World Economics Association

(WEA)

Conferences, 2013

The political economy of economic metrics
28th January to 25th February, 2013

Title of paper:
Energy as the Numéraire of any Given Economy[1]

Abstract:
The actual economic theories are based on money as the unit of accounting, measuring and exchange. This paper discusses the usage of energy as a physical characteristic of all commodities, all goods and services as the numéraire for measuring the size of any given economy in order to redefine the quantity theory based on a physically measurable unit.

The monetary value is not a real characteristic of the commodities and goods. Physical characteristics on the other hand *are* real characteristics and they are precisely measurable. This allows measuring a *precise and physically real GDP in energy units* which represents an exactly metered value opposing the inflation corrected *money based 'real GDP'*.

Introducing energy units to measure the GDP allows redefining the quantity theory as a relation of a given amount of money representing a given and real based physically measurable amount of commodities, goods and services. It allows to explicitly define the size of any given economy by its amount of energy necessary to create all different kinds of capital and consumer goods. It also fully avoids the problem that the existing definition is a reasoning circular in itself. Measuring an economy by the money used in that economy to define the amount of money circulating in that economy is a closed loop. It is impossible to measure the absolute value of any economy since no currency today is defined by a physically existent value. Changing this allows redefining the quantity theory.

Setting a given amount of energy as the available input also allows defining the limits of growth. Without more energy available for being productively used this describes the limit of growth and introduces a value in physical units.

JEL:
E01, E19, O47, Q43

Author:
Olaf Schilgen,
John-F.-Kennedy-Place 5, 38100 Braunschweig, Germany
email: wea@schilgen.com

[1] The research for and the content of this paper is neither the result of any for-pay consulting or employment relationship, nor do I have any financial interest in the topic of the paper.

1. Introduction

The actual economic theories are based on money as the unit of accounting, measuring and exchange. This results into two problems.

The first problem: These money or currency based economic theories and definitions without any direct link to any measurable real characteristic of the real world economy represent some kind of a tautology. Measuring a given economy by its monetary value which in reverse depends on the amount of money circulating in this given economy which also is in reverse the value for defining the monetary base for this economy is a reasoning circular in itself. This might be okay for an already existing economy, but for setting up a totally new economy there has to be some kind of definition to create a price level for the real things from the beginning.

The second problem: The actual view describes the economic process without defining any necessary input or output. All necessary items to produce goods are weighted by its production factor, its cost share. This has already been criticized (Hall, Klitgaard, 2012):

> *"Unlike their classical predecessors, neoclassical economists do not even bother to include process of how things are actually made in their analyses. They just take the input prices, put them into a function, and the price and quantity of output is automatically generated. Here lies the historical source of the economists' underestimation of energy as a production factor, because in industrial market economies energy cost, on the average, is only 5-6% of the total factor cost (and of GDP). Therefore, economists either neglect energy as a factor of production altogether, or they argue that the contribution of a change of energy input to the change of output is equal only to energy's small cost share of 5-6%."*[2]

The main purpose of (Hall, Klitgaard, 2012, 248) is to put the focus on the high importance of the energy as an essential production factor:

> *"Thus we face the inevitable contraction in the availability of our most important fuels […], we must face the possibility that our own economy […], which is almost universally based on the concept of continual growth […], may need a massive rethinking of how to go about thinking about itself and planning for the future: in other words, a new economics. This book is meant to give you the conceptual tools to do that."*[3]

The importance of energy to do things or to do work is shown and methods of enlarging the factor and with that the importance of energy are the purpose of (Hall, Klitgaard, 2012).

By going deeper into the theoretical concepts this paper describes one possibility of using the energy as the base of the economic theory. The possibility of using energy is justified by the fact that energy is used by each part of any economy. Instead of money energy should be used as the numéraire of the economy as a whole.

The monetary value is not a physically existing characteristic of the commodities and goods but physical characteristics including the necessary input of energy *are* real characteristics

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[2] Hall, Charles A.S.; Klitgaard, Kent A., 2012 'Energy and the Whealth of Nations', New York, Springer, p.135

[3] Hall, Charles A.S.; Klitgaard, Kent A., 2012 'Energy and the Whealth of Nations', New York, Springer, p.248

and therefore they are precisely measurable. This allows measuring a *physically real GDP in Joule units* which represents an exactly metered value of real existing characteristics opposing the inflation corrected *money based 'real GDP'*.

