Environmental Innovation and Societal Transitions 9 (2013) 33–37

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

Analysis

Why energy's economic weight is much larger than its cost share

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ARTICLE INFO

Available online 1 October 2013

Keywords:
Cost share theorem
Economic growth
Energy
Output elasticities
Technological constraints

ABSTRACT

Energy conversion and entropy production determine the growth of wealth in industrialized economies. Novel econometric analyses have revealed energy to be a production factor whose output elasticity, which measures its economic weight, is much higher than its share in total factor cost, while for labor just the opposite is true. Although this result is at variance with neoclassical economic theory, it is compatible with the standard maximization of profit or time-integrated utility if appropriate technological constraints on capital, labor, and energy are taken into account. Shifting the burden of taxes and levies from labor to energy is an adequate policy consequence.

1. Introduction

The INSEAD homage to Professor Robert U. Ayres is an excellent opportunity to reconsider the role of energy in the economy – a field to which Bob Ayres has contributed so much. This paper is a short summary of quantitative analyses that are reported in the books of Ayres and Warr (2009) and Kümmel (2011).

I have been led into economics by the first and the second law of thermodynamics. They say that nothing happens in the world without energy conversion and entropy production. More precisely, the first law states: Energy is conserved; it consists of valuable *exergy*, which can be converted into useful work, and useless *anergy*, which is, for instance, heat dumped into the environment. The second law

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2210-4224/$ – see front matter
http://dx.doi.org/10.1016/j.eist.2013.09.003

reveals entropy as the ugly twin of energy in the following sense. Entropy production is unavoidable in all real-life processes, which cannot run without energy conversion. It destroys exergy and increases useless anergy. This imposes thermodynamic limits to improvements of technical energy efficiency. Furthermore, entropy production in energy-conversion processes involves emissions of particles and heat, which lead to environmental pollution and climate change.

Concern about environmental and resource problems has grown since the 1970s. Together with the economic recessions in the wake of the oil-price explosions between 1973 and 1981, this has motivated numerous studies by natural scientists, engineers, and economists on energy, entropy, and the economy. A number of these studies are discussed in the two above-mentioned books. As a result of the interdisciplinary efforts there is now consensus that "Energy generation, distribution, and use are critical to modern economies, both as an input to industrial production and as an important element of consumer spending. At the same time, current patterns of energy generation and use contribute significantly to environmental problems, such as climate change and air pollution." (OECD, 2013).

2. Productive physical basis and market superstructure

A modern economic system – a national market economy or a sub-sector of it – consists of a physical basis that produces goods and services, and a market superstructure, where economic actors trade these goods and services. Price signals from supply-demand frictions provide feedback from the market superstructure to the productive physical basis.

Economics as a social science is mainly concerned with the behavior of the actors in the market superstructure, where everybody is striving for wealth. The main focus of economic research has been based so far on observations, which may be summarized by: "Wealth is allocated on markets, and the legal framework determines the outcome." The productive physical basis consists of the sectors agriculture, industry, and services. Here wealth is created by energy conversion, and environmental pollution emanates from entropy production. In other words, energy conversion and entropy production determine the growth of wealth.

Three production factors (inputs) are active in the productive physical basis of the economy:

(1) Energy-converting devices and information processors together with all buildings and installations necessary for their protection and operation. They form the production factor K (capital).
(2) People who manipulate and supervise the capital stock K, constituting the production factor L (labor).
(3) Energy (more precisely exergy), which activates the machines of the capital stock, forming the production factor E.

These three factors drove 20th century economic growth. Entropy production, and the limited capacity of *space* to absorb emissions without drastic perturbations of the biosphere, will rule the 21st century. The emissions of infrared-active greenhouse gases like CO_2 from the combustion of fossil fuels threaten climate stability. This, in combination with the pivotal role of energy in economic growth as described subsequently, indicates the economic, ecological, and technological challenges of the future.

3. A model of energy and economic growth

The value added of goods and services is the output of an economic system. In order to look into the question of how it depends on the inputs, one must properly aggregate and measure output and inputs. In principle, the output and the production factors capital, labor, and energy can be aggregated in physical terms. The physical units that result from the aggregation of output and capital in terms of work performance and information processing are related to inflation-corrected monetary units by equivalence factors. Routine labor is measured by man-hours worked per year, and energy is measured by Peta-Joules consumed per year. Fossil and nuclear energies, and solar radiation as well, are practically 100 percent exergy. The empirical data for output and inputs that we use in the subsequent econometrics are taken from the national accounts and the national labor and energy statistics.