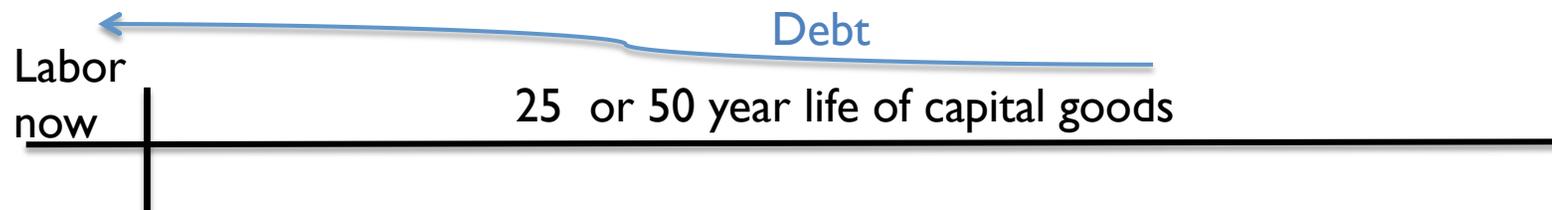
Finding based on research of Turchin and Nefedov in “Secular Cycles”

Why add debt?

- ▶ Any division of labor requires some kind of at least informal debt
 - ▶ I will hunt; you gather and take care of the children
 - ▶ Requires sharing of output
- ▶ When businesses started, need for debt became more acute
 - ▶ Can't pay workers in widgets or pixels every day
- ▶ All money is really a promise for future goods and services
 - ▶ Even gold coins
 - ▶ These future goods and services may or may not materialize
 - ▶ I would call money a form of “debt”

Why add debt? (Continued)

- ▶ Capital spending generally requires debt
- ▶ Problem: need the use of human labor and resources in one period
 - ▶ Benefit comes later and is not certain
- ▶ Need some way to pay for this labor and resources
 - ▶ Debt – Provides “money” to pay workers and to purchase resources
 - ▶ “Pulls forward” the hoped-for benefit of capital goods



Why add debt? (continued)

- ▶ Debt makes the whole system work more smoothly
 - ▶ Easier to add concentrations of all kinds
 - ▶ College education more affordable
 - ▶ Consumers can afford to buy homes, cars, vacation travel
 - ▶ Businesses can purchase other businesses
 - ▶ ***Need to add debt is part of the entropy of the system***
- ▶ Some financial approaches are not called debt, but act similarly
 - ▶ Issuance of stock is similar to debt without a time limit
 - ▶ “Equity” sounds better than debt
 - ▶ If company fails, outcome is similar
 - ▶ Derivatives act like debt
 - ▶ Government programs with promised benefits are debt-like
 - ▶ People plan their lives around them; hard to eliminate

Why add debt? (continued)

- ▶ Debt indirectly affects the price of commodities
 - ▶ More debt = more demand = higher prices
- ▶ Governments feel like they can be in charge
 - ▶ Can issue debt themselves
 - ▶ Can influence interest rates; lower rates expected to increase debt
- ▶ Debt can be carried to absurd lengths
 - ▶ Negative interest rates
 - ▶ Debt can be issued to hide problems with previous debt
 - ▶ Debt may fund capital projects with virtually no chance of payback
 - ▶ US subprime home loans in early 2000s
 - ▶ Japan: Unneeded road projects

Important

Growth in wage disparity tends to lead to falling energy prices

- ▶ Rich and poor people spend their incomes differently
 - ▶ Poor: most of income spent on commodities
 - ▶ Wealthy: most of income on services; paper investments; properties used by others
- ▶ Examples of cutbacks for poor people
 - ▶ Developed countries – Young adults live with parents longer
 - ▶ Don't buy own homes, cars
 - ▶ Less developed countries – Migrant workers in China move back to countryside
- ▶ If wage disparity increases
 - ▶ Stock markets and asset prices likely to continue to rise
 - ▶ These are bought by the rich
 - ▶ Commodity prices, including energy prices, may fall

