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"Summary of article by Cutler J. Cleveland, Robert Costanza, Charles A.S. Hall and Robert Kaufman: Energy and the U.S. Economy: A Biophysical Perspective"

Between the mid-1940s and the early 1970s, the US economy showed generally good performance. Since 1973, however, performance indicators such as labor productivity, inflation and growth rates have been relatively disappointing, and mainstream economic models can not entirely explain this shift and its underlying causes. A theoretical perspective that recognizes the importance of natural resources, especially fuel energy, may help; some economic problems can be understood more clearly by explicitly accounting for the physical constraints imposed on economic production.

In this perspective, the focus is on the production process, i.e., the economic process that upgrades the organizational state of matter into lower-entropy goods and services. This process involves a unidirectional, one-time throughput of low-entropy fuel that is eventually lost as waste heat. Production is a work process, and like any work process it will depend on the availability of free energy. The quality of natural resources is also important to this process, because lower quality resources will always require more work to upgrade them into final goods and services.

Based on this biophysical perspective, four hypotheses are presented and discussed below.

ENERGY AND ECONOMIC PRODUCTION

Hypothesis 1: A strong link between fuel use and economic output exists and will continue to exist.

Rather than viewing the economy as a closed system, it must be seen as an open system embedded within a larger global system that depends on solar energy. The global system produces environmental services, foodstuffs, and fossil and atomic fuels, all of which are derived from solar and radiation energies in conjunction with other important resources. Fossil and other fuels are used by the human economy to empower labor and produce capital. Fuel, capital and labor are then used to upgrade natural resources to produce goods and services. Production is a process using energy to add order to matter. Since fuels differ in the amount of economic work they can do per unit heat equivalent, both quantity and quality of fuel play a role in determining levels of economic production. An important quality of fuels is the amount of energy required to locate, extract and refine the fuel to a socially useful state. This can be measured by a fuel's Energy Return on Investment (EROI), which is the ratio of the gross fuel extracted to the economic energy required directly and indirectly to deliver the fuel in a useful form.

Standard economic theory views fuel and energy as just one set of inputs that is fully substitutable with other inputs, but this is incorrect. Free energy upgrades and organizes all other inputs, and it is a complement in the production process that cannot be created by combining the other factors of production. The specific amount of energy needed to produce goods and services is called the embodied energy.

If one considers the last one hundred years of the US experience, fuel use and economic output are highly correlated. An important measure of fuel efficiency is the ratio of energy use to the gross national product, E/GNP. The E/GNP ratio has fallen by about 42% since 1929. We find that the improvement in energy efficiency is due principally to 3 factors: 1) shifts to higher quality fuels such as petroleum and primary electricity; 2) shifts in energy use between households and other sectors; and 3) higher fuel prices. Energy quality is by far the dominant factor.

LABOR PRODUCTIVITY AND TECHNICAL CHANGE

Hypothesis 2: A large component of increased labor productivity over the past 70 years has resulted from increasing the ability of human labor to do physical work by empowering workers with increasing quantities of fuel, both directly and as embodied in industrial capital equipment and technology.

Economic models generally present technological advances as means to increasing labor and capital productivity. These effects of technological change are measured as a residual after accounting for all tangible factors; energy and natural resources are not considered tangible factors, thus leaving a large residual. From an energy perspective, however, the increases in labor productivity are actually driven by increased fuel use per worker-hour. In the pre-1973 period, when fuel prices were falling relative to the price of labor (the wage rate), labor productivity was rising as fuel was substituted for labor due to the change in relative prices. In the post-1973 period, as the price of fuel rose relative to wage rates, the data indicates declining labor productivity.

ENERGY AND INFLATION

Hypothesis 3: The rising real physical cost of obtaining energy and other resources from the environment is one important factor that causes inflation.

High inflation rates can be explained by the linkages between fuel use and money supply. If the money supply is increased, stimulating demand beyond levels that can be satisfied by existing fuel supplies, then prices will rise. This implies that when the costs of obtaining fuel are high, fiscal and monetary policies may not be successful in stimulating economic growth.

ENERGY COSTS AND TECHNOLOGICAL CHANGE

Hypothesis 4: The energy costs of locating, extracting and refining fuel and other resources from the environment have increased and will continue to increase despite technical improvements in the extractive sector.

It has been argued that technological innovations for mining low-quality ores can address the problems associated with the depletion of high-quality mineral deposits. Evidence of this is seen in the constant or declining amount of inputs used per unit output in the extractive sector during this century.

From a physical perspective, however, such a sanguine view of the depletion and scarcity of important natural resources is unwarranted. The extraction of lower-quality ores requires the use of more energy-intensive capital and labor inputs. Over the last few decades, there has been an increase in the direct fuel input per unit of output of fuels and minerals. The present rising energy costs of fuel extraction do not bode well for future exploitation of non-renewable resources.

The EROIs for natural gas, petroleum and coal have fallen dramatically over time in the continental US. In Louisiana, the EROI for natural gas declined from 100:1 in 1970 to 12:1 in 1981, and a similar decline was observed in the petroleum industry. Nationally, the EROI for coal has fallen from 80:1 in the 1960s to 30:1 in 1977. Another indicator of the increasing cost of fuel extraction is the rise in the real dollar value of the mining sector share of real GNP, from 3-4% over most of this century to about 10% by 1982. Continued economic growth depends on our ability to develop sources of energy with more favorable EROIs.

CONCLUSION

Declining EROIs for fuels and increasing energy costs for non-fuel resources will have a negative impact on economic growth, productivity, inflation and technological change. To maintain current levels of economic growth and productivity we will need to either develop alternative fuel technologies with EROI ratios comparable to those of petroleum today, or the efficiency of fuel use to produce economic output must increase.[1]

Notes

1. Author's note: The empirical analyses in this paper have been enriched and updated. An additional decade of information substantiates the basic conclusions of the paper. The interested reader is referred to Robert K. Kaufmann, "A Biophysical Analysis of the Energy/GDP Ratio," in Ecological Economics 6 (1992): 35-56; and Robert K. Kaufmann, "The Relation Between Marginal Product and Price: An Analysis of Energy Markets," in Energy Economics 16 (1994): 145-148.