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Peak Oil, Secular Stagnation, and the Quest for Sustainability

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22.1 Introduction [1]

As we write and rewrite these final chapters, in 2010 and then 2017, the US national economy continues to struggle. There has been little inflation-corrected growth of the economy for more than a decade, wages for most Americans remain stubbornly low. The stock market crashed during the Great Financial Crisis, beginning in the summer of 2007. By 2009, the Dow Jones Industrial Average was down from its then-historic high of 14, 198 points to a low as 8000, barely half the peak of the preceding fall. However, the stock indexes have subsequently recovered, with the post-crisis period surpassing all previous records. As of November 10, 2017, the Dow Jones Industrial Average stood at 23,422.21, an all-time high. This boom in stock values, coupled with wage stagnation, has been a primary driver of the inequality mentioned in Section III. In 2014, economists Emmanuel Saez and Thomas Piketty found that during the recovery, from 2009 to 2012, that the top 1% of income earners received 95% of all the gains in income [2]. More than half of this increase was from capital income and capital gains. Since stock prices have increased another 58%, there is no reason to believe that the share of the top 1% of income earners has decreased. Many of our states are facing severe budgetary problems, schools and colleges everywhere are facing severe budget shortfalls. Political promises of the left and the right are increasingly viewed with suspicion or hostility. The rich get richer, and the poor get poorer.

The most abrupt change in our economy began in the summer of 2008 with the highest oil prices ever (almost $150 a barrel) and historically high prices for other energy and most raw materials. The Dow Jones Industrial average was down from its then historic high of 14,198 to as low as 8000, barely half the peak the preceding fall. Each week the stock market lost 5% or 10% of its value. A series of disasters struck the financial markets, with many of the largest, most prestigious, and seemingly impervious companies declaring bankruptcy, by the end of November. Many investors lost from one-third to one-half of the value of their stocks. Since then the financial markets have recovered, but the growth of the real economy has been tepid, at best. Europe and Japan have continued to grow very slowly, if at all, a situation called "secular stagnation." Few understand the role of energy in either secular stagnation or as a driving force in the financial explosion. In earlier years, periods of financial excess would occur at the end of boom periods of economic growth. However, since the 1970s, financial speculation showed marked increases even in times of slow growth or recession. Mainstream economics tends to view the rise of the financial sector and speculation as a drain on the economy, as investment in the real economy (factories, mines, oil wells) is displaced by purely financial investments in paper claims on real assets. Yet, if one believes, as do we, that the normal state of a monopolized economy is towards slow growth or stagnation, then profit expectations in the real economy decline with growing excess capacity. Money channeled into finance would not necessarily be invested in the real economy. It may not be invested at all, but held as cash in corporate coffers. Perhaps financial speculation is one of the few things that is keeping the economy growing at a tepid 2%, rather than experiencing permanent recession or depression. After the financial crash, the nation's central bank, or the Federal Reserve, flooded the economy with liquidity to avoid another great depression. Most of this money flowed into the financial sector, propping up stock prices [3].

Fewer still understand the underlying role of energy. The North Sea, once the source of enormous amounts of oil for the United Kingdom and Norway, has declined greatly. Europe is again beholden to Russia and the Middle East for its economic lifeblood. The summer of 2017 also saw the twelfth year in a row in which the global production of conventional oil essentially did not rise (although there was a modest increase in "all liquids", often reported as "oil", driven by an increase in natural gas liquids) leading some to say that the long predicted "peak oil," the time of maximum global oil production, had indeed arrived. Total energy use in the United States had not increased for almost a decade. The use of oil went down by about eight percent since its peak in early 2008. World conventional oil production has essentially been flat. It is not quite clear whether this is a good sign of decreasing use of CO_2-emitting fossil fuels or a sign that our economies are beginning to be in real trouble. Meanwhile, populations and their aspirations continue to increase relentlessly in much of the "less-developed" world, especially India and China.

From the point of view of mainstream economics and business executives, economic growth is the most important of all goals. Most policies are justified to the degree that their proponents say they will produce economic growth. But if the energy needed to drive economic growth is in decline, and the concentrated economy produces slow growth on its own terms, then perhaps few, if any, policies can produce economic growth. Slow growth is likely to become "the new normal," for both biophysical and internal economic reasons. A group to which we belong believes that the world has entered a new mode, one that was predicted in many ways in the 1960s and 1970s by some geologists, ecologists, and economists. This is a world of limits, one in which our once-trusted tools of conventional economics are no longer sufficient by themselves, if indeed they ever were, of righting economic wrongs and allowing us all to maximize our material well-being. While there is no question that under the auspices of conventional economics, many parts of the Western world, and increasingly Asia, have done very well in increasing human material well-being, the perspective that we raise is whether our growth in wealth has been due to really understanding our economies or, as we believe, more to simply our increased ability to pull more cheap oil, gas, and coal out of the ground to allow the increased economic work that is the basis of our wealth. To some extent, any set of theories about economics in the past was bound to be at least partly correct because with more and more energy it was possible to generate more and more wealth, whatever one's theoretical premises!

22.2 What Is the Source of the Crash of 2008?

Many factors merged to cause the financial crash of 2008—the subprime mortgage crisis, high foreclosure rates, and Wall Street's sale of opaque financial products known as derivatives. Behind these are many aspects of greed, corruption, and malfeasance, not to mention the moral hazard caused by lax political oversight. It is not the intent of this book to focus on the personalities and moral shortcomings behind these issues, but we believe one good and detailed summary of much of this can be found at ▶ http://www.informationclearinghouse.info/article28189.htm. While we do not wish to downplay these "moral" issues, we also believe that the root cause of the current downturn and our difficulty in climbing out of the recession was the same one that sparked four out of the last five world recessions: the high price of oil [4]. Why did most economists and financial analysts (and models like the Wharton model) not see this coming? One hypothesis, advanced by Nobel laureate Paul Krugman is that the economics profession "went astray because economists, as a group, mistook beauty, clad in impressive-looking mathematics, for truth" [5]. We agree. As the market debacle has shown, mathematical elegance in economics is not a substitute for scientific rigor, something we have discussed in many previous papers [6, 7], and in chapter 20. If physical quantity of energy and its effect on energy prices are crucial functions impacting the economy, and they are not in our models, then of what utility are the models?

As of this writing, global production of conventional oil has been nearly flat since 2005, so that peak oil, or at least a cessation of reliable growth at the former rate of two to four percent per year, appears to have occurred—with the remaining debate only about whether there may be a subsequent peak and how soon we begin a slide down the other side, even given the temporary respite from hydraulic fracturing. If we have passed the global peak in oil production, then indeed the end of cheap oil will soon be upon us, and our ability to grow or even maintain economies is likely to decrease. Because of the critical importance of liquid and gaseous petroleum for essentially everything we do, we have serious reservations as to whether conventional economics and business or governmental policies can guide us again to growth or indeed to manage an economy where growth is no longer possible (e.g., ◘ Fig. 4.10). Thus the question becomes: "Can we improve upon our ability to do economics and financial analysis by using procedures that focus more on the energy available (or not) to undertake the activity in question?" In other words, are finances beholden to the laws of physics?

We think yes. Thus the question becomes: can we supplement or improve upon our ability to do economics? Resource scientists have predicted such a financial crash, or more accurately cessation of growth, for a long time [7–11]. Any good physical or biological scientist knows that all activity in nature—or anywhere—is associated with energy use. Consequently, many in the scientific community were not the slightest bit surprised by the financial crash or its timing. Colin Campbell, a former oil geologist and cofounder of the Association for the Study of Peak Oil, predicted in 2006 that we are likely to see an end of year after year economic growth and a movement to an "undulating plateau" in oil production, prices, and economic activity, with periodic high prices in oil-generating financial stress and a cessation or even reduction of growth. These financial strains would, in turn, cause a decrease in oil use and hence a price decline, with lower oil prices then leading to new economic growth and new increases in oil use and, eventually, oil prices. In other words, he foresaw very large impacts of restrictions in oil availability, and consequent price increases, on the market. According to Campbell, "Every single company on the stock market is overvalued from the perspective of what the cost of running that company will be after peak. Value is determined by performance which has been based on cheap oil." This approach has been used to develop a model by Murphy and Hall [9] which seems to be a pretty good predictor of the present situation.

Many other analysts have remarked upon, and even predicted, the probable impact of peak oil, or at least oil price increases, on the financial status of the United States and the world. A thoughtful, chilling, and ultimately correct view of the implications of peak oil on the American economy was presented by Gail Tverberg in January 2008 on the energy blog site "The Oil Drum" [10]. Her predictions, which we thought impossibly pessimistic at the time, have been vindicated in great detail. Many analysts foresaw these issues as early as the 1960s, including the authors of the famous but cavalierly dismissed "Limits to Growth" study of 1972, ecologists Garrett Hardin and Howard Odum, economists Kenneth Boulding, Paul Baran, Paul Sweezy, Nicholas Georgescu-Roegen, John Bellamy Foster and others. But for those who bothered to read and think about what these authors were saying, the future is clear. Charles Hall made his retirement decisions in 1970 based on the assumption that peak oil and a crash of stocks would occur in about 2008 [11]. The reason is that all of these people understood that—of necessity—real growth is based on growth in real resources, and that there are limits to those resources. The case for peak oil was clearly laid out almost 60 years ago by Hubbert [12, 13] who predicted, in 1955 that the US peak in oil production would occur in 1970, which it did. The United States has struggled to exceed the 1970 value in the intervening half century but has not done so as of November 2017 (see Fig. 7.5) and still imports nearly half the oil it uses.

While many economists place a great deal of faith in increasing technology, in fact technology does not operate on a static playing field but continually competes with declining resource quality. There is little or no evidence that technology is winning this game over time because the energy return on investment keeps falling [14–17]. It is important to understand that, at least so far, the Limits to Growth model is an almost perfect predictor of our current situation [18]. Resource-based analysts understand and appreciate that the recent turmoil in much of our financial structure has many plausible causes. But they also know energy underlies all of these issues. The fundamental dilemma is this: if oil, the most important energy source to fuel the economy, goes through the inevitable path of growth, plateau, and eventual decline (i.e., peak oil) while the financial market is built on the assumption of unfettered growth, then something has to give. Eventually the aspirations and assumptions of indefinite growth in assets, production, and consumption must collide with the reality of an ever-constricted source of the energy that fuels real growth.

Part of the financial stress is attributable to cheap oil that then becomes dear. Starting in the early 1990s, relatively inexpensive oil, declining interest rates, and globalization all contributed to economic growth and to declines in risk premiums for virtually all asset classes. Capital went further out on the risk curve to make up for reduced returns and increased leverage (that is, a reduction in "money in the vault" relative to what was loaned) became the new norm. As volatility seemed to disappear, even more leverage was piled on to the system. Along with the changing landscape in global credit markets came cheap financing for US home buyers. The low price of energy also greatly increased discretionary income which further encouraged people to take advantage of this cheap financing, adding to massive residential development. According to financial analyst George Soros this created a self-reinforcing "reflexive" system, where increasing home values increased collateral, which encouraged further borrowing in the household sector and in lines of credit for consumption and so on [19]. The system had been built on the premise that large amounts of discretionary spending would always be available and the notion that everyone was entitled to a McMansion, a "lawyer foyer," and a home theater. Since the construction of homes far outpaced population growth, most of the growth was due to the perceived demand for these larger houses. To get the area needed, we had to build out from the cities. The largest growth in real estate had been in the exurban areas, which were most vulnerable to gas price spikes.

Discretionary wealth—that which is available for nonessential investments and purchases—is extremely sensitive to volatile energy prices [21]. Since most oil use is not discretionary but needed for getting to or undertaking work, it is relatively price inelastic, that is the response of consumers is not particularly sensitive to changes in price. Consequently, discretionary income dropped substantially when gasoline and other energy prices, which had been creeping up from a very low level in 1998, increased sharply in 2007–2008. The United States reached a "tipping point" in 2006–2008 [20] as the price of oil rose temporarily to nearly $150 a barrel. The assumption that the suburban lifestyle would be sustainable became a question in many potential owner's mind. This perception appeared to be an important initiator of a decline in aggregate demand, particularly for exurban real estate. It also may have initiated the massive de-leveraging initiated we are now experiencing globally. (There is a good summary of the various analyses by Rubin, Hamilton, and others who argue that oil price increases were behind these, and past, recessions [22–23]). Massive household debt could not be supported when the value of the underlying collateral declined: a decline triggered by the spike in energy prices. As the collateral disappeared, huge derivative positions that had been built in the previous decade experienced margin calls. A spiral of forced selling pressured all asset classes further, and forced the banking sector essentially to freeze in September of 2008. Will this faltering of the suburban model be a preview of our ultimate response to peak oil? Perhaps. Examining the general pattern of oil price increases and probability of them continuing can help us understand these things better in the longer term.