Connection of Energy Prices with Debt Levels

Use of debt permits two different valuations of “worth” of commodities, ***both debt based***

▶ First valuation

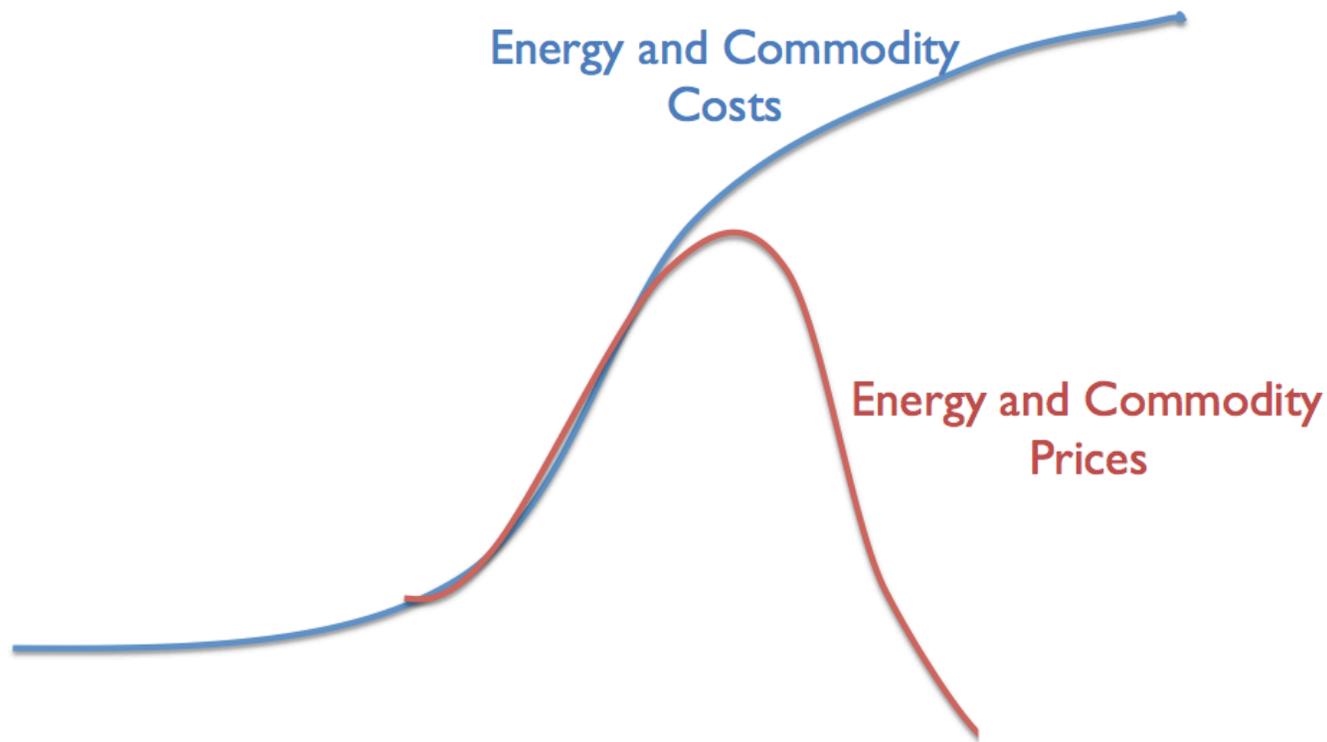
- ▶ Amount it costs to create the commodity
- ▶ Many of these cost items are “debt based”
 - ▶ Loans may be based on assumption that oil will be \$100 per barrel
 - ▶ This loan is used to pay wages

