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Household transitions to energy efficient lighting

Bradford Mills [a],*, Joachim Schleich [a,b,c]

[a] Virginia Polytechnic Institute and State University, Blacksburg, VA, USA
[b] Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany
[c] Grenoble Ecole de Management, France

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ABSTRACT

New energy efficient lighting technologies can significantly reduce household electricity consumption, but adoption has been slow. A unique dataset of German households is used in this paper to examine the factors associated with the replacement of old incