A BRIGHTER FUTURE? QUANTIFYING THE REBOUND EFFECT IN ENERGY EFFICIENT LIGHTING

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Overview

Adopting energy-efficient technologies - such as replacing incandescent light bulbs (ILs) or halogen bulbs by energy efficient compact fluoroscent bulbs (CFLs) or Light Emitting Diodes (LEDs) - may result in lower electricity savings than expected from strictly an engineering-economic assessment due to the 'rebound effect' (e.g. Khazzoom, 1980; Brookes, 1990). Households may change behavior in response to the lower effective costs of lighting services of energy-efficient light bulbs by letting bulbs burn longer, using more bulbs for additional lighting services, or increasing the luminosity of bulbs. In addition to this *direct rebound* effect, there may also be indirect and macroeconomic rebound effects (e.g. Greening et al., 2000, Sorrell, 2007, van den Bergh, 2011 or Turner. 2013). The empirical evidence for quantifying the size of the rebound effect in residential lighting is rather weak. Greening et al. (2000) find a 5% to 12% rebound in residential lighting based on four studies, but also raise doubts about the methodological soundness and strength of results of the studies. For the first decade of this century, Fouquet and Pearson (2012) estimate a -0.5 price elasticity of lighting demand in the UK. In this paper, we estimate the direct rebound effect of bulb replacements in the residential sector in Germany distinguishing explicitly between rebound effects associated with changes in luminosity and in burn time.

Methods

In May and June of 2012 a representative computer-based survey of more than 6000 German households was carried out within an existing panel. The questionnaire asked for information on the new and old bulb in the last bulb replacement. To limit recall bias participating households were equipped with a visual interface, where photographs of different bulb types could be shown, the survey included an opt-out possibility ("I don't remember") and the analysis is restricted to observations where the replacement occurred in 2012 (72%) or in 2011/2010 (25%). Most new bulbs replaced a broken or burned out bulb (86%). Most bulb replacements were in the living or dining room (30%), and concerned switches where the the initial bulb was the main bulb, i.e. the primary source of light in the room (74%). For the empirical analyses we exclude replacements involving tubes and fixture replacement. Changes in luminosity are captured in the survey by asking households about the wattage of the initial and the new bulb. Five different wattage categories were given per bulb type, with the categories being specific to the wattages commonly associated with each bulb type. Standard figures from the literature were then used to transform the wattage figures into luminosity per bulb. Second, to asses the impact of bulb switches on increases or decreases in burn time, respondent indications of positive or negative changes in bulb burn time with the replacement bulb from among the following categories (in minutes): 0, <15, 15 to 30, 30 to 60, >60 are analyzed. Where information on percentage change in burn time is required, we relate these responses to standard benchmark figures on burn time by room type and by purpose. Data availablility allows us to calculate the *efficiency elasticity of useful work* $(S = \Phi t)$ as direct measure of the rebound effect (e.g. Sorrell and Dimitropoulos, 2008)

(1) $$\eta_{S,\varepsilon} = \frac{\partial \Phi}{\partial \varepsilon}\frac{\varepsilon}{\Phi} + \frac{\partial t}{\partial \varepsilon}\frac{\varepsilon}{t} = \eta_{\Phi,\varepsilon} + \eta_{t,\varepsilon}$$

where Φ stands for luminosity (in lm), t reflects burn time (in h) and ε reflects efficiency (measured in lm/W). Hence, the efficiency elasticity of useful work may be decomposed into the elasticity of luminosity (*luminosity rebound*) and the elasticity of burn time (*burn time rebound*). Note that our estimate of the rebound does not suffer from the potential shortcomings of econometric analyses estimating the rebound via the price elasticity of energy demand or energy services. Since rebound effects are thought to be caused by behavioral change, our analysis considers efficiency to remain unchanged if the initial bulb and the replacement bulb are of the same type. A switch to a less efficient bulb is defined analogously. Accordingly, about 23% of the switches involved a transition to a more efficient bulb technology and are used for the rebound effect calculations. About 5% of bulb replacements entailed a switch to a less efficient bulb. Results are calculated both for the replacement of the average bulb and for the most frequently documented bulb switch, i.e. for the main bulb in the living or dining room (modal bulb).

Results

When the replacement bulb is more efficient than the initial bulb, it is about 24% brighter on average (13% for modal switch) and burns about 5.5 minutes per day longer (9 minutes for modal switch). The total rebound is calculated and partitioned into contributions from changes in luminosity and changes in burn time based on a discrete version of equation (1). Our analysis also distinguishes between intial bulb types (ILs versus halogens) and replacement bulb types (CFLs versus LEDs). When an average IL or a halogen bulb is replaced by a CFL or an LED the total direct rebound effect is slightly above 6%. The larger part of this rebound (ca. 60%) results from higher luminosity of the replacement bulb. For the modal bulb, the total rebound effect is just below 3% and the larger part (ca. 60%) is due to a longer burn time. The difference in total rebound between non-modal and modal bulbs is statistically significant (7% versus 3%, $p<0.1$). There appears to be no difference in the magnitudes of the total rebound or its components for bulb switches involving initial ILs versus initial halogen bulbs when looking at the combined transitions to CFL and LEDs. However, when an average halogen bulb is replaced by an LED rather than by a CFL, the total rebound is much smaller (0% versus 23%, $p<0.1$), in particular because the luminosity rebound is smaller when the replacement bulb is an LED rather than a CFL (-2% versus 20%, $p<0.05$). Similarly, there appears to be no difference in rebound effects by replacement bulb types, when considering the combined transitions from IL and halogen bulbs. But when the replacement bulb is an LED, the total rebound is larger, when the initial bulb is an IL bulb rather than a halogen bulb (10% versus 0%, $p< 0.1$). Again, this difference is mainly due to the luminosity rebound, which in this case is larger for initial ILs than for halogens (6% versus -2%, $p<0.1$).

Conclusions

Our findings suggest that the direct rebound of residential lighting is overall rather low, and may be particularly low (in percentage terms) in high use bulbs. Thus, energy savings from the recent EU ban on incandescent (and halogen) bulbs or other types of energy efficiency standards for lighting are unlikely to be dissipated by substantial increases in lighting use (in terms of either burn time or luminosity). Similarly, the predicted strong future diffusion of LEDs is not expected to spur substantial direct rebound effects that would mitigate attendant energy savings. On the one hand, the stated increase in energy services may satisfy additional household needs for luminosity or burn time, and hence increase household welfare. Higher luminosity and longer burn time may also reflect a rational response to inferior performance of energy efficient bulbs stemming from lower (perceived) lighting quality or warm-up periods. The analysis provides some evidence that changes to CFLs, which are often perceived to have lower light quality, are associated with greater increases in luminosity and with lower increases in burn time than changes to LEDs. The size of the rebound may also depend on the technologies available on the market. In particular, to avoid a loss in luminosity, consumers are expected to rather purchase energy efficient bulbs with higher luminosity than with lower luminosity compared to the initial bulb. Higher luminosity of energy efficient replacement bulbs may also stem from a lack of information or bounded rationality due to poor information display on bulb packages or from consumer inability to process the technical information, thus providing a rationale for policy intervention.

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