▶ Second valuation

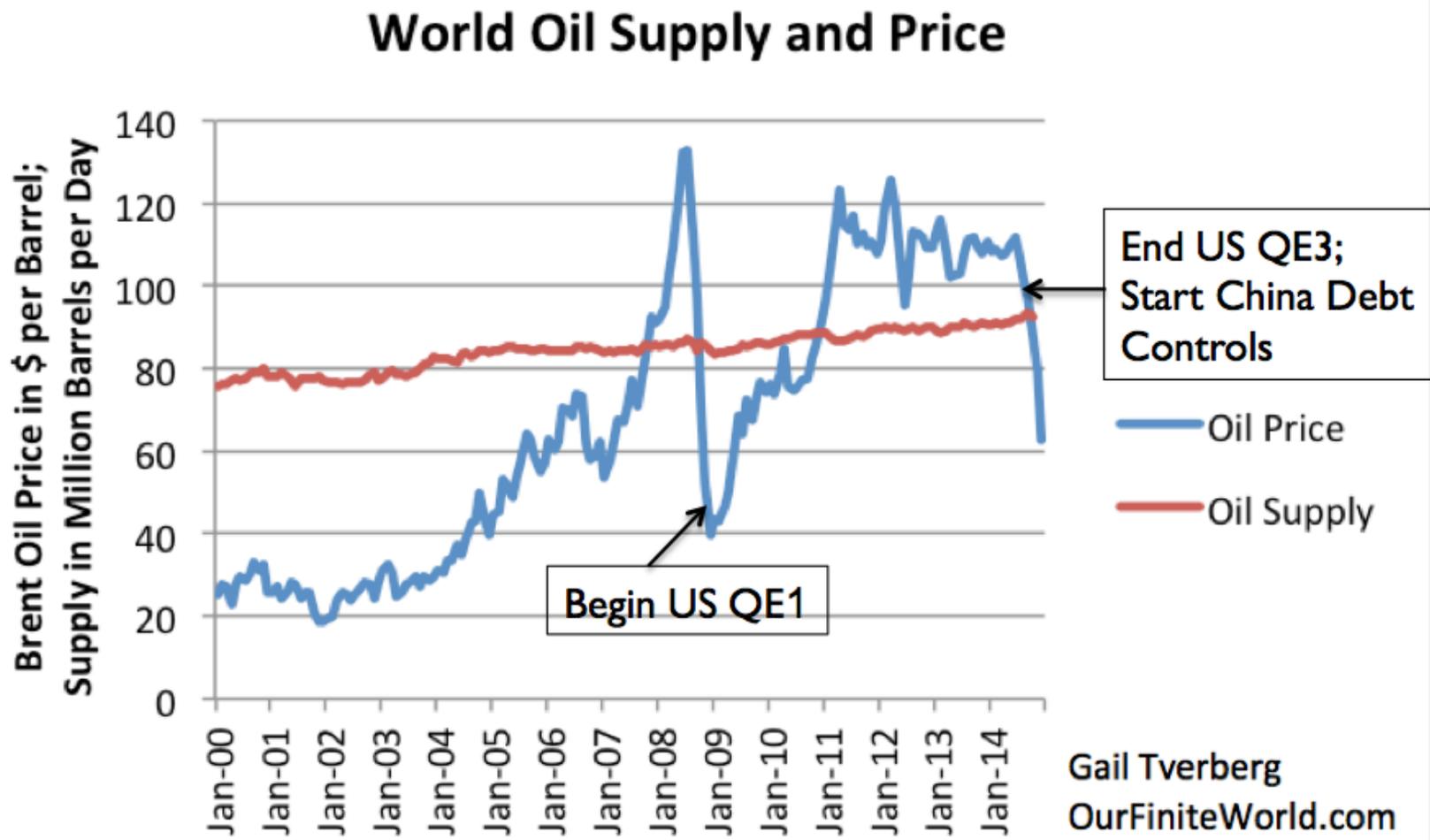
- ▶ Amount citizens of the world can afford
- ▶ This depends on combination of wages and debt
- ▶ As long as wages rise as quickly as commodity prices, affordability is usually not a problem
 - ▶ Big problem when wages of workers at bottom of hierarchy stop rising
 - ▶ Need an increasing amount of debt to hide the wage problem

Possibility of different *price* compared to *production cost* appears very late

- ▶ Mismatch is a sign that cost of energy production is higher than consumers can afford
 - ▶ No longer can be hidden by rising debt

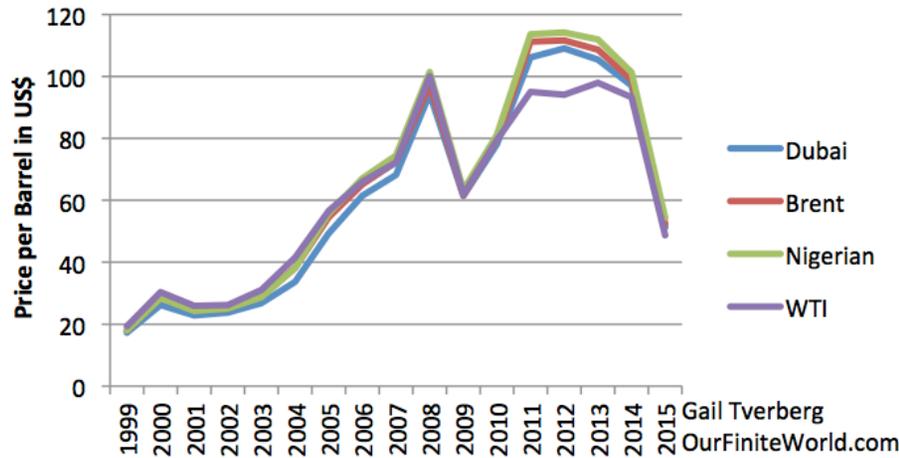


Connection with debt shown by price declines in 2008 and 2014 - 2016

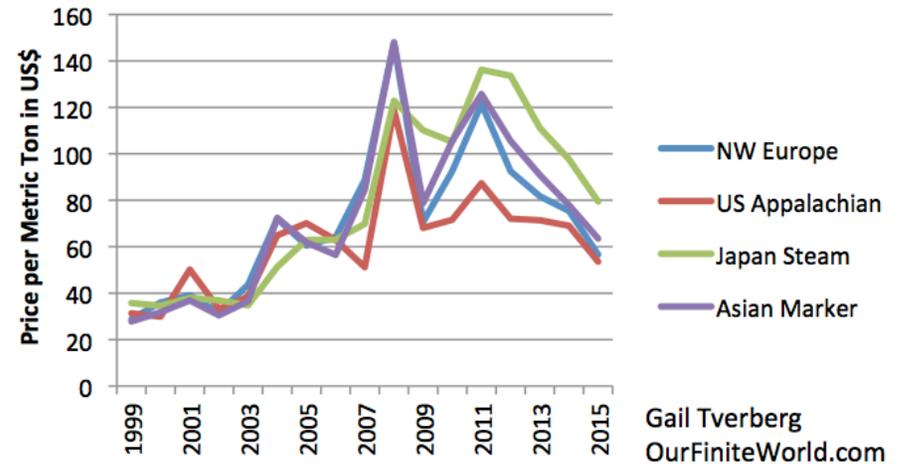


Prices of oil, coal, and natural gas tend to rise and fall together

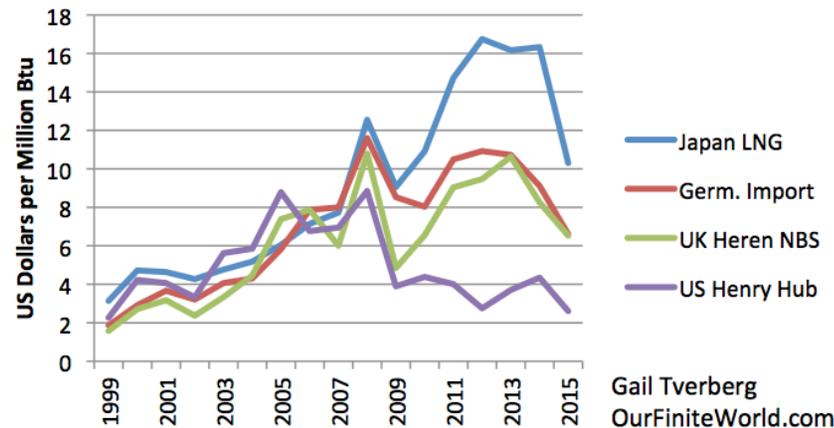
Oil Prices Since 1999



Coal Prices Since 1999



Natural Gas Prices Since 1999



Based on 2016 BP Statistical Review of World Energy

Concerns if energy prices are based on debt levels

- ▶ (1) Fossil fuel prices will stay fairly low
 - ▶ World leaders could in theory cause debt levels to rise
 - ▶ Haven't succeeded so far
 - ▶ Partly has to do with relativities of various currencies
 - ▶ Negative interest rates--latest attempt to fix problem
- ▶ (2) All fossil fuels will peak simultaneously
 - ▶ Peak will come because of low prices
 - ▶ Won't follow Hubbert curve

