ECOLOGICAL ECONOMICS 67 (2008) 104–108

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ANALYSIS

Physical energy cost serves as the "invisible hand" governing economic valuation: Direct evidence from biogeochemical data and the U.S. metal market

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ARTICLE INFO

Article history:
Received 17 October 2006
Received in revised form
25 November 2007
Accepted 4 December 2007
Available online 16 January 2008

Keywords:
Chemical elements
Embodied energy
Energy cost
Gibbs free energy
"Invisible hand"
Value theory
Biogeochemical data

ABSTRACT

Energy supply is mandatory for the production of economic value. Nevertheless, tradition dictates that an enigmatic "invisible hand" governs economic valuation. Physical scientists have long proposed alternative but testable energy cost theories of economic valuation, and have shown the gross correlation between energy consumption and economic output at the national level through input–output energy analysis. However, due to the difficulty of precise energy analysis and highly complicated real markets, no decisive evidence directly linking energy costs to the selling prices of individual commodities has yet been found. Over the past century, the US metal market has accumulated a huge body of price data, which for the first time ever provides us the opportunity to quantitatively examine the direct energy-value correlation. Here, by analyzing the market price data of 65 purified chemical elements (mainly metals) relative to the total energy consumption for refining them from naturally occurring geochemical conditions, we found a clear correlation between the energy cost and their market prices. The underlying physics we proposed has compatibility with conventional economic concepts such as the ratio between supply and demand or scarcity's role in economic valuation. It demonstrates how energy cost serves as the "invisible hand" governing economic valuation. Thorough understanding of this energy connection between the human economic and the Earth's biogeochemical metabolism is essential for improving the overall energy efficiency and furthermore the sustainability of the human society.

1. Introduction

Inflation, unemployment, stock prices, and economic growth, in fact all aspects of the human economy deteriorate when energy prices surge. Not only have wars been waged over energy resources, but their use lies at the root of anthropogenic climate change. Understanding the energy basis underlying the human economy may be more critical for

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0921-8009/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2007.12.011

Table 1 – Metal based value system (European)

Ratio	Roman empire	France	UK	Italy	Notes
240	Libra (327.48 g)	Livre	Pound	Lira	Libra=£=Pound
12	Solidus (16.37 g)	Sol	Shilling	Soldo	Solidus=$=Dollar
1	Denarius (1.36 g)	Denier	Penny	Denaro	1~1.5 g (8–15th century.)

improving the overall energy efficiency and sustainability of humanity than any single technological innovation or political decision.

Physical scientists have long noticed the indispensable role energy plays in economic systems (Soddy, 1933; Georgescu-Roegen, 1971; Costanza, 1980, 2004; Odum, 1996; Ayres, 1998). In 1886, Boltzmann suggested that life is primarily a struggle over available energy (Costanza, 1980). Soddy later studied the flow of energy underlying the economy and proposed the energy cost theory for economic valuation in 1933(Soddy, 1933; Costanza, 1980). Previous input–output energy analyses have revealed an aggregate correlation between energy consumption (embodied energy) and economic output at the national level (Costanza, 1980, 2004; Cleveland et al., 1984). Nevertheless, little is known about the direct link between the energy cost of production and the selling prices of individual commodities. Because the correlation between energy cost for production and the selling prices of individual commodities on the real market is extremely complicated, Costanaza admitted (2004), "Given, on the one hand, the enormous data requirements to calculate energy costs accurately and, on the other hand, the pervasive market imperfections complicating market prices, there is no unambiguous correct answer."

Over the past century, the US metal market has accumulated a huge body of price data. Such abundant data for the first time provided us the opportunity to quantitatively examine the direct energy-value correlation of individual commodities: the purified elements (mainly metals). The following sections report our analysis on the market price data of 65 purified chemical elements (from 1959 to 1998) relative to the total energy consumption for refining them from naturally occurring geochemical conditions. Based on the unambiguous energy-value correlation shown by the analysis, we further discuss how physical energy cost underlies conventional economic concepts, such as the ratio between supply and demand or scarcity's role in economic valuation.

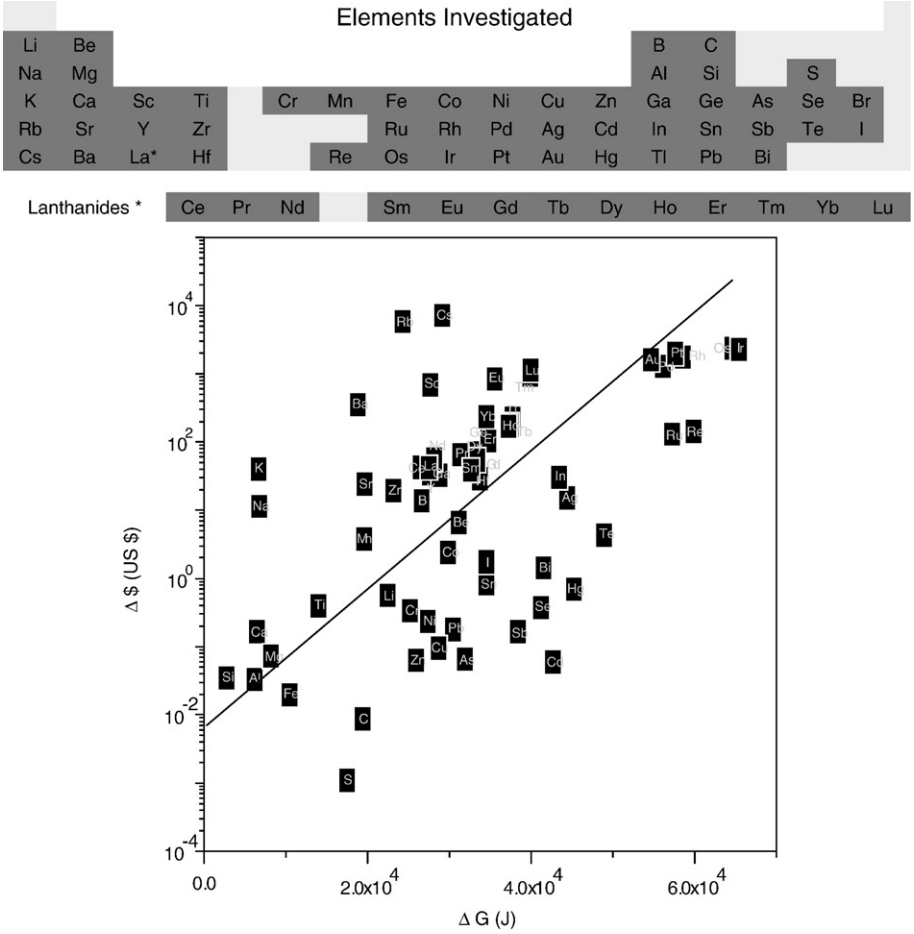

Fig. 1 – The investigated elements and their energy-value correlation. Prices are from data of 1998, unit is in 1992 constant US dollar.