Representing a given and real based physically measurable amount of commodities, goods and services allows redefining the **quantity theory** as a relation of a given amount of money. It allows to explicitly defining the size of any given economy by its amount of energy necessary to create all the different kinds of capital and consumer goods.

Setting a given amount of energy also allows to define the limits of growth. Redefining the economic theory on the numéraire energy also gives a better understanding of the importance of energy for any economy. Since the redefined economic theory is based on productively used energy the economy thereby is represented by a given amount of energy available for productive use in the given economy.

2. Neoclassical economic model

The existing neoclassical model of production ignores the important role of energy. (Hall, Klitgaard, 2012) did a very important job on describing this explicitly:

> *"**Myth 1b: Economic Production Can Be Described Without Reference to Physical Work.***
> *The neoclassical economists' model of production does not require any specific physical input but is solely an exchange of existing input among firms. The economic process is driven not by the availability of physical resources, but rather human ingenuity as depicted in the still widely used Cobb-Douglas function. […]"* [4]

The flowchart of this neoclassical model shows this phenomenon by ignoring any input. (Hall, Klitgaard, 2012) shows and comments this flowchart as followed:

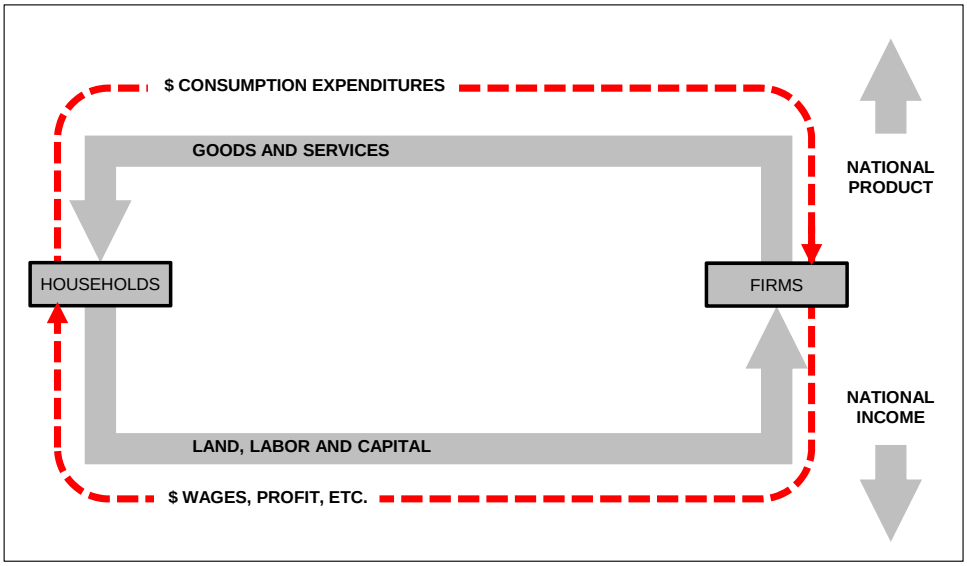

Figure 1: Neoclassical Economic Process

[4] Hall, Charles A.S.; Klitgaard, Kent A., 2012 'Energy and the Whealth of Nations', New York, Springer, p.133

"The neoclassical view of how economies work. Households sell or rent land, natural resources, labor, and capital to firms in exchange for rent, wages, and profit (factor payments). Firms combine the factors of production and produce goods and services in return for consumption expenditures, investment, government expenditures, and net exports. This view represents, essentially, a perpetual motion machine." [5]

Naming the neoclassical view a perpetual motion machine makes the point clear what is missing in this view.

(Hall, Klitgaard, 2012) go on with their criticism:

"The preoccupation with pure technological change as the driver of economic growth has caused earlier neoclassical economists to virtually ignore the critical importance of energy in powering the modern economy [8]. In contrast, many natural scientists and some economists have concluded that the explosion of economic activity during the twentieth century was due to the increase in the ability to do work through the expanding use of fossil fuel energy. In fact the neoclassical economists' technology residual disappeared when energy was included as an input. Energy as a factor of production was more important than either capital or labor for Germany, Japan and the United States in recent decades [6]. Ayers and Warr further found that most improvements in "technology" have been simply an increase in the quantity of energy used or the efficiency of getting it to the point where the work is done. Although NCE [neoclassical economic] models purport to show that technology alone has driven the industrial economy, historically, it has been a technology that mostly has found new sources of, and applications for, energy."

