The Rebound Effect: An Analysis of the Empirical Data for Lighting

Jeffrey Y. Tsao, Sandia National Laboratories, 505-844-7092, jytsao@sandia.gov
Harry D. Saunders, Decision Processes Incorporated, 925-743-8400, hsaunders@decisionprocessesinc.com
Paul Waide, International Energy Agency, +33-1-40-57-66-21, paul.waide@iea.org

Overview

We have collected and self-consistently analyzed data for per-capita consumption of artificial light, per-capita gross domestic product and cost of light. The data span a wide range (three centuries, six continents, five lighting technologies, and five orders of magnitude), and are consistent with a linear variation of per-capita consumption of light with the ratio between per-capita gross domestic product and cost of light. From a practical perspective, this result represents the historically consistent baseline assumption for constructing future scenarios of consumption of light and associated energy. From a theoretical perspective, this result has implications on the "rebound effect," of current interest in energy economics.

Methods

Our starting point was five recent datasets estimating consumption of light. The first dataset represents estimates from the monumental work by Fouquet and Pearson on consumption of light in the United Kingdom over a 300-year time span (Fouquet and Pearson 2006). The second dataset represents estimates from the recent comprehensive study by the International Energy Agency on consumption of light in various nations or groups of nations for which grid electricity is available, mostly in the year 2005 (IEA 2006). The third dataset represents an estimate from the extremely thorough bottoms-up survey by Navigant of consumption of light in the United States in 2001 (Navigant 2002). The fourth dataset represents estimates by Mills and co-workers of the consumption of light in China in 1993 (Min et al. 1997) and in populations in 1999 for which grid electricity was not available (Mills 2005). The fifth dataset represents an estimate of consumption of light in China in 2006 (Li 2007).

Using these five datasets as a starting point, we filled in gaps in the datasets, estimated demand factors auxiliary to the datasets, and self-consistently integrated across the datasets. The result is a quantitative picture of the per-capita consumption of light and associated power, and how these depend on luminous efficacy, cost of light and associated power, and gross domestic product and population.

Results

Our central result is that per capita consumption of light is, to a very good approximation, proportional to the ratio between per-capita gross domestic product (*gdp*) and cost of light (*CoL*), obeying the expression

$$\varphi = \beta \cdot \frac{gdp}{CoL}, \tag{1}$$

where $\beta = 0.0072$ is the fraction of *gdp* expended on light. This expression is consistent with data spanning: 3 centuries (1700-2006), 6 continents (Africa, Asia, Australia, Europe, North America, South America), 5 types of fuel (tallow, whale oil, gas, petroleum, electricity), 5 overall families of lighting technologies (candles, oil lamps, gas lamps, electric incandescent bulbs, electric gas-discharge bulbs or tubes), 1.4 orders of magnitude in per capita gross domestic product, 4.3 orders of magnitude in cost of light, and 5.4 orders of magnitude in per capita consumption of light. No empirical evidence is found for a saturation in per-capita consumption of light, even in contemporary developed nations.

The implication is that the income and price elasticities of demand for artificial light are unity or nearly unity. These elasticities are higher than have been previously found (as reviewed in Greening et al (2000)). The reason, we believe, is that previous studies have focused on relatively short (months to years) time periods during which societal-use paradigms for lighting are relatively static. It is only over longer (decades to centuries) time periods that radically new societal-use paradigms may be expected to emerge, with associated radical changes in consumption of lighting. It is in fact these radically new societal-use paradigms that were envisaged in the first formulation of the rebound effect (Jevons 1906; Alcott 2005).

Conclusions

From a practical perspective, this result represents the historically consistent baseline assumption for constructing long-term future scenarios for consumption of light and associated power. In other words, there is a massive potential for growth in the consumption of light if new lighting technologies are developed with higher luminous efficacies and lower cost of light. Whether history is predictive of the future cannot be known, of course, and plausible arguments can be made in either direction. Given that lighting accounts for about 6.5% of world energy consumption and is poised at the brink of a technology revolution, this issue is of great current interest for forecasting future energy consumption and informing public policy.

References

Alcott, B. (2005). "Jevons' paradox." Ecological Economics 54: 9-21.

Fouquet, R. and Pearson, P.J.G. (2006). "Seven Centuries of Energy Services: the Price and Use of Light in the United Kingdom (1300-2000)." Energy Journal 27: 139-77.

Greening, L.A., Greene, D.L., and Difiglio, C. (2000). "Energy Efficiency and Consumption - the Rebound Effect - a Survey." Energy Policy 28: 389-401.

IEA (2006). Light's Labour's Lost: Policies for Energy-efficient Lighting. International Energy Agency.

Jevons, W.S. (1906). The Coal Question: An Inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines. Macmillan and Co.

Li, Jinmin (2007). "Unpublished estimate of consumption of light and associated energy in China 2006."

Mills, E. (2005). "Environment - the Specter of Fuel-Based Lighting." Science 308: 1263-64.

Min, G.F., Mills, E., and Zhang, Q. (1997). "Energy Efficient Lighting in China - Problems and Prospects." Energy Policy 25: 77-83.

Navigant (2002). U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program.