22.3 Energy Price Shocks and the Economy

At the start of 1973, oil was cheap at $3.50 a barrel. The United States was still the world's largest producer. Peak oil had just occurred in the United States in 1970, but no one noticed. The economy kept growing, fueled by increasing oil imports. As domestic oil production in the United States declined from 1970 to 1973, foreign suppliers gained leverage. In late 1973, both political events that precipitated the Arab Oil Embargo and an accident that severed an export oil pipe in the Middle East caused the price of oil to jump from 3 to 12 dollars a barrel. In a matter of months, these events created the largest recession since the Great Depression. The price spike had at least four immediate effects upon and within the economy: (1) oil consumption declined, (2) a large proportion of capital stocks and existing technology became too expensive to use, (3) the marginal cost of production increased for nearly every manufactured good, and (4) the cost of transportation fuels increased.

By 1979, the price of oil had increased by a factor of 10, to $35 a barrel. The proportion of gross domestic product that went to buying energy increased from 6% to 8% to 14%, restricting discretionary spending while causing previously unseen "stagflation". The prices of other energies, and commodities more generally, increased at nearly the same rate, driven in part by the price increase of the oil that was behind all economic activities. Then, in the 1980s, all around the world, oil that had been found but not developed (as it had not been worth much previously) suddenly became profitable, and it was developed and overdeveloped. By the 1990s, the world was awash in oil, and the real price fell to nearly what it was in 1973. The energy portion of GDP fell to about 6%, essentially giving everyone an extra 8% of their incomes to play with. The impact on discretionary income, perhaps a quarter of the total, was enormous. Many invested in the stock market, but then found themselves victims of the "tech bubble" of 2000, as excess capacity began to build in the technology sector. Real estate was considered a "safe" bet, so many invested in what was really surplus square footage. Speculation became rampant as real estate became valued for its financial returns rather than as a place to live. For a while, it seemed as if investment in real estate was a sure path to wealth. As we now recognize, most of that increase in wealth was illusory. With energy price increases from 2000 to the summer of 2008, an extra 5% to 10% "tax" from increased energy prices was added to our economy as it had been in the 1970s, and much of the surplus wealth disappeared. Speculation in real estate was no longer desirable or possible as consumers tightened their belts because of higher energy costs. Then the housing market crashed.

While this energy perspective is not a sufficient explanation for all that has happened, the similar economic patterns in response to the energy price increases of both the 1970s and of the last decade give the "energy trigger" considerable credibility. In systems theory language, the endogenous aspects of the economy that the economists focus on (Fed rates, money supply, etc.) became beholden to the exogenous forcing functions of oil supply and pricing that are not part of economists' usual framework.

22.4 The Relation of Oil and Energy More Generally, to Our Economy

While economics is overwhelmingly taught as a social science, in fact, our economy is completely dependent upon the physical supply and flow of resources. Specifically, our economy is overwhelmingly dependent upon oil, which supplied about 40% of US energy use in the 2000s, followed by natural gas and coal at about 25% each, and nuclear at a little less than 5%. Hydropower and firewood supply no more than 4% each. Wind turbines, photovoltaics, and other "new solar" technologies together account for less than 2% (although that percentage may be increasing). Global percentages are similar. Our economy has been based on increased use of fossil fuels for most of its growth. Until 2008, we added much more new capacity with fossil fuels than with new solar, which has added a bit to the total use rather than displaced fossil fuels. Since 2008, growth in both energy and the economy has been very slow (Fig. 13.5), and the remaining economic activity is still based on about the same energy mix, although in the US gas is displacing coal.

Because of the enormous interdependency of our economy, there is not a huge difference in the energy requirements for the various goods and services that we produce. A dollar spent for most final demand goods and services uses very roughly the same amount of energy no matter what the good or service is. An exception is money spent for energy itself, which includes the chemical energy plus another ten or so percent which is the energy needed to get it (i.e., the embodied energy). For 2017 an average dollar spent in the economy required about 5 megajoules for that activity. Money spent for chemicals such as paint might use 12, but for most final demand goods and services the number is nearer to the mean. For heavy construction in the petroleum industry, the estimate is about 11 MJs per dollar and for very heavy industry such as obtaining oil and gas about 16 MJs per dollar. Year by year less energy is used per dollar, due mostly to inflation but also increasing efficiency, especially as the economy turned from goods to services and manufacturing moved overseas. There continues to be decreasing energy return on energy invested (EROI) for our major fuels as we go after ever more difficult resources [15–17].

22.5 Energy and the Stock Market

We include here some preliminary analyses that we think show the importance of energy to Wall Street and the economy more generally. First, Wall Street prices reflect not only something about the real operation of the economy but also a large psychological factor often called "confidence." Our hypothesis is that the energy used by the economy is in some sense a proxy for the amount of real work done. Thus over time, the inflation-corrected Dow Jones Industrial Average (DJIA), an index of financial speculation about the potential future profits of top industrial corporations, should have the same basic slope as the use of energy in society. It should also "snake" around the real amount of work done, reflecting issues of confidence, speculation, and so on. Over sufficient time, however, the DJIA must return approximately to the real energy use line. To test this hypothesis, we plotted the DJIA from 1915 until 2008 along with the actual use of energy by the US economy. Our hypothesis would be supported if the slope of these two lines are similar over the longer time period. In fact from 1915 until 2010, the DJIA had the same basic slope as the use of energy, and it has greater variability, consistent with our hypothesis (Fig. 7.8). We hypothesize that the Dow Jones will, over the long run, continue to snake about the total energy use in response to periods of irrational exuberance and the converse. If US total energy use continues to stagnate or decrease, as it has for the last decade, this hypothesis implies no sustained real growth for the Dow Jones. Investors and analysts should question whether any speculative boom can continue indefinitely. Failure to assess critically this possibility was a factor in both the financial panic that preceded the Great Depression, and the in Great Financial Crisis of 2008-09.