So, (Hall, Klitgaard, 2012) expanded this neoclassical flowchart with some minor changes:

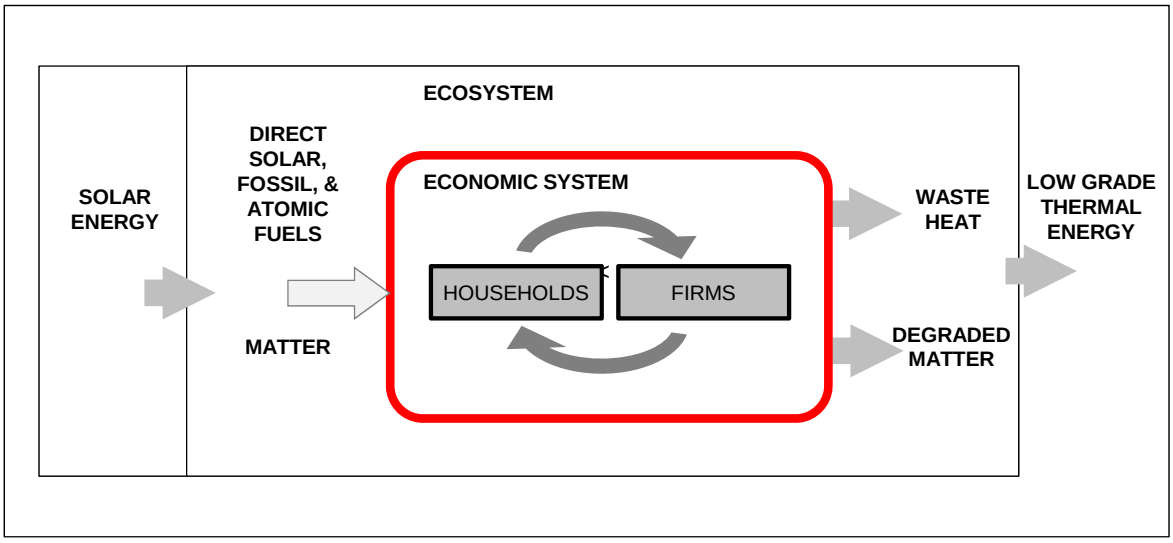

Figure 2: Neoclassical Economic Process with added Energy and Matter Flow

(Fig. 5.2) Our perspective, based on a biophysical viewpoint, of the minimum changes required to make Fig. 5.1 conform to reality. We have added the basic energy and

[5] Hall, Charles A.S.; Klitgaard, Kent A., 2012 'Energy and the Whealth of Nations', New York, Springer, p.134, Fig. 5.1

material input and output that is essential if the economic processes represented in Fig. 5.1 are to take place (Source Daly 1977).[6]

The conclusion of this is that energy is important for doing work. In fact, physically spoken, it is not energy which is 'important for doing work' but energy explicitly is doing work. 'Doing work' physically means to use a given amount of energy by time to do some kind of work. Even the brain needs some kind of energy to think.

Accepting the fact about the importance of energy in the real world economy is made possible by considering the basic principles of physics which shows that neither any real goods or services nor any virtual thought can be created without a minimum amount of energy. Following Albert Einstein's formula even matter can be converted into energy. The atom bomb has proved this theoretical idea to be true.

The explicitly named phenomenon that energy replaces most or every 'technological residual' from the neoclassical economic theory is easily understood by a simple explanation: If a given company's business is to transport sand from A to B and is doing this by pure muscle power from a lot of employees it is costly. But replacing all the employees by one small transport car with a small engine does not mean it is much more efficient. As for the money value it can be more efficient but physically seen the work to transport the sand has to be done anyway. The transport car has to deliver the same physical transport energy as all the employees. The fact that the transport car today does deliver this amount of energy much cheaper than the necessary number of employees does not mean that it is more efficient as far as the energy is concerned. Without more detailed information it is not possible to answer this question.

This paper is not looking into this kind of question in detail. It deals with the question to think about the possible consequences for the economic theory itself, for the numéraire on which all the economic formula are based on.

