The Essence of Biophysical Economics

Kent A. Klitgaard*

ABSTRACT

As the world enters the "second half of the age of oil, characterized by declining energy quality and quantity and rising prices, a new economics is needed to explain this unprecedented phenomena. Biophysical economics is the beginning of just such a theory. This essay delineates a set of theoretical principles, compares and contrasts biophysical economics with both mainstream and ecological economics, and grounds the theory in both energy studies and the insights of heterodox political economy.

INTRODUCTION

We are about to enter the second half of the age of oil. This era will commence when oil production peaks, or when humans have extracted half the oil that was once in the ground. The second half of the age of oil will also be the end of cheap oil, as the supply of cheaply extracted and refined oil will be in decline while global demand continues to increase, driven primarily by large emerging economies such as China and India. In October of 2009 the International Society for Biophysical Economics was formed, in an attempt to better understand the dynamics of the post-peak era. The meeting was chronicled in the New York Times as a new approach to economics (Gronewald 2009). Biophysical economics did not materialize from a vacuum. Rather it was the culmination of many years of research on the role energy plays in economic development, the limits to economic growth, and the insights of political economy (Cleveland, et al. 1983, Hall, et al. 1986, Hall and Klitgaard 2006, Gowdy, et al 2010a, 2010b, Hall and Klitgaard 2011). Biophysical economics shares a great deal with ecological economics, although some major differences exist, but shares relative little with the variants of mainstream economics. The basic elements of biophysical economics include:

A focus on stocks and flows of matter and energy, rather than upon individual behavior. A great emphasis is placed on energy quality as well as the quantity of energy available.

The study of economics should be approached as a physical science as well as a social science. Therefore its analyses must be consistent with the known laws of science and the knowledge of other scientific disciplines; economies and societies are complex systems that interact with natural systems and are characterized by the properties of natural systems: inputs and outputs; boundaries; interactions; and the existence of positive as well as negative feedbacks.

*Wells College, Department of Economics – Email: kentk@wells.edu

Economics should be placed in a historical context, and focus upon explaining the evolution of social structures and institutions;

The economy should be studied as an actual social system, one that it concentrated, globalized and financialized not as an abstract system of perfect competition.

The belief that heterodox political economy is a more fruitful approach to integrate nature into the human economy than is mainstream neoclassical economics.

BIOPHYSICAL ECONOMICS AND ECOLOGICAL ECONOMICS

Biophysical economics shares some major principles with ecological economics. The most important is that the economy is a subsystem embedded in the finite and non-growing primary system of planet Earth. As a sub-system the economy is subject to the limits of the primary system and must obey the fundamental laws of science, especially the laws of thermodynamics and the conservation of matter and energy. With this, we agree, although we believe that ecological economics has not pursued the idea of the internal limits to growth or the effects upon working people of pursuing low-cost production across the globe. Ecological economics has pursued two separate directions: natural capital and the steady-state economy (SSE), and both flow from the insights of Herman Daly, whose importance we recognize, even in criticism.

The natural capital approach is the most neo-classically oriented, and the most problematic. The premise is that the stocks of nature are capital, which is only turned into resources when they are removed from nature and placed within the flows of the economy. For example, lumber is a resource and a forest is a capital asset. Unfortunately the National Income and Product Accounts treat the depletion of natural capital as current income and do not depreciate stocks of nature. Rather they treat their depletion as current income. If stocks of nature were valued properly as capital assets, the market system could then allocate them efficiently. While biophysical economists commend the valuing of natural assets, we do not make the next step that they will be allocated efficiently once their price is known. There are broader considerations in the stagnating macroeconomy that keeps this from occurring. I will develop this critique in the final section.