In the past, we also hypothesize that the amount of wealth generated by the US economy should be closely related to fuel energy use. Cleveland et al. found that the gross national product of the United States was highly correlated with quality-corrected energy use from 1904 to 1984 ($R^2 = 0.94$) [24]. This high correlation appeared to be much poorer for the period 1984 until 2008, a period during which inflation-corrected GDP doubled while energy increased by only a third. It is possible that the divergence is due not to increasing efficiency but rather an increasing proclivity of governments to underreport on inflation (see the online group ► shadowstatistics.com). Correcting for this, if indeed that is needed, would make the relation of energy use and GDP growth much tighter through the 1990s and 2000s. Also, it is very clear that much of U.S. heavy industry has been moved overseas, although we still import the products.

22.6 A Financial Analyst Concurs

Jeff Rubin, Chief Economist at CIBC World Markets, wrote in a recent book that defaulting mortgages are only one symptom of the high oil prices [22]. Higher oil prices caused Japan and the European Nations to enter into a recession even before the most recent financial problems hit. According to Rubin: oil shocks create global recessions by transferring billions of dollars of income from economies where consumers spend every cent they have, and then some, to economies that sport the highest savings rates in the world. While those petro-dollars may get recycled back to Wall Street by sovereign wealth fund investments, they don't all get recycled back into world demand. The leakage, as income is transferred to countries with savings rates as high as 50%, is what makes this income transfer far from demand neutral. By any benchmark, the economic cost of the recent rise in oil prices is nothing short of staggering. The oil impact is much more staggering than the impact of plunging housing prices on housing starts and construction jobs, which, according to the press, has been the most obvious brake on economic growth from the housing market crash. And those energy costs, unlike the massive asset write downs associated with the housing market crash, were borne largely by Main Street, not Wall Street, in both America and throughout the world. This big increase in oil prices has caused the annual fuel bill of OECD countries to increase by more than $700 billion a year, with $400 billion of this going to OPEC countries. Rubin asks: "Transfers a fraction of today's size caused world recessions in the past. Why shouldn't they today?" We and others believe that there is ample evidence that our economy is beholden to energy supplies and prices, and that good investors and good economists need to learn a great deal more about energy. This is one reason why we are attempting to tackle this problem head on through the development biophysical economics. But getting the economists to rethink their intellectual training will be a tough job, no matter how much that is needed [23].

22.7 Is Growth Still Possible?

There was little inflation-corrected growth of the US economy or in its use of energy from 2004 through about 2015. Is this just part of the normal business cycle or something new? Numerous mainstream theories have been posited over the past century that have attempted to explain business cycles. Each offers a unique explanation for the causes of—and solutions to—recessions, including Keynesian Theory, the Monetarist Model, the Rational Expectations Model, Real Business Cycle Models, NeoKeynesian models, etc. Yet, for all the differences among these theories, they all share one implicit assumption: a return to a growing economy is both desirable and possible, i.e., GDP can grow indefinitely. Historically, the US economy has grown at rather slow average rate of 1.9% per year since the Civil War. Some decades, such as the 1890s or the

1930s, showed profound declines. However, the decades after the Second World War until the 1970s showed sustained growth. Economists began to take the unique postwar phenomenon as normal. Of course, economic growth in the era preceding the use of fossil fuels was less than 1%. But if we are entering the era of peak oil, then for the first time in history we may be asked to grow the economy while simultaneously decreasing oil consumption, something that has yet to occur in the United States for 100 years. Oil more than any other energy source is vital to today's economies because of its ubiquitous application as transportation fuel, as a portable and flexible energy carrier and as feedstocks for manufacturing and industrial production. Historically, spikes in the price of oil have been the proximate cause of most recessions [4]. On the other hand, expansionary periods tend to be associated with the opposite oil signature: prolonged periods of relatively low oil prices that increase aggregate demand and lower marginal production costs, all leading to, or at least associated with, economic growth. This has happened (modestly) from 2008 to 2017.

By extension, for the economy to sustain real growth there must be an increase in the flow of net energy (and materials). Quite simply economic production is a work process and work requires energy. Thus to increase production over time, i.e., to grow the economy, we must either increase the energy supply or increase the efficiency with which we use our source energy. This is called the energy-based theory of economic growth. This logic is an extension of the laws of thermodynamics, which state that: (1) energy cannot be created nor destroyed, and (2) energy is degraded during any work process so that the initial inventory of energy can do less work as time passes. As Daly and Farley [26] describe, the first law places a theoretical limit on the supply of goods and services that the economy can provide, and the second law sets a limit on the practical availability of matter and energy. In other words, to produce goods and services energy must be used, and once this energy is used it is degraded to a point where it can no longer be reused to power the same process again.

22.8 An Energy-based Theory of Economic Growth

This energy-based theory of economic growth is supported by data: the consumption of every major energy source has increased with GDP since the mid-1800s at essentially the same rate that the economy has expanded (Figs. 22.1 and 22.2). Throughout this growth period, however, there have been numerous oscillations between periods of growth and recessions. Recessions are defined by the Bureau of Economic Research as "a significant decline in economic activity spread across the economy, lasting more than a few months, normally visible in real GDP, real income, employment, industrial production, and wholesale-retail sales" [27]. From 1970 until

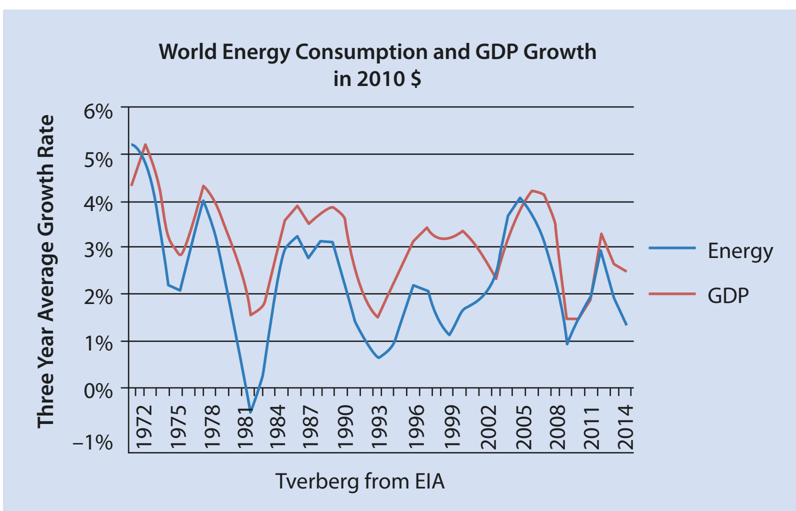

Fig. 22.1 Correlation of year on year (YoY) changes in oil consumption with YoY changes in real GDP, for the United States from 1970 through 2008 (Source: Gail Tverberg. Oil consumption data from the BP Statistical Review and real GDP data from the St. Louis Federal Reserve)