This paper shows the importance of energy by citing Hall and Klitgaard. It explains the fact that there is no single part of any given real economy which can exist, be described or even be transported without a given amount of energy.

The next step is to show what the result of this could be in the question of the consequences for the quantity formula. The quantity formula is also described on a monetary value base and the next step is to show a new possibility for defining a given amount of currency for any measured amount of economy.

3. The new quantity theory based on energy as a numéraire

The quantity theory has been introduced by John Stuart Mill, David Hume and more.[7] It is stated that there is a direct relationship between the amount of money and the price level and therefore also the inflation rate.

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[6] Hall, Charles A.S.; Klitgaard, Kent A., 2012 'Energy and the Whealth of Nations', New York, Springer, p. 136, Fig. 5.2

[7] http://en.wikipedia.org/wiki/Quantity_theory (13.01.2012)

The quantity theory is normally defined as *the amount of money (**M**)* times *the velocity of money (**V**)* equal to the *price level (**P**)* times *the trade volume (**Y**).*

The formula for this is: ***M * V = P * Y***

The intention of the quantity theory is to give a formula to define the relationship between the amount of money according to a given size of an economy at a given price level and a given trade volume. The basic problem is that both sides of this relationship are based on money as the numéraire. There is no chance of having any physically real measured part of a given economy used in this formula. The only way of using this formula is to put a money value on a given part of the economy and then integrate it into the formula.

Coming back to the energy it is therefore only possible to integrate the energy into the calculation by putting a money value on the amount of energy.

But since energy is contained in every single part of the economy there is one more opportunity: Redefining the quantity formula on a new numéraire on the trade volume (Y) to describe the ‘amount of economy’. What does the trade volume measure? It summarizes all trade goods in this given economy and therefore expresses the amount of goods and services produced and delivered. Since there has been shown that nothing in a real world economy can exist without energy usage, there is one conclusion to be made: if the total amount of goods, measured by the trade volume, adds up to a size of ‘1’, it implies that the amount of energy for this given economy also adds up to a size of ‘1’.

This is valid for the assumption that the given economy is stable in the given timeframe and does neither grow, nor shrink, nor get any inside change like ‘technology’ or ‘efficiency’. The questions relating to the changes made by these factors are to be analysed later on. For now the possible changes of the quantity theory present the topic to be discussed.

If the sum of this is given and the economy is stable for the moment then the energy used in this economy is also ‘1’ like the sum of all trade also adds up to ‘1’. The trade volume, measured in money value, can be replaced by the amount of energy used in this given economy. But the amount of energy has not necessarily to be measured in its money value, it can directly be measured in its physical value.

Using the energy changes the monetary based view to the real based view.

Before explaining these changes in detail, a flowchart of the economy described by its physical factors of energy flow and matter flow but not by its monetary values is presented.

