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The Role of Energy in Economic Growth

Posted by nate hagens on October 19, 2011 - 9:58am
Topic: Economics/Finance
Tags: economic growth, energy use, gdp [list all tags]

Ecological economist David Stern recently wrote a paper on the importance of energy for economic growth aptly titled 'The Role of Energy in Economic Growth'. His overview paper follows a long chain of biophysical research on this topic from Schumpeter in the 50s to Georgescu-Roegen in the 70s to Herman Daly, Charles Hall, Cutler Cleveland etc. in the present day. This type of thinking - that energy is its own special input to the production function and is non-substitutable (we can't make stuff without energy), is still outside of mainstream economic discourse, who follow the classic exogenous growth model (Solow) where labor and capital are all that matter. But if energy is special, and has declining marginal returns (i.e. fossil fuel depletion), that has enormous implications for future growth prospects and the modus operandi for our institutions. Yet it is still widely assumed in economic/financial circles that energy is just the same as other commodity inputs and that a high enough price will create its own energy supply in perpetuity.

Incorporating the premise that energy is separate and unique in the production function is a necessary (but not sufficient) change we have to make to our economic theories. Professor Stern's paper, written for economists, is a step towards bridging the assumption chasm that underestimates energy's role in our human ecosystem. I invited David to write a short overview of his paper (guest post), which is below the fold.

Energy use has increased over time in close association with GDP both globally and in individual countries. This figure, based on World Bank data:

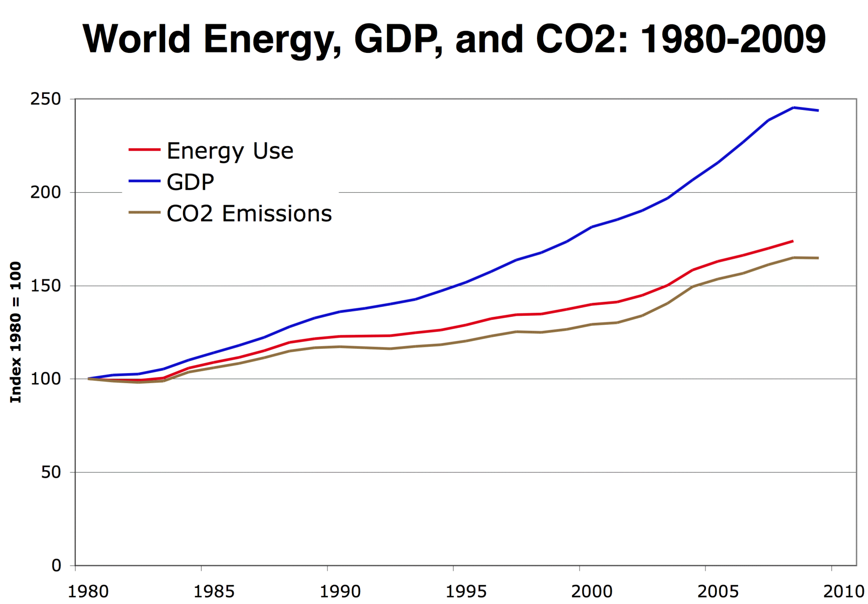

Figure 1

Figure 1 shows that the two variables also have similar fluctuations around the trend – the growth in energy use slows in recessions – which suggests that there is a real relationship between them. However, energy use has grown much more slowly than has GDP. This means that energy intensity – energy used per dollar of GDP – has declined steadily over time. When we look at a snapshot in a given year there is also a strong relationship between per capita energy use and income per capita across countries:

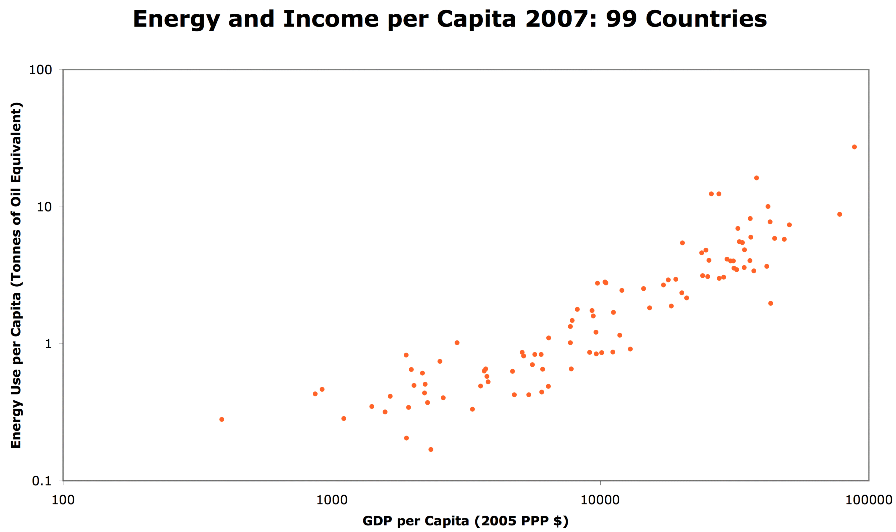

Figure 2 *Source: International Energy Agency, World Bank*

This leaves many unanswered questions:

Does energy availability and quality drive economic growth? Or is energy use merely a side effect of growth? Has the relationship between energy and growth changed over time? And what factors have reduced the energy needed to produce a dollar of GDP?

In a [paper in this year's *Ecological Economics Reviews*] (a [free working paper version is available here]), [I] attempt to answer these questions in a review and synthesis of the literature on the role of energy in economic growth.

While physics shows that energy is necessary for economic production and, therefore, economic growth, the mainstream theory of economic growth, except for specialized resource economics models, pays no attention to the role of energy. Ecological economists, on the other hand, often ascribe the central role in economic growth to energy. I argue that criticism of mainstream economic growth models that ignore energy is legitimate, but theories that try to explain growth entirely as a function of energy supply, while ignoring the roles of information, knowledge, and institutions, are also incomplete.

As a step towards reconciling mainstream and ecological economics models of economic growth, I present a simple model that embeds the mainstream [Solow economic growth model] within a more general framework where energy and capital are poor substitutes. The model allows technological change to affect energy and labor productivity separately and differently so that we can distinguish between energy- and labor-augmenting technological change. In other words technological change that increases the productivity of energy and technological change that increases the productivity of labor.

The model shows that when effective energy - the product of the quantity and quality of energy and the level of energy augmenting technology - is scarce it will strongly constrain economic growth, but when effective energy becomes more abundant it is much less of a limiting factor and the conventional mainstream model explains economic growth fairly well. This explains why mainstream economic growth theory ignores energy – it is mostly designed to explain the last sixty years of economic history when energy has been abundant and cheap in developed countries.

Stern and Kander (2011) show that the growth of energy use and energy augmenting technological change were the main sources of growth in Sweden in the 19th and early 20th century. However, in the late 20th century labor augmenting technological change became the dominant driver of technological change. This explains the industrial revolution as a releasing of the constraints on economic growth due to the development of methods of using coal and the discovery of new fossil fuel resources.

This model also explains why the cost of energy as a share of the value of output fell dramatically over time as shown by this graph:

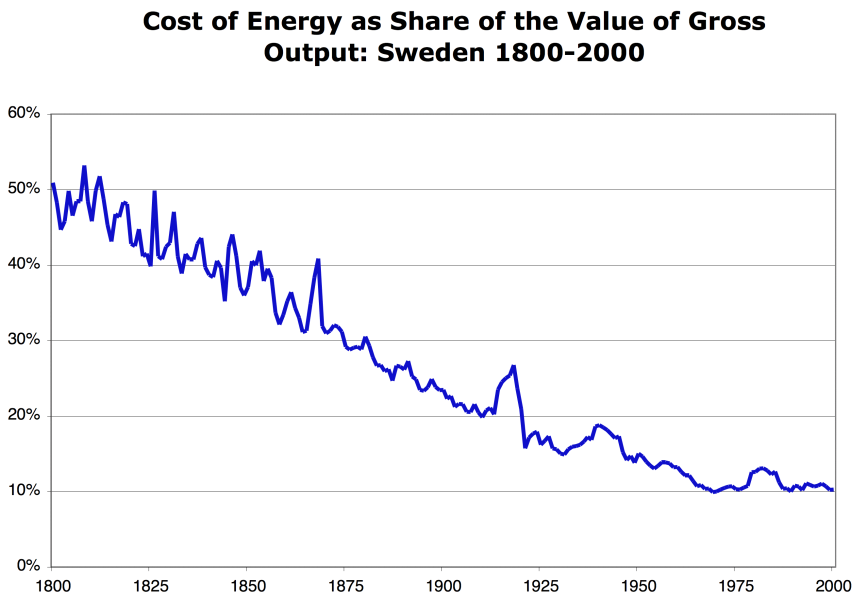

Figure 3 *Source: Stern and Kander (2011)*

When inputs are relatively hard to substitute for one another (elasticity of substitution of less than one) a fall in the relative price of an input reduces its share of costs or income. This is what has happened to energy relative to labor and capital over two centuries in Sweden. Preliminary work by Kander and others suggests that a declining energy cost share is common to several countries.

Energy intensity has not only fallen globally over the last few decades as we showed above but has declined for at least 150 to 200 years in many countries including the United States:

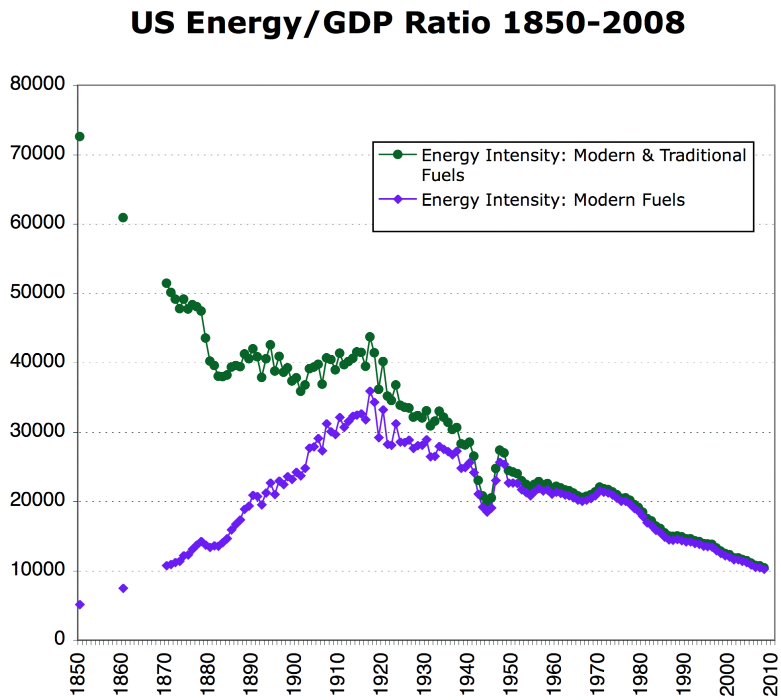

Figure 4 *Sources: [U.S. E.I.A.](), U.S. Bureau of Economic Analysis, [Angus Maddison]()*

The graph shows that when only modern commercial forms of energy are considered energy intensity follows an inverted U shape curve. But this is not the case when traditional biomass, muscle power etc. are considered.

The factors that have driven the decline in energy intensity can be grouped in the following categories:

–substitution between energy and other inputs

–technological change

–shifts in the composition of the energy input

–shifts in the composition of output

–structural change

The most important driver of reduced energy intensity appears to have been technological progress. More disaggregated data typically show a smaller role for technological change and a larger role for structural change. Shifts to higher quality fuels have also reduced energy intensity in some countries such as the U.S. but in others like China and India in recent decades or Germany and Britain in the 19th century, the switch towards coal has increased energy intensity, everything else constant.

It is commonly thought that the increasing share of the service sector in economic activity over time would reduce energy intensity but the gains from this are less than widely believed as the service sector still requires significant energy inputs to support the infrastructure of office buildings, shopping malls etc. Evidence also shows that trade does not result in reductions in energy use and pollution in developed countries through the off-shoring of pollution intensive industries.

The paper implies that future constraints on energy use would limit economic growth but reductions in energy use would not reduce living standards back to those of previous centuries due to much improved technology. The ultimate limit to economic growth in an environmentally or resource constrained world is how much we can continue to improve energy productivity. Though thermodynamics prescribes precise answers for simple processes, the ultimate limit at the macro-economic level is not clear.