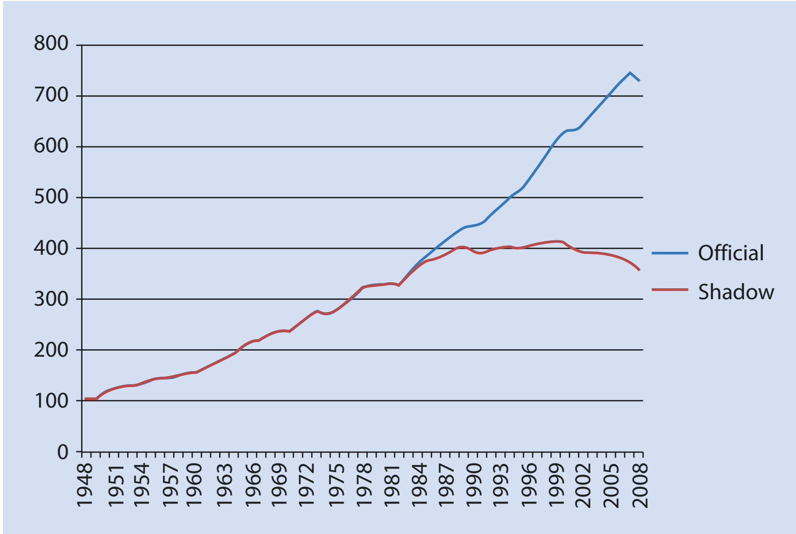

Fig. 22.2 One attempt to correct the GDP for the "deflated" inflation factor by using the inflation corrections year by year since 1984 supplied by the group shadowstatistics. If larger inflation estimates are used, the economy has grown very little since 1984, and there may have been no improvement in efficiency which is how energy is changed to GDP (Source: Hannes Kunz) (see also: ▶ http://www.leap2020.eu/the-true-us-gdp-is-30-lower-than-official-figures_a5732.html)

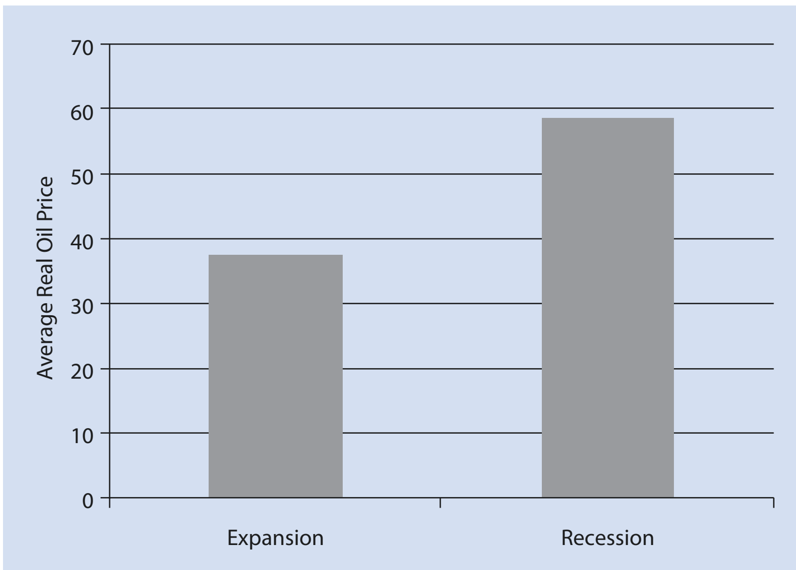

Fig. 22.3 Real oil prices averaged over expansionary and recessionary periods from 1970 through 2008

2007, there have been five recessions in the United States. Examining these recessions from an energy perspective elucidates a common mechanism underlying each recession: oil prices are lower and oil consumption increases during periods of economic expansion while oil consumption decreases and oil prices are higher during recessions (Fig. 22.3). Oil price increases precede essentially all recent recessions.

Plotting the year on year (YoY) growth rates of oil consumption and real GDP provides a more explicit illustration of the relation between economic growth and oil consumption (Fig. 22.1). But correlation is not causation, and an important question is whether increasing oil consumption causes economic growth, or conversely, whether economic growth causes increases in oil consumption [28]. Cleveland et al. [29] analyzed the impact of these two factors on the causal relation between energy consumption and economic growth. Their results indicated that increases in energy consumption caused economic growth, especially when they adjusted the data for quality and accounted for substitution. Other subsequent analyses that adjusted for energy quality support the hypothesis that energy consumption causes economic growth, not the converse [30]. In sum, our analysis indicates that about 50% of the changes in economic growth over the past 40 years are explained, at least in the statistical sense, by the changes in oil consumption alone. In addition, the work by Cleveland et al. [29] indicates that changes in oil consumption cause changes in economic growth. These two points support the idea that energy consumption, and oil consumption in particular, is of the utmost importance for economic growth.

Yet changes in oil or energy consumption are rarely used by neoclassical economists as a means of explaining economic growth. For example, Knoop [31] describes the 1973 recession in terms of high oil prices, high unemployment, and inflation yet omits mentioning that oil consumption declined four percent during the first year and two percent during the second year. Later in the same description, Knoop claims that the emergence from this recession in 1975 was due to a decrease in both the price of oil and inflation, and an increase in money supply. To be sure, these factors contributed to the economic expansion in 1975, but what is omitted, again, is the simple fact that lower oil prices led to increased oil consumption and hence greater physical economic output. Oil is treated by economists as a commodity, but in fact it is a more fundamental factor of production than either capital or labor. Thus we again present the hypothesis that higher oil prices and lower oil consumption are both precursors to, and indicative of, recessions. Likewise, economic growth requires lower oil prices and simultaneously an increasing oil supply. The data support these hypotheses: the inflation-adjusted price of oil averaged across all expansionary years from 1970 to 2008 was $37 per barrel compared to $58 per barrel averaged across recessionary years, whereas oil consumption grew by two percent per year on average during expansionary years compared to decreasing by three percent per year during recessionary years (Figs. 22.1 and 22.3).

Although this analysis of recessions and expansions may seem like simple economics, i.e., high prices lead to low demand and low prices lead to high demand, the exact mechanism connecting energy, economic growth, and business cycles is rather more complicated. Hall et al. [21] and Murphy and Hall [9, 32] report that when energy prices increase, expenditures are reallocated from areas that had previously added to GDP, mainly discretionary consumption, toward simply paying for the more expensive energy. In this way, higher energy prices lead to recessions by diverting money from the general economy toward energy only. The data show that recessions occur when oil expenditures as a percent of GDP climb above a threshold of roughly 5.5%, or, stated somewhat differently, when all energy becomes more than 12 percent of the economy (Fig. 22.4).

22.9 Predicting Future Economic Expansion

Each time the US economy emerged from a recession over the past 40 years there was an increase in the use of oil even while a low oil price was maintained. Unfortunately oil is a finite resource. What are the implications for future economic growth if following a recession: (1) oil supplies are unable to increase with demand or (2) oil supplies increase but at an increased price? To undertake this inquiry, we must examine first the current and probable future status of oil supply; then we can make inferences about what the future of oil supply and price may mean for economic growth.

Since oil consumption causes change in economic growth, understanding how both peak oil and net energy will impact oil supply and price is important to understanding the ability of our economy to grow in the future. To that end, we review both the theory and current status of peak oil and net energy as they pertain to oil supply, and then discuss how both of these may influence oil price. Optimists about future oil availability usually start with the correct observation that there is a great deal of oil left in the Earth, probably three to ten times what we have extracted, and, usually, with the assumption that future technology driven by market signals will get much of that oil out. There are at least two problems with that view. The first is that of "peak oil." It is clear we have, or soon will, reach a physical limit in our ability to pump more oil out of the ground. For a long time, oil production grew at three to four percent a year. Now there has been little or no growth in global oil production since 2004. The second problem is that the oil left in the ground will require an increasing quantity of energy to

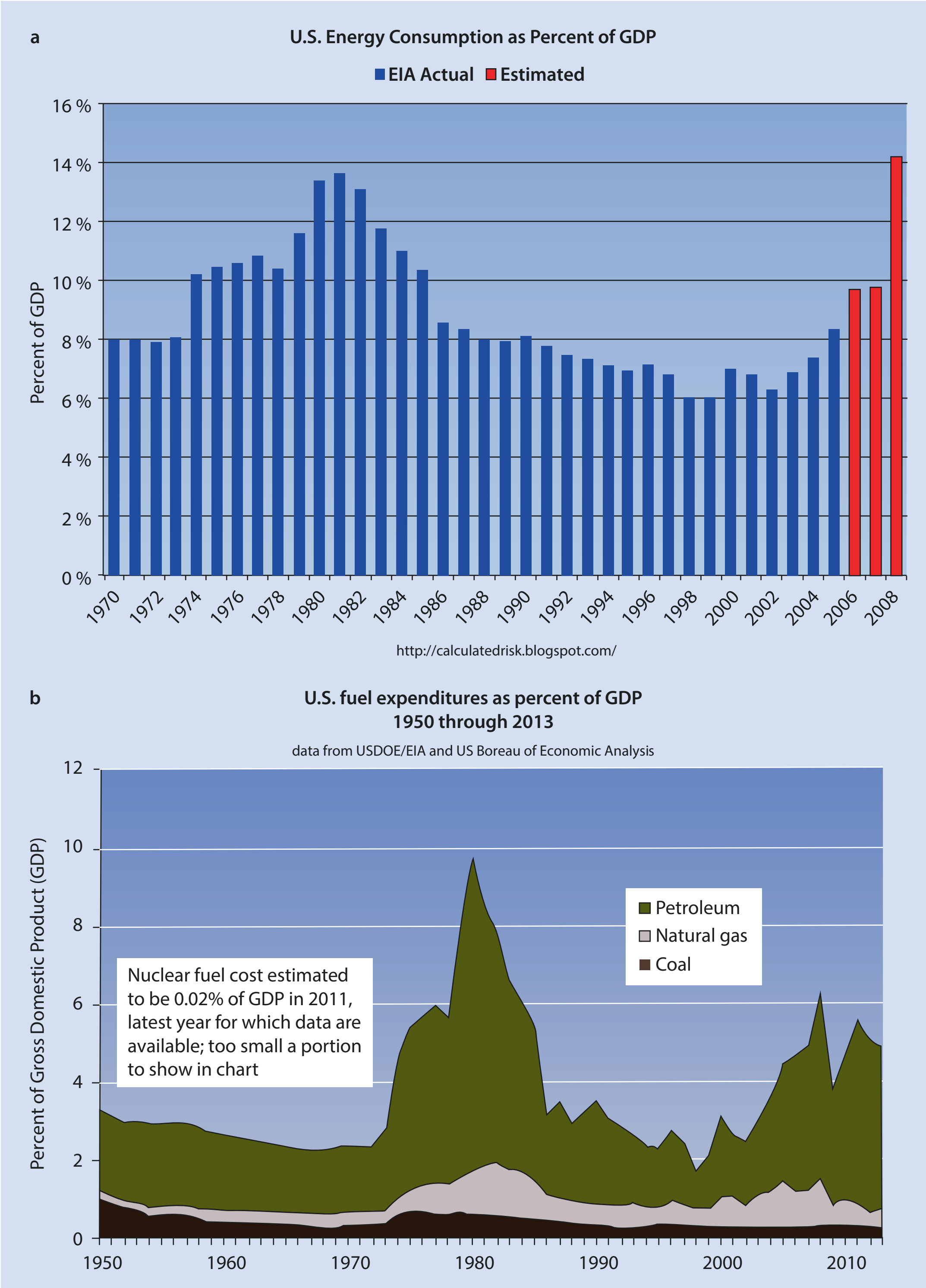

Fig. 22.4 Two estimates of the cost of fuel as a percent of U.S. GDP. **a** The threshold above which the economy moves toward recessions is about 10 to 12 percent. **b** A second, more conservative estimate