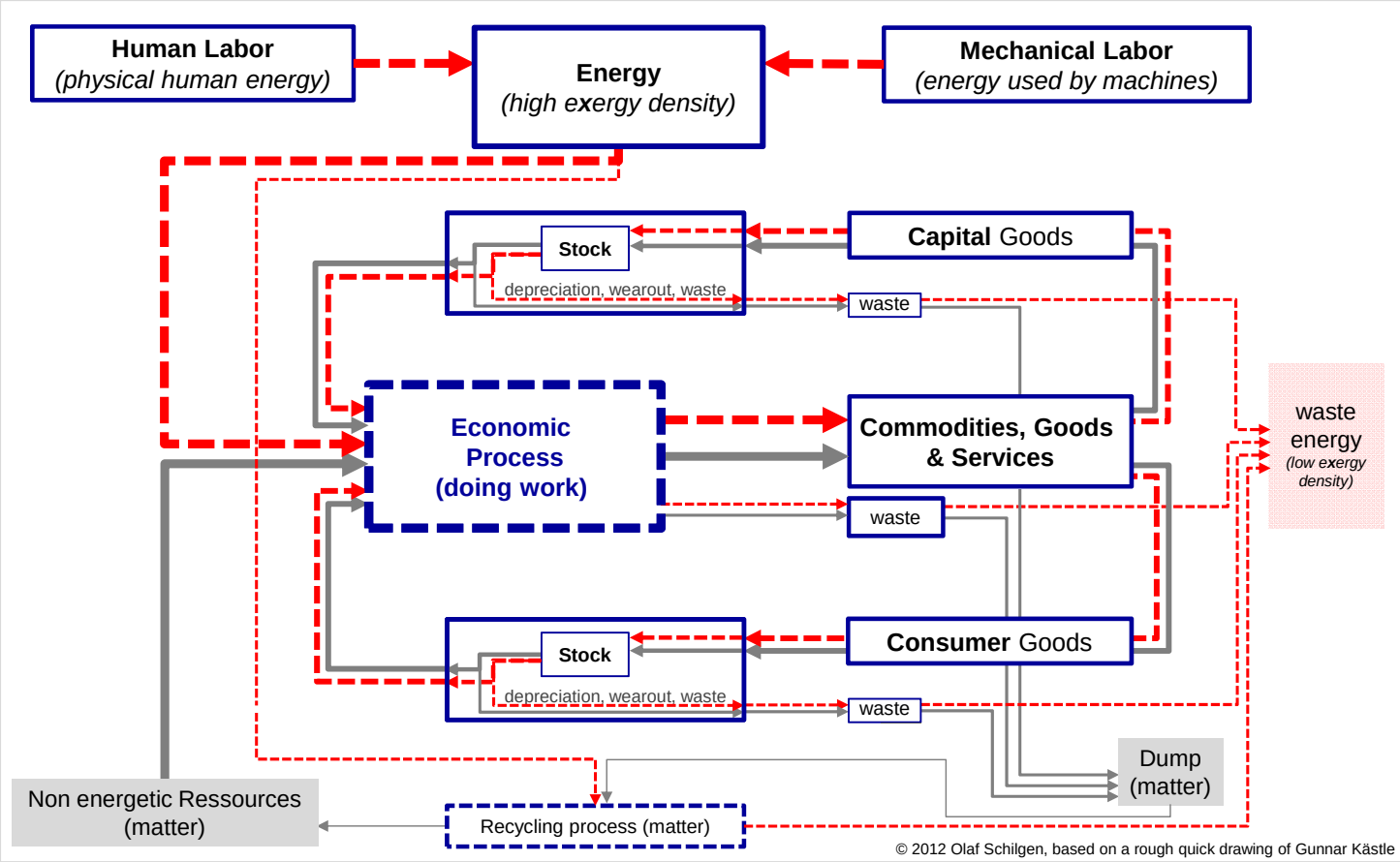

Figure 3: Real Economy flow of energy and matter

It is shown that the *input of energy* into this economic system *is neither recyclable nor replaceable*, unlike matter which is recyclable by using a given amount of energy.

As shown above the input of energy *is essential for doing work* or even '*is*', physically spoken, the activity itself at its core value.

The open question is, following this line of logical statement, why not to define the 'size' of any economy by its physical energy, by its amount of work?

By using the energy to define the 'size' of an economy it is the possible to reduce the quantity formula to its core statement: Defining the *'amount of money'* related to the *'amount of economy'*.

The shortened new quantity formula is: *the amount of money* ***(M)*** equal to *the amount of energy productively used* ***(G)***.

Or as a short formula: ***M*** = ***G***

(M) is *the sum of money* in a given currency,

(G) is the physical measured value of *the 'amount of economic activity'* as a physical equivalent to the GDP, formerly defined by *price level* ***(P)*** *times trade volume* ***(Y)***.

Changes in the price level can still be expressed: ***(P) * (Y) = (G)***

The following expression is also valid: ***P * Y / M = 1***

And if this is valid, the resulting value of ***(G)*** is also *= 1*, which was defined at the beginning.

Applying these changes the price level is no longer necessary to define the amount of money. Furthermore there is no need to integrate the inflation rate into this formula for correcting nominal prices to inflation corrected 'real' prices. The 'size' of the economy is finally measurable without using a money system.

Open questions:

Since this method is new there are open questions to be discussed more in detail. One question is: How can the energy productively used in a given economy be measured?

