Think piece on
Lighting, Energy Consumption, and Human Productivity

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Artificial light has long been a significant factor contributing to the quality and productivity of human life. It expands the productive day into the non-sunlit hours of the evening and night, and during the day it expands productive spaces into the non-sunlit areas of enclosed dwellings, offices and buildings.

Because we value artificial light so highly, we consume huge amounts of energy to produce it. We estimate that the production of artificial light consumed roughly 6.5% of total global primary energy in 2005. This percentage is large and, coupled with increasing concern over energy consumption, has inspired a number of projections of light and associated-energy consumption into the future. Such projections are of special interest at this point in history when lighting technologies are evolving rapidly. Filament-based incandescent technology is giving way to gas-plasma-based fluorescent and high-intensity-discharge (HID) technology; and over the coming 5-10 years both may give way to solid-state-lighting (SSL) technology.

Projections of the consumption of light and associated power are difficult, however, because there is no consensus regarding the factors that underlie the demand for light. Hence, relatively arbitrary assumptions must be made, the most common of which is that demand for light is independent of the efficiency (and hence cost) with which it is produced and delivered. If true, then technology evolution leading to efficiency improvement would not lead to an increase in light consumption, but rather to a decrease in energy consumption. If not true, however, there might instead be an increase in light consumption, a type of "rebound" effect that would lessen the decrease in energy consumption.

Because of the importance of possible rebound effects, much work has been expended trying to understand and quantify them, both theoretically and empirically. For any particular energy service, however, its magnitude has been difficult to quantify, especially over longer time periods for which its magnitude can be anticipated to be largest. Nearly all empirical studies of which we are aware focus on relatively short (months to years) time periods during which societal-use paradigms for an energy service 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 that service. It is in fact these radically new societal-use paradigms that were envisaged in the first formulation of the rebound effect.

Recently, a number of careful estimates have been made of the consumption of light in various nations over diverse geographic, economic and temporal circumstances. In our work, we have built on these estimates -- filling in gaps in the datasets, estimating demand factors auxiliary to the datasets, and self-consistently integrating the datasets -- to create a quantitative picture of the consumption of light. These estimates span a wide enough (over five orders of magnitude) dynamic range to enable accurate correlations between the consumption of light and its underlying demand factors. They also span a long enough (decades to centuries) time period to enable quantitative conclusions to be drawn about the rebound effect in this important energy service over historically significant time scales.

Indeed, lighting appears to be uniquely well suited amongst the various energy services for such a quantitative study. Its output (light), is more easily defined and estimated than the outputs (e.g., weight times distance traveled, or change in temperature times volume or heat capacity of space) of other energy services. Though it has had a long history of technology innovation, each major lighting technology has had a reasonably well-defined historical period of maturity or dominance, without the accounting difficulties associated with a massive proliferation of sub-technology variants, each with a different energy efficiency, market penetration and cost structure.

We find that the data are consistent with a simple expression in which per-capita consumption of artificial light varies linearly with the ratio between per-capita gross domestic product and cost of light. The expression is plausible, but we make no serious attempt to explain its origin. Instead, we consider its explanation (both for developing and developed countries) an interesting direction for future work, and at present consider it to be simply an empirical result, though one with important implications.

A first implication is that, extrapolated and aggregated to the world in 2005, 0.72% of world gross domestic product and 6.5% of world primary energy was expended to purchase 130 Plmh of artificial light at a primary energy cost of 29.5 Quads.

A second implication is that it represents the historically consistent baseline assumption for constructing future scenarios for consumption of light and associated energy. 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. Indeed, this empirical result has powerful implications on the rebound effect discussed in the Introduction, and an important direction for future work will be to understand quantitatively these implications.

Finally, we believe another possible direction for future work would be to extend this empirical work on the consumption of artificial light to the consumption of other energy services (e.g., transportation). It would be especially interesting to combine, as has been done here, historical time-series with contemporary cross-sectional data. In this way, one could gain a broader understanding of the rebound effect not just on the relatively short (months to years) time periods during which societal-use paradigms for an energy service are relatively static, but over the longer (decades to centuries) time periods during which radically new societal-use paradigms emerge, with associated radical changes in consumption of that service.