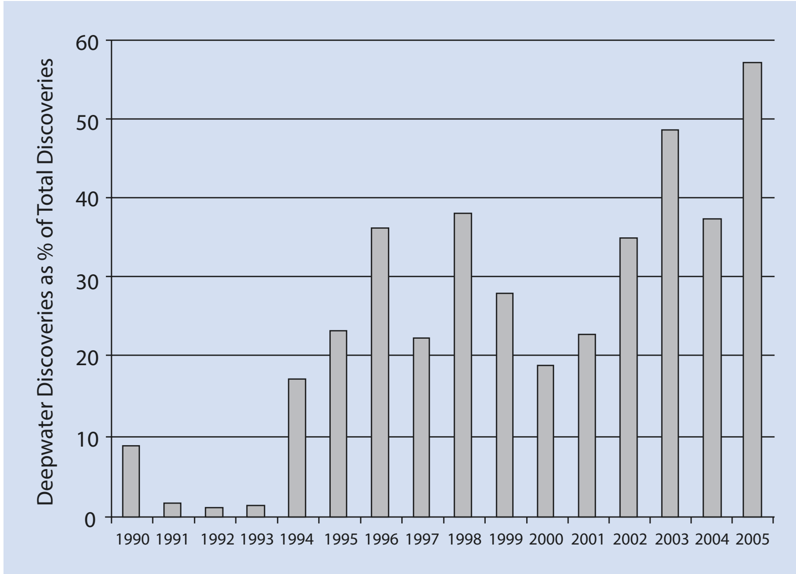

Fig. 22.5 Deepwater oil discoveries as a percent of total discoveries from 1990 through 2005 (Source: Jackson 2009)

extract, at some point as much as is in the oil. There is a clear trend that the EROI of oil production is declining in each region for which data are available. This shows that depletion is more important than technical advances. Gagnon et al. [16] report that the EROI for global oil extraction declined from about 36:1 in the 1990s to 18:1 in 2008. This downward trend results from at least two factors: first, increasingly supplies of oil must come from sources that are inherently more energy intensive to produce, simply because firms have developed cheaper resources before expensive ones. For example, in 1990 only two percent of discoveries were located in ultra-deepwater locations, but by 2005 this number was 60 percent, (Fig. 22.5). Second, enhanced oil recovery techniques, such as the injection of steam or gases are being implemented increasingly. For example, nitrogen injection was initiated in the once super-giant Cantarell field in Mexico in 2000, which boosted production for 4 years, but since 2004 production from the field has declined precipitously. Although enhanced oil recovery techniques increase production in the short term, they also increase significantly the energy inputs to production, offsetting much of the energy gain for society. Thus it seems that additional oil is unlikely to be available, and if so it will have a low EROI and hence high price.

Forecasting the price of oil, however, is a difficult endeavor as oil price depends, in theory, on the demand as well as the supply of oil. Following the economic "crash" of 2008 most OECD economies around the world have been contracting or at least not growing. Thus the flat rate of oil production since 2004 did not cause a huge sustained increase in the price of oil. One thing we can do with some accuracy is to examine the cost of production of various sources of oil to calculate the price at which different types of oil resources become economical (Fig. 22.6). We can then estimate how much oil would be available at a given price. If the price of oil is below the cost of production, then most producers of that oil will cease operation. If we examine the cost of production in the areas in which we are currently discovering oil, hence the areas that will provide the future supplies of oil, we can calculate a theoretical floor price below which an increase in oil supply is unlikely.

Roughly 60% of the oil discoveries in 2005 were in deepwater locations (Fig. 22.5). Based on estimates from Cambridge Energy Research Associates [33], the cost of developing that oil is between $60 and $85 per barrel, depending on the specific deepwater province. Therefore, oil prices must exceed roughly $60 to $90 per barrel to support the development of even the best deepwater resources. These data indicates that an expensive oil future is necessary if we are to expand our total use of oil, that is, to grow economically. But these prices will discourage that very growth (Fig. 22.6). Indeed, it may be difficult in the future even to produce the remaining oil resources at prices the economy can afford. As

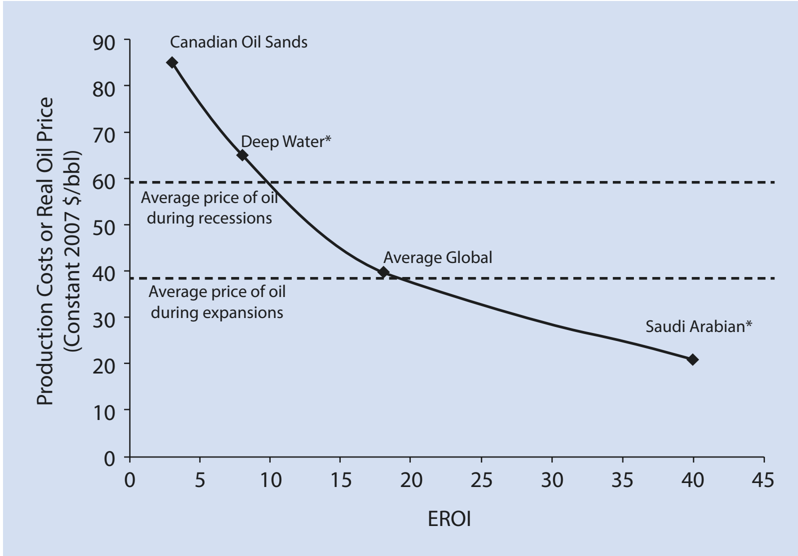

Fig. 22.6 Oil production costs from various sources as a function of the EROI of those sources. The dotted lines represent the real oil price averaged over both recessions and expansions during the period from 1970 through 2008. Data on EROI from Murphy and Hall [32], Gagnon et al. [24], and the data on the cost of production comes from CERA [33], *asterisks* are educated guesses

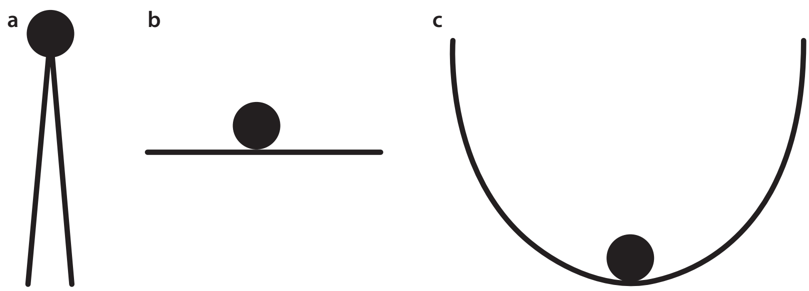

Fig. 22.7 Three types of equilibrium: unstable **a**, neutral **b**, and stable **c**. The third situation seems to represent what we face in the world today

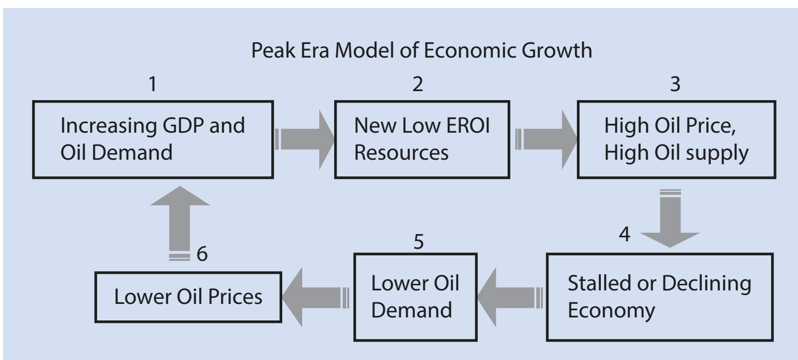

Fig. 22.8 Peak oil era model of the economy. Cycle of relation of economic grown (or recession) and oil prices

a consequence, the economic growth witnessed by the United States and globe over the past 40 years may be a thing of the past.

One way to think about this situation is to borrow a concept from systems theory. A very general concept is that many systems seek an equilibrium point because there are dynamic forces that resist change. An example is a marble in a bowl (Figs. 22.7 and 22.8). The marble seeks its equilibrium position at the bottom of the bowl. One can push the marble up the side with your finger, but the marble easily slips off your finger and goes back to the equilibrium position. This might represent the situation our economy is in now, kept at a more or less constant GDP by growth being discouraged by rapidly increasing oil prices at levels of consumption barely above where we are now, but maintained from further shrinking by decreased oil prices with contraction—indeed this is a recipe for a steady state economy.

22.10 EROI and Prices of Fuels

Since EROI is a measure of the efficiency with which we use energy to extract energy resources from the environment, it can be used as a proxy to estimate generally whether the cost of production of a particular resource will be high or low, or perhaps even energy costs themselves [34]. For example, production from Canadian oil sands have an EROI of roughly 4:1, whereas the production of conventional crude oil has an average EROI of about 10–20:1 and Saudi crude much higher. The production costs for oil sands are roughly $85 per barrel compared to roughly 60 dollars for average US oil and $20 per barrel for Saudi Arabian conventional crude. Thus there is an inverse relation between EROI and price, indicating that high EROI resources are generally relatively inexpensive to develop and low EROI resources are generally more expensive to develop (Fig. 22.6). As oil production continues, we can expect to move further toward the upper left of that picture. We see no evidence that technology has lowered EROI even as it extends our resources. In summary, relatively low EROI appears to translate directly into higher oil prices, so that if we have to move to lower EROI oil in the future the price is likely to be higher, restricting economic activity and growth [35]. At the time of this writing it is not known whether renewable energies such as photovoltaic or wind turbine electricity can replace a substantial portion of fossil fuels.

22.11 Summary

The main conclusions to draw from this discussion are:

1. Over the past 40 years, economic growth has required increasing oil consumption;
2. The supply of high EROI oil cannot increase beyond current levels for any prolonged period of time;
3. The average global EROI of oil production will almost certainly continue to decline as we search for new sources of oil in the only places we have left: deep water, arctic, and other hostile environments;
4. We have globally no more than 20–30 years of conventional oil remaining at anything like current rates of consumption and anything like current EROIs, and less if oil consumption increases and/or EROI decreases;
5. Increasing oil supply in the future will require a higher oil price because mostly only low EROI, high-cost resources remain to be discovered or exploited;
6. Developing these higher-cost resources is likely to cause economic contraction as oil costs exceed five and total energy costs exceed ten percent of GDP;
7. Using oil-based economic growth as a solution to recessions is untenable in the long-term, as both the gross and net supplies of oil have, or will soon, begin, at some point, an irreversible decline.

A similar assessment could be developed for other energy resources.

This growth paradox leads to a highly volatile economy that oscillates frequently between expansion and contraction periods, and as a result, there may be numerous peaks in economic activity and in oil production but little trend. In terms of business cycles, the main difference between the pre- and peak oil era is that business cycles appear as oscillations around an increasing trend in the pre-peak era but as oscillations around a flat trend following the peak. For the economy of the United States and most other growth-based economies, the prospects for future, oil-based economic growth are bleak, and we do not have another model that would allow for growth. It seems clear that the economic growth of the past 40 years will not continue for the next 40. A resolution to these problems can occur if economic growth was no longer the goal. Society must begin to emphasize energy conservation over growth and adjust our population numbers, jobs, living patterns, and aspirations accordingly.

Questions

1. What events of 2008–2011 might be construed as indicating some limits to the three or four percent per year growth that the United States and much of the world had previously expected? These new limits may or may not be related to biophysical limitations. How would you assess this situation?

2. Have events since the publication of this book in late 2011 changed your answer to the previous question?
3. What was the main reason that Nobel Prize economist Paul Krugman put forth for the market crash in 2008?
4. Do you think that finances are beholden to the laws of physics? Why or why not?
5. What is the relation of an "undulating plateau" to peak oil?
6. Can you discuss financial "leverage" with respect to energy and other resources?
7. Discuss some of the financial issues that were related to the "oil crises" of the 1970s.
8. Do you think that price gives signals as to the future availability of energy? Why or why not?
9. If energy supplies are indeed restricted is economic growth still possible? What would be the requirements for that?
10. What is the relation historically between the price of energy and discretionary spending?
11. What has been the relation between the amount of oil that is consumed in a given year and the price of that oil? What might be a reason for that?
12. As the EROI for a given source of oil declines how does that relate to its price?
13. How might we best respond to a future of limited oil supplies should it occur, which seems likely?
14. Due to the depletion of high EROI oil the economic model for the peak era, i.e., roughly 1970–2020, is much different when viewed as net rather than gross energy from oil. Why is that?

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