For answering this question it is helpful to refer to the fact that the total energy consumption of most modern economies is very well known. There is no need to measure this energy consumption since it has already been measured. But not all energy consumed in an economy is exergy, which is defined as the productive part of energy. Of all the energy consumed in an economy a given amount is just used for heating or lighting and therefore not used productively in the economic process. But energy for heating normally is used to keep good production conditions and all material in a well-defined surrounding and therefore is necessarily productively used. It is important to divide unproductively used energy from productively used energy in an economy in order to measure the economy by its productively used energy consumption. In order to achieve this division of unproductively and productively used energy there is more work to be done later on.

Another open question is: Is the energy consumption a useful method to measure a given economy? As shown above the very important role of energy has already been discussed by enlarging its importance above its sheer monetary valued productivity factor. As it is also shown that there is no single part of any real existing economy without a minimum amount of energy necessary for its existence it can be stated that using this kind of measuring includes each part of any given economy. It is obvious that all parts of any given economy have to add up to the sum of '1' in a given timeframe and a given level of industrialization. As long as all parts of the economy need a positive value of energy for its existence the conclusion can be made that a growing economy will always produce an also growing value by measuring this economy by its energy productively used. This does not necessarily mean that the measured value of any given economy always has exactly the same relation between the money based 'summarized' value and the really 'measured' value of the productively used energy.

But measuring two different kinds of characteristics of a given 'thing' (the economy) can by definition not always result in a constant relation between both values if the 'thing' (the economy) changes or grows. For example: measuring a balloon by its weight and by its volume gives different values as long as the balloon gets blown up.

One important question is also how the 'ingenuity' of humans is measured by using this method. The answer is, it is not measured in a given timeframe. Ingenuity does not change any part inside this economic system without necessarily being put into real existence by building up capital goods for doing more work later on with again more productively used energy necessary to run these capital goods. So ingenuity is never measured by this method but the created capital goods do need the ingenuity for existing – and productively used energy to form matter into the capital goods.

One more question is how human labour is measured. The answer is that it is measured by the same unit as the energy in total is measured, namely by the amount of physical work which is delivered from all human employees into the economic system. But it has to be noted that this amount of energy is more or less insignificant in modern economies since humans do not deliver a very huge amount of energy per time in comparison to the energy productively used by machines and delivered by the source of fossil fuels, atomic fuels or the coming renewable fuels. Since modern economies are based on a constant huge amount of energy necessarily used human employees tend to be more in the role of a controller of the energy flows than anything else. In modern economies employed humans are very seldom only paid for sheer physical work which could be replaced by a machine running with significantly cheaper energy available through the different kind of fuels. Further discussion is necessary to describe the role of this principle in the process of the industrialization of modern times. But it is valuable work since in comparison no civilization before the beginning of productively use of external energy has ever shown any process of a beginning industrialization. In his well discussed book (Morris, Ian 2010) stated the importance of unlocking the energy trapped in fossil fuels besides the importance of the geology as the main reason why the west rules. He writes at the end of the introduction:

> *"[...], those people best placed to exploit it - at first chiefly the British, then their former colonists in America- created new kinds of empires and economies and unlocked the energy trapped in fossil fuels. And that, I will argue, is why the West rules."*[8]

Again we find a proof for the importance of energy for the economic system. (Morris, Ian 2010) explicitly expresses the energy's importance for its role in the history of the industrialization of the west beginning in Great Britain with the invention of the steam 'engine', a unique phenomenon during the last 10.000 years of history of coming and disappearing cultures.

One more remark on the point of measuring the 'size of any given economy' has to be made. This method is in principle good for measuring each given economy during history. And by thinking about the amount of energy productively used it is obvious that there *was* in fact a limit of energy for productively usage. Since no machines have been invented for using the already known coal or even wood fire to do more than heating something there has in fact been an already existing limit of growth. The only possible method of putting more energy into productively usage has been using strong animals or stolen slaves. But even this external energy input was limited by the amount of food and fodder available in the former economies.

Since there has been no other source of energy than more or less human labour it can therefore be stated that the 'size of former economies' has more or less been directly bound and scaled by the number of humans to do labour.

More details of using this method are to be explored later on.