The steady-state approach of ecological economics is closer to the premises of biophysical economics, in that the limits to growth are already upon us. They are not just problems of the future. Since we have already exceeded nature's limits in many cases, the economy must actually shrink in order to step back from current overshoot. Most advocates of the steady-state contend this may be accomplished within the confines of the current institutional structure of the market economy. But this entails a theoretical separation of market forces that act in concert in the actual economy. Analytically Daly separates allocation from distribution and optimal macroeconomic scale. In his assessment, markets are simply devices for allocation and they do this efficiently (Daly 1996). Distribution, however, must be judged on the principle of justice and macroeconomic scale upon sustainability, not upon allocative efficiency. A sustainable scale and just distribution must also be the products of economic planning.

Biophysical economics contends that this is not the case. Allocation and distribution are connected intimately, and the neoclassical theory of income distribution (marginal productivity) is based on the same mathematical and theoretical structure as is allocation. Perfectly competitive equilibria produce both allocative efficiency and equity. They are difficult to separate, as market outcomes in the real world can and do produce profound degrees of inequality. Such disparities, grounded in the labor process and the international division of labor, cannot simply be fixed easily by means of economic policy. They are deeply embedded in the mechanism of allocation. Growth, or more precisely capital accumulation, is the very essence of the present capitalist economy. Moreover, economic growth has been the vehicle for the expansion of employment and the reduction of poverty. It would be difficult to reduce the scale of output without major consequences for employment, and consequently, for a more skewed income distribution. In short, it is hard to imagine theoretically a non-growing capitalism. Biophysical economics is based on the idea that economic growth rates are already slowing in the wealthy industrial nations, and that the onset of nature's strict biophysical limits will limit economic growth and capital accumulation to an even greater degree. Biophysical economics is an economics for the era of degrowth. In fact, the United States' economy has already begun to experience slower rates of economic growth since the 1960s, and especially since the peak of domestic oil production in 1970, despite pro-growth agendas of liberal and conservative administrations alike.

Decade	Annual Growth Rate
1960s	4.4%
1970s	3.3%
1980s	3.0%
1990s	3.2%
2000s	1.7%

Source: U.S. Department of Commerce
Bureau of Economic Analysis

Despite the current rhetoric that unleashing entrepreneurs will restore vibrant growth, the Commerce Department data show that the years of the most conservative administrations (Reagan, Bush I & II) produced the slowest growth rates of the post-World War II era. But growth is not just a matter of economic policy. Growth rates in the first two years of the 2010s remain mired at an average of 2.1 percent despite an expansive fiscal stimulus, shrinking taxes, and persistent easy money policy. Biophysical economists contend that the shrinking of growth rates are connected deeply to the rising cost and declining quality of energy. Postwar economic growth was built upon political hegemony and cheap petroleum. As both begin to fade there is little likelihood that marginal adjustments in taxing and spending can restore the biophysical basis of economic growth in the post-peak era.

Biophysical economics begins with the study of flows of matter and energy, rather than with individual maximizing behavior. It does not begin with the individual as a "hedonistic globule of self aggrandizement" (Veblen 1898), or end with the universal declaration of efficiency and equity to be found by means of free market equilibrium. Instead of adopting the idea that an economy can be analyzed adequately by looking solely at the exchange mechanism (an approach that began with Bastiat and permeates neoclassical thought) the principles of biophysical economics begins with the relation between humans and nature. The biophysical approach defines economics substantively in the tradition of Karl Polanyi.

The substantive meaning of economics derives from man's dependence for his living upon nature and his fellows. It refers to the interchange with his natural and social environment, insofar as this results in supplying him with the means of material want satisfaction (Polanyi 1957.)

A CRITIQUE OF NEOCLASSICAL ECONOMICS

Biophysical economics begins with the study of stocks and flows of matter and energy, which puts it in direct opposition to mainstream economics. Neoclassical economics starts with rational, acquisitive, and self-interested individuals and the ends with the formation of equilibrium prices that create efficient and equitable market outcomes. Unfortunately the set of assumptions needed to produce these outcomes are neither consistent with the current research in behavioral science, nor do they conform to the laws of thermodynamics. The assumptions are driven primarily by the calculus of constrained optimization and include provisions such as all economic agents operate independently from one another, all market goods and productive inputs have close substitutes, and that prices are capable of carrying all the information needed for consumers and producers to make rational decisions that lead to optimal and efficient allocations (Gowdy, et al. 2010).