Hubbert developed model based on assumption of no complexity; no entropy

- ▶ Also, nearly unlimited supply of alternate fuel

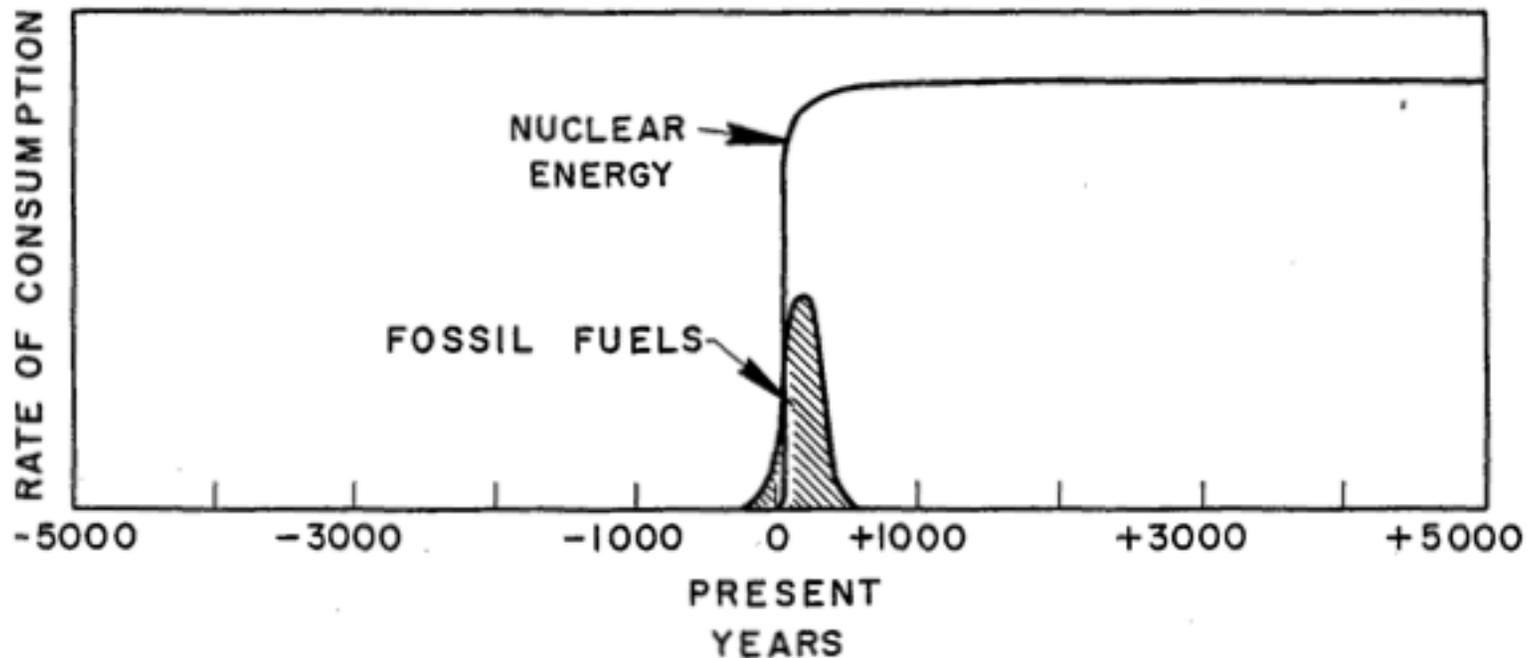


Figure 30 - Relative magnitudes of possible fossil-fuel and nuclear-energy consumption seen in time perspective of minus to plus 5000 years.

Source: <http://www.hubbertypeak.com/hubbertype/1956/1956.pdf>

Using Hubbert's model, "running out" of fossil fuels is the big concern

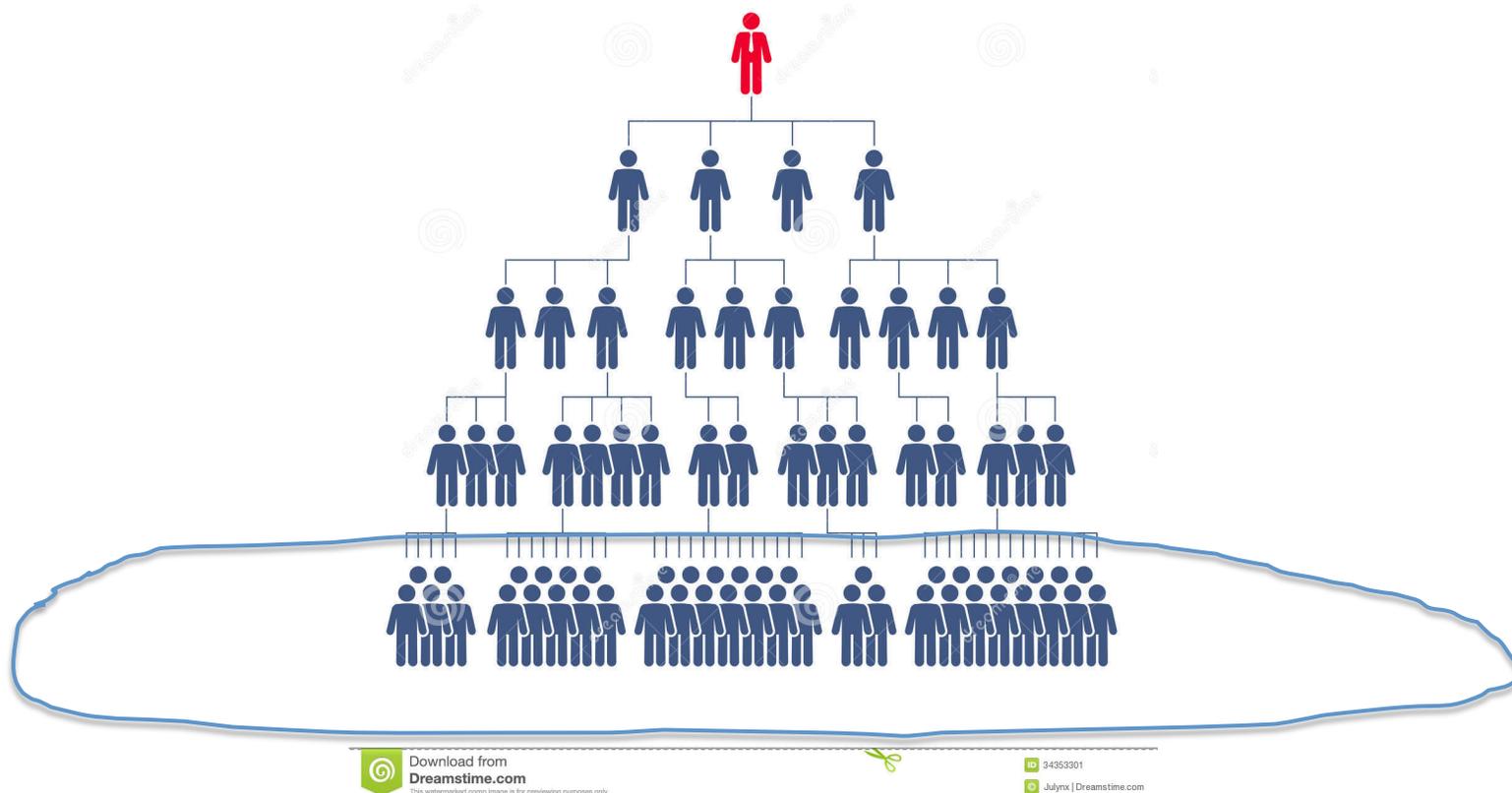
- ▶ If running out the big concern, need substitutes that minimize fossil fuel use
 - ▶ EROI based on fossil fuel use is well suited to this task
 - ▶ Simply choose fuels with highest EROIs
- ▶ There is no rule saying that models need to be "complete"
 - ▶ In fact, they generally aren't
- ▶ Economists did not provide adequate guidance on how the economy really works
 - ▶ "Running out" was the view of most analysts
 - ▶ Choosing EROI thresholds seemed sufficient to recognize how the economy works