4. Evaluating the assumptions

Today it is a well-known fact that the energy consumption rises if the economy grows. The causation today is normally that there is 'more need' of energy as long as the economy is

[8] Morris, Ian, 2010, 'Why the West rules - for now, The patterns of history, and what they reveal about the future', New York, Farrar, Straus and Giroux, p. 35

running faster. This is explicitly well-shown by (Tverberg, Gail, 2012) in different articles. (Tverberg, Gail, 2012) shows the very close tie between the consumption of oil in an economy, explicitly in the whole world as one big economy:

> *"If we graph historical data, there is significant evidence that growth rates in real GDP are gradually decreasing. In Europe and the United States, expected GDP growth rates appear to be trending toward expected contraction, rather than growth. This could be evidence of **Limits to Growth**, of the type described in the 1972 book by that name, by Meadows et al.*

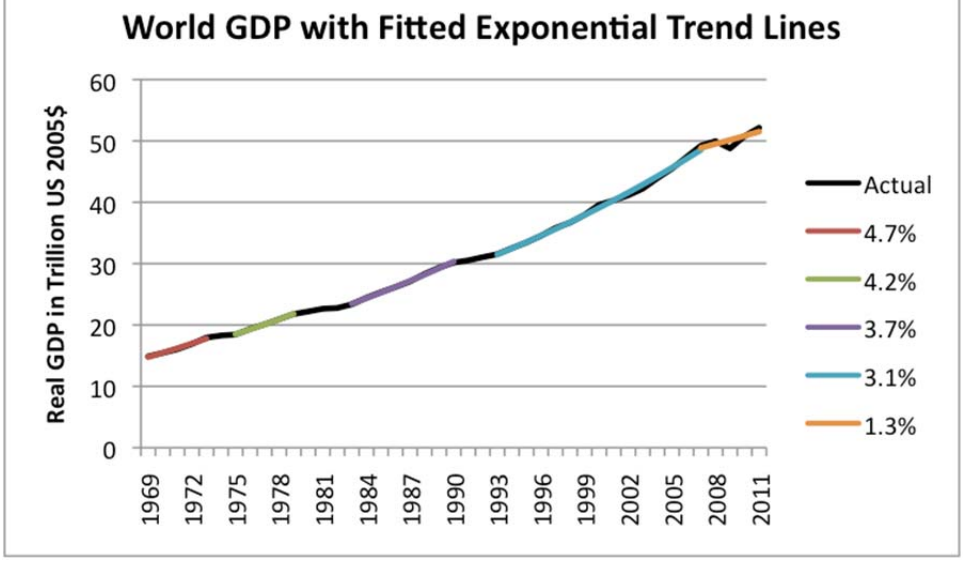

Figure 1. World Real GDP, with fitted exponential trend lines for selected time periods. World Real GDP from USDA Economic Research Service. Fitted periods are 1969-1973, 1975-1979, 1983-1990, 1993-2007, and 2007-2011.

Figure 4: World GDP with Fitted Exponential Trend Lines

*Trend lines in Figure 1 [Figure 4] were fitted to time periods based on oil supply growth patterns (described later in this post), because **limited oil supply** seems to be one critical factor in real GDP growth. It is important to note that over time, each fitted trend line shows less growth. For example, the earliest fitted period shows average growth of 4.7% per year, and the most recent fitted period shows 1.3% average growth.*

In this post we will examine evidence regarding declining economic growth and discuss additional reasons why such a long-term decline in real GDP might be expected.

Connection of GDP Growth with Oil Supply Growth

It should not be surprising to find that there is a close tie between GDP growth and oil supply growth. Oil is used in many ways, from the manufacture of goods (synthetic cloth, pharmaceuticals, chemicals, asphalt for roads), to transport of goods and people, to food production (plowing, harvesting, weed killers, diesel irrigation), to operating construction equipment, to mining. While it is possible to substitute away from oil in some situations, or to find more efficient ways of using the oil, we have literally trillions of dollars of machinery in the world that uses oil right now. Because of this, the rate of substitution away from oil is necessarily very slow.

James Hamilton has shown that in the United States, 10 out of 11 post-World War II recessions were associated with oil price spikes. He has also published a paper specifically linking the recession of 2007-2008 with stagnating world oil production and

the resulting spike in oil prices. I wrote an academic paper, Oil Supply Limits and the Continuing Financial Crisis, explaining some of the connections I see involved.

[…]

Figure 2 [Figure5], below, shows world oil supply (broadly defined, including biofuels) with trend lines fitted to periods exhibiting similar growth patterns. It is these same time periods that I fit trend lines to in Figure 1, with one small exception. I had consistent real GDP data going back only to 1969, so stopped at 1969 rather than 1965 with GDP.