Neoclassical economics is defined by the idea of scarcity. "Economics is the study of the allocation of scarce resources among alternative uses." However, all scarcity in the neoclassical sense is relative scarcity. The behavioral assumptions about acquisitiveness, in conjunction with the mathematical functions, yield human beings with unlimited wants. No matter how abundant resources or market goods may be, they are always scarce relative to unlimited wants. Absolute scarcity, or an insufficient quantity of a good or resource, is not problematic as neoclassical economics assumes all resources and products have substitutes. Even though these substitutes are not immediately present, they can be found by either technological change or trade. One must question how we can ever achieve sustainability if people behave as neoclassical postulates assert they do, and when the ecological footprint of the Earth is already 1.5 times the aggregate biocapacity. In essence neoclassical economics begins with the position that one needs to study only the processes of exchange and price formation in order to capture fully the nature of an economy. Moreover the economy is the primary system, not a subsystem. No larger system, such as the planet, can constrain the economy. Rational individuals respond to price incentives, and prices carry all the useful information needed to make rational and self-interested decisions. Moreover, positive feedback loops are either absent or dominated by negative feedback loops Prices alone regulate the market. A single price exists that satisfies both buyers and sellers. Once an equilibrium price is achieved any perturbation will enable the negative feedbacks to restore equilibrium. The market equilibrium will also exhibit allocative efficiency. Prices will equal the marginal cost of bringing another unit of output to the market. This solution, however, will exist only under the condition of perfect competition where businesses are willing to accept no economic profit. This efficiency can only exist in the case where an enormous number of equally powerless firms, with neither technological advantage, priority command over resources, nor innovative products or processes. Equity, or fairness, occurs when every “factor of production” (workers, landowners, entrepreneurs) receives exactly their contribution to output, no more and no less. Where the funds for technological innovation will come from is not addressed directly in the theory of pure exchange.

Furthermore, there are no differences between individual markets, say for and the market economy as a whole. Since firms are numerous, small and powerless no one single entity can influence the all-important market price. The macroeconomy is simply an aggregation of myriad small firms that behaves the same as do the individual entities. In other words neoclassical economics does not recognize the existence of complex positive feedbacks in the overall system. The economy as a whole can be depicted as a simple “circular flow.” In the end the value of the output in money terms equals the sum of the factor payments. The system remains in stable balance. Power remains diffuse and periods of depression are theoretically impossible. This conception is inconsistent with the laws of thermodynamics. For the economy to balance there can be no waste in terms of production or distribution. But every productive process that involves energy produces waste in the form of scrap and heat. This cannot be accounted for in the neoclassical conception of the circular flow.

Finally, neoclassical economics sees itself as universal science—able to explain any situation in any spatial location at any time in history. Human behavior comes from “human nature,” and the postulates concerning this behavior are accepted without empirical testing as “maintained hypotheses.” Any discussion of the importance of institutional structure is dismissed save the study of economic history, where the process of becoming as mass consumption society is chronicled and celebrated (Rostow 1960, DeVroey 1975).

However the real world is vastly different than are the abstractions of neoclassical economics. Real individuals are simply not like the rational maximizers of satisfaction posited by neoclassical economics. Households are more than units of consumption. They are also refuges from the hectic day-to-day world. They are where the next generation is reproduced and nurtured. When the neoclassical postulates of rational, self interest are subjected to empirical testing evidence does not confirm the postulates. Humans are as likely to be vindictive or altruistic as they are rational. Moreover humans exist in society. There is no consistent evidence that preferences are self-regarding, and independent of any other preference structure (Gowdy, et al. 2010). In addition business firms are not “perfectly competitive” as is required for the achievement of an allocatively efficient and equitable equilibrium. Real world firms have advantages of location and power. While firms may have once been small, their evolution and development after the age of fossil fuels resulted in large concentrated industries that possess sufficient power as not to have to accept zero profits. Giant multinational corporations, operating in the world’s megacities, are not organized in the same manner as are small town family businesses. Biophysical economics focuses explicitly on power relations in both the physical sense of energy per unit of time, and in the social sense of control over others. The changing nature of energy and control over markets and processes tells much about the character of a society that simply cannot be inferred from price.