Candidates for what brings the system down if problem is complexity, entropy

- ▶ Too much un-repayable debt
- ▶ Too many people without jobs, or with only low-paying jobs
 - ▶ Cannot afford to buy the output of the system
- ▶ Too much pollution
- ▶ Government organizations start falling apart
 - ▶ UK starts the trend by leaving Eurozone
- ▶ Energy exporters collapse from lack of revenue

What metric is most similar to EROI of fish?

- ▶ My answer: Metric based on buying power of workers and unemployed at the bottom of the hierarchy



If wages are high enough, non-elite workers can buy the goods and services they need

- ▶ Corresponds to adequate return on human energy



Sources: https://commons.wikimedia.org/wiki/File:Grape_worker.jpg

http://www.clipartpanda.com/clipart_images/cell-phone-icon-png-36533728

What fossil fuel EROI comparisons miss

- ▶ (1) Energy sources based primarily on capital goods have higher debt needs than other energy sources
 - ▶ Examples: wind, solar PV, nuclear
- ▶ (2) Debt and equity financing have real costs associated with them
 - ▶ Equal to interest and dividend costs, for many years
 - ▶ Also, ratio of debt to GDP tends to hit a maximum level

What fossil fuel EROI comparisons miss (continued)

- ▶ (3) Intermittent sources of electricity cannot be compared to non-intermittent ones
 - ▶ Complexity requires that all grid electricity be of high quality
 - ▶ EROI calculations should include cost of removing intermittency; fixing other “issues”
- ▶ (4) EROI calculations do not consider the need for high energy concentrations
 - ▶ Oil not comparable to coal because of higher energy concentration
 - ▶ Financial cost comparisons may be better

Conclusions

- ▶ We may have hit peak total energy per capita in 2013
- ▶ Debt problems seem to be keeping fossil fuel prices low
 - ▶ Any future economic system will likely also require debt
- ▶ Hubbert's model represents a simplification
 - ▶ Omissions may distort the model's predictive power
- ▶ EROI of human labor is a measure of what workers at the bottom of the hierarchy can sell their labor for
 - ▶ This EROI cannot fall too low, or the system will not have enough buyers for its output