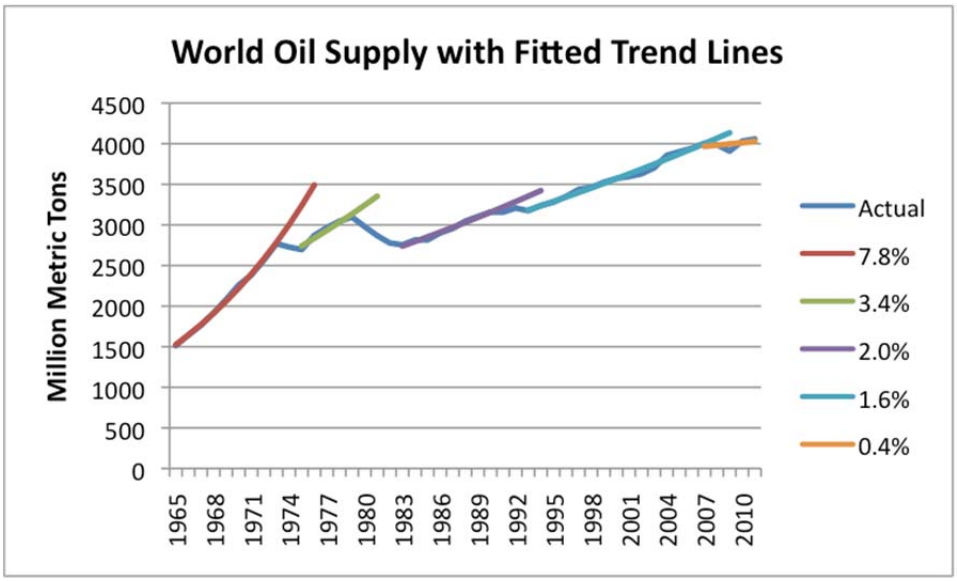

Figure 2. World oil supply with exponential trend lines fitted by author. Oil consumption data from BP 2012 Statistical Review of World Energy.

Figure 5: World Oil Supply with fitted Trend Lines

What we see in Figure 2 is a pattern of falling growth rates in oil supply rates, similar to the declining pattern we saw for real GDP in Figure 1. In Figure 2, the growth in oil supply falls from 7.8% per year in the first fitted period, to 0.4% per year in the last fitted period. The "gaps" that I didn't fit lines to were periods of falling oil consumption. A glance up at Figure 1 shows that these periods where no line was fit (that is, the places where the black "actual" data shows through on Figure 1) correspond to relatively flat GDP periods–as a person would expect, if high prices/short supply are associated with recession."[9]

Again there is the proof of a close relationship between oil and the economy. The oil in this example can easily be replaced by the expression 'energy' because of its core value for modern economies since it is mostly used as a very cheap source of pure and easily usable and transportable energy.

This example of the very close tie between one of the most important sources of energy for modern economies is based on a quite long timeframe and shows a highly significant correlation.

[9] Tverberg, Gail, 2012, 'Evidence that Oil Limits are Leading to Declining Economic Growth', http://ourfiniteworld.com/2012/07/13/plan-for-lower-growth-in-real-gdp-going-forward/

This correlation has to be analysed by its significance by including all other forms of energy like coal, gas, and atomic and renewable fuels but a rough assumption can be made that it is most likely that a similar correlation by other forms of energy used for production in an economy will be shown.

5. Conclusion

The conclusion of this paper is that it is not only possible but useful to connect the economic theory with the real world by defining a numéraire based on the energy productively used for understanding the real world economic flows of energy and matter.

The great work of (Tverberg, Gail,2012-2) shows that there is a very close link of energy and economy. (Tverberg, Gail, 2012-3) has already put this correlation on the table by explicitly naming its importance for the **Limits of growth** and for the basic principles causing the different unexplained phenomenon's going on in the **Financial Crisis** and its correlation to the rate of the **GDP growth rate**.

This paper describes another possibility of putting one more piece of the puzzle into the game named '**economic theory**' in order to understand the origin of wealth.

As a final conclusion this paper states that the **origin of wealth** is the amount of energy productively used to create and run the economy. This should find its way into the economic theory by redefining the economic theory on its core value, **energy**.

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