THE CRUCIAL ROLE OF ENERGY

Biophysical economics makes no claim that economics is a universal science whose principles are embedded deeply in “human nature” and therefore should not be subject to change. Rather, by focusing on how the human economy is shaped by its use of energy, biophysical economics looks at social evolution. Biophysical economics has more interest in the explanation of changes in institutional structure over the course of time than in price formation. Rather, it focuses upon questions of energy quality. Economic limits will likely result from the decline in the quantity, and increase in price, of available energy. The challenge is not simply technological, but economic. Great fortunes can be gained or lost in the transition of energy regimes, and the short-term horizons embedded in market processes have yet to embrace alternative technologies or conservation as long as fossil fuels remain cheap. But soon global oil production will peak just as domestic production in the continental United States peaked in 1970. While some energy needs, especially the generation of electricity, can be, and are being, met by abundant natural gas, not all can be. Natural gas does not power many vehicles as the expensive supportive infrastructure is not yet built. Moreover the techniques used to extract the natural gas, such as hydraulic fracturing and horizontal drilling, leave behind myriad potential problems such as the reduction of water quality, the overwhelming of local sewage treatment systems, and the impact of moving heavy equipment to the drilling sites on the integrity of local roads and upon local air quality. Finally, while natural gas emits far less carbon dioxide per unit of heat than does coal, one cannot reduce the concentration of carbon dioxide in the atmosphere from an estimated 390 parts per million to the needed 350 ppm by increasing carbon emissions at a decreasing rate. We must cut fossil fuel use, not just change its composition.

DIMINISHING MARGINAL RETURNS AND THE ENERGY RETURN ON INVESTMENT

The debate on energy quality goes back to Ricardo and his principles of diminishing marginal returns. Just like the English aristocracy and gentry put the most fertile land into production first while leaving the least fertile lands for later, humans have exploited the most accessible and best quality hydrocarbons first. The Earth’s crust has been subjected to computer modeling and seismic testing. The result has been few new discoveries, and those that show any promise are smaller in size, and subject to either hostile climates, hostile politics, deepwater, incompletely reduced bitumen (as in the Athabasca Tar Sands), or low quality “heavy sour” crude. It will become more expensive in terms of energy, as well as in terms of dollars, to extract and refine the remaining hydrocarbons. Energy prices, just like food prices for Ricardo, will tend to rise, and the impact upon society will be profound.

The Energy Return on Investment (EROI) is the principle measure of energy quality. It is a measure of the energy returned to society divided by energy put into a particular activity. It turns out to be a pure number, as the units of energy are the same for numerator and denominator. Costs of oil production and exploration were low in the early days of domestic oil production. More sophisticated, and more expensive, technologies will be needed to tap deep water and Arctic sources. The EROI was estimated at 100:1 when large discoveries of oil in Texas and Oklahoma made the 1930s the decade of peak discoveries. After domestic oil production peaked in the 1970s the costs of production increased and the EROI fell to about 40:1. By 2000 the EROI for domestic oil was only 14:1 (Hall and Klitgaard 2011). A great deal of work is being done currently on refining the EROI concept. The figures given were for the wellhead. But should the costs of refining and transporting the fuel also be included? Should the costs of transforming the oil into fertilizer, growing food, and feeding the families of the oil workers be included? These are important questions. What level of EROI will we need in order to support health care and education systems? Hall and colleagues estimate that an EROI of at least 5:1 will be needed to support a sustainable civil society (Hall, et al. 2009). As the energy surplus declines with falling EROI, the economic surplus upon which modern society is built, may be destined to follow.