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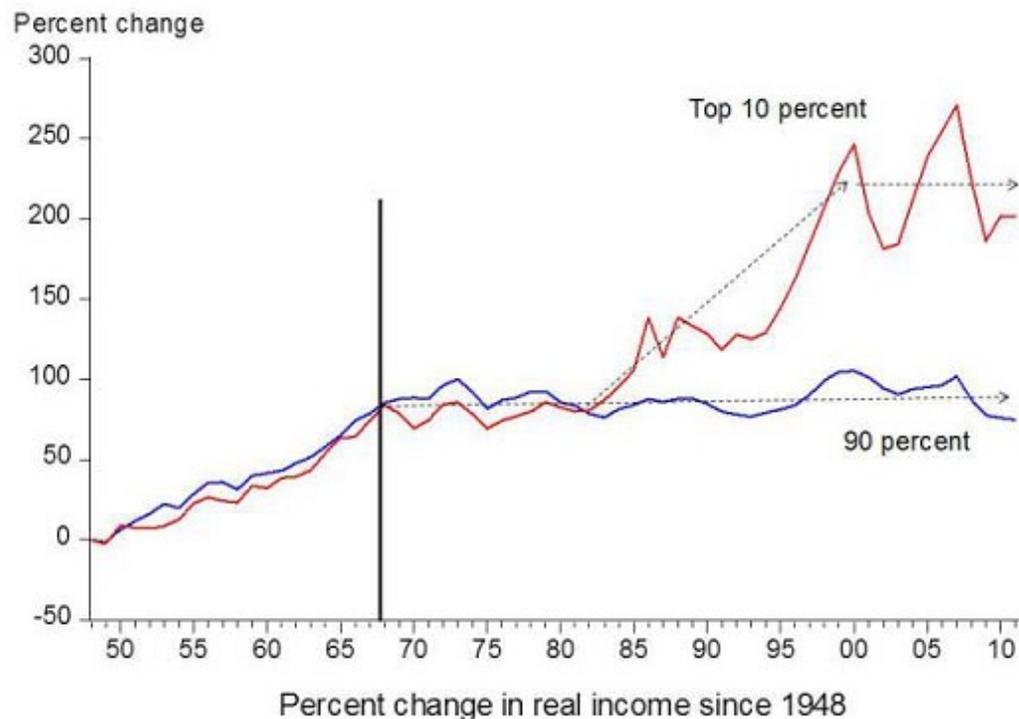
Supplemental information on income disparity

- ▶ Two ways incomes can become more unequal
 - ▶ (1) Same number of workers; some get paid more
 - ▶ Globalized companies need to compete world-wide
 - Leads to pressure to pay leaders more
 - ▶ Larger proportion of highly educated workers
 - ▶ (2) Some workers drop out of workforce
 - ▶ Need to spend more years in school, so not working
 - ▶ First advanced education in area with few jobs
 - Need to start over on new educational path
 - ▶ Wages so low that they don't cover transportation, child care
 - ▶ Lose good-paying job to overseas competition or automation
 - Only alternative jobs are minimum wage, part-time

Supplemental information on income disparity (continued)

US wages stopped growing with productivity gains about 1968 – 1970 (US peak oil)

Wages started becoming more unequal in 1981 (Reagan growth in debt)



By Emmanuel Saez, based on an analysis IRS data, <http://www.forbes.com/sites/louiswoodhill/2013/03/28/the-mystery-of-income-inequality-broken-down-to-one-simple-chart/#3c4802a94f486c7362f94f48>

Supplemental information on income disparity (continued)

- ▶ US labor force participation rates plateaued about 1998; starting falling in 2002
- ▶ Corresponds to globalization dates; China joined WTO in 2001