ECONOMIC SURPLUS AND HETERODOX POLITICAL ECONOMY

Rather than taking relative scarcity as its starting point, biophysical economics stresses economic surplus and absolute scarcity. An economic surplus is the difference between the value of a society's output and the cost of producing it (Baran and Sweezy 1966), and a surplus approach is clearly implied by the substantive definition of economics. Biophysical economics also accepts the point that absolute scarcity is not transcended easily by trade or technology. Even if substitutes can be found or new technologies developed, the transitions are often difficult and full of conflict. In the biophysical sense technology is not a "black box" process in which output is magically increased without any addition to inputs. Technological change is dependent upon energy! Most of the great epoch-making innovations of the 19th and 20th centuries such as the steam engine, the railroads, the automobile, electrification required an increase in net energy in order to transform the economy. Without an energy surplus there would be little economic surplus. It is this energy surplus that allows expanding population to concentrate in cities, achieve higher standards of living, and to provide health care, education, and innovations. Energy is not simply another input into production.

The substantive definition also implies that economic theory needs to be grounded in production, in the process of how human beings use energy to transform the products of nature into useful products that satisfy human need. Prices themselves are determined largely by the cost of the cost of production, including energy costs. Biophysical economics puts the analytical focus upon production while neoclassical economics treats it peripherally, by the same method (constrained optimization) used to calculate how goods satisfy human psychological preferences. Combining a focus on the institutions of production and a historical perspective creates an analytical need to trace the evolution of market economies, not just take them for granted. This is important because over the long course of human history, market economies have occupied a small niche in time and space. The historical time frame of the dominance of market economies occurs mostly, although not exclusively, in the time of fossil fuels as a source of energy and power. For the vast major of its existence the human population can be characterized by three phenomena. 1) a small energy surplus obtained from the solar flow; 2) craft production for direct use; and 3) a low and stable population.

Solar energy is essentially unlimited and non-polluting. Unfortunately it is diffuse, hard to capture and hard to store. For eons before the evolution of humans, plants served this purpose. Humans at first simply appropriated the energy surplus as they found it (hunters and gatherers) and later, with the development of agriculture, transformed the capture of solar energy to provide more food. However, as stated by anthropologist Joseph Tainter, solar energy was local and current, which limited the economic surplus. Such early societies tended to produce for direct use, rather than producing large quantities of products to be sold on markets. Certainly trade has existed since antiquity, but early societies produced use values and traded their surpluses. Production for exchange, or production of commodities, would not appear until the 16th century. By finding innovative ways to use solar energy, such as harnessing wind and water, early societies could increase the energy surplus and therefore the economic surplus. It was this surplus that allowed the cities of the ancient world to thrive. When the energy surplus disappeared many complex ancient cities simply collapsed (Tainter 1990). The modern world, on the other hand, is characterized by: 1) a large energy surplus obtained from fossil fuels; 2) mass production for profit and for market exchange; and 3) a large and rapidly growing population. Around the beginning of the 18th Europeans, having depleted most of the wood upon which their societies were built turned to coal as a rather inferior substitute. However they soon found that coal could be turned into a hotter burning fuel called coke by the same process by which wood is turned into charcoal. The industrial revolution was based, biophysically, upon this new fossil hydrocarbon. Fossil hydrocarbons were ancient and global. They were relatively cheap, highly energy dense, and easy to capture and easy to store and transport. However the industrial revolution was more than increased use of hydrocarbons and machines. It also entailed social transformations in the scale upon which work was organized, the degree of skill and control working people were able to exert, and the very conception of what wealth was. It was during this time frame that economics evolved as a separate discipline.

In the earliest era the study was known as classical political economy. It was grounded in the questions of how was wealth created and distributed, and to how did an economy grow? To pursue these questions classical political economists looked primarily at the process of production. How were the products of nature transformed into useable commodities that could be sold on markets by means of machinery and human labor? Furthermore, their primary unit of analysis was that of social class, and the abstract analytical categories of land, labor and capital had their material bases in social classes of a landed aristocracy, wage-workers, and those who employed money to produce goods and services by means of hired wage labor. The overall grounding ambition was to discover any underlying laws of the accumulation of wealth (DeVroey 1975, Hall and Klitgaard 2011).

All theories of classical political economy contained the position that capital accumulation and economic growth were self-limiting. Eventually the growing, “progressive” state would succumb to a long stagnation known as the stationary state, a situation that Adam Smith termed “melancholy.” Different classical political economists enunciated different reasons for the stationary state. Smith believed that it was due to the evaporation of new and lucrative investments as the economy matured. Thomas Malthus believed the growth in human population and the transfer of wealth from the aristocracy to an emerging class of capitalists lie at the heart of the problem. David Ricardo saw the problem in diminishing returns. Of all the classical political economists only John Stuart Mill saw the stationary state as a social improvement. Only in the stationary state could the cutthroat competition of Victorian capitalism give way to a more refined and genteel pursuit of knowledge and beauty. Although Karl Marx did not subscribe to a stationary state theory, he believed that continued capital accumulation and economic growth were self-limiting. Once the economy becomes dominated by large-scale monopolies (which Marx predicted) and sophisticated fossil fuel driven machinery creates an ever-growing surplus, the inability to find an adequate number of spending outlets, coupled with a lack of price competition among monopolies, makes the long-term tendency towards stagnation re-emerge (Baran and Sweezy 1966, Hall and Klitgaard 2011). Traditional spending outlets (consumption, investment, civilian government spending) have been inadequate to fully absorb the economic surplus. This is the primary course of declining growth rates since the 1960s. If spending on productive uses is insufficient then waste in the form of planned obsolescence, and automobile-dependent suburban sprawl, can absorb the surplus partially. But in the end, the overall trajectory of history has been towards stagnation. One explanation of periods of prosperity is that is that stagnation has been postponed by a series of “epoch-making innovations” that both revolutionize production and create the ability to absorb the economic surplus (Baran and Sweezy 1966). Most, if not all, epoch-making innovations such as the steam engine, the railroad, electricity, and the automobile, have been fossil-fuel intensive. Whether growth can continue in the absence of fossil-fuel led innovation is a question for much further research and beyond the scope of this paper. Nevertheless, this means that the focus on economic surplus also gives political economy, as well as biophysical economics, a very different perspective on the difference between the economy-as-a-whole and the individual firm.

THE INSIGHTS OF POLITICAL ECONOMY

Biophysical economics returns to the insights of political economy: that the economy is best analyzed by starting at the point of production, that economic surpluses and absolute scarcities exist and are a superior analytical mechanism than is relative scarcity, and that conflicts over the production and distribution of the economic surplus are an important component of the story of economic evolution. Biophysical economics believes strongly that the human economy is subject to limits to growth. To the traditional subject matter of political economy, which focuses upon the internal limits to continued growth and capital accumulation, biophysical economics adds an analysis of external limits by focusing explicitly on energy. The limits may take the form of absolute scarcities, along with rising prices and decreasing quality, of fossil fuels, or the limits may be in the atmosphere’s ability to absorb additional carbon from the burning of these fuels. The two aspects of energy throughput will certainly interact, and they will impact the course of future growth, the reproduction of the economy, and most certainly the quality of life in urban areas. The looming biophysical limits, those posed by peak oil, declining EROI, and the potentially enormous cost of dealing with climate change are likely to occur in the same historical period, exacerbating an economy whose growth potential has been declining for decades. Biophysical economics, which recognizes the possibilities of a climate-compromised and energy short world, will be a better guideline to building such a sustainable society than the present individualistic, growth oriented forms of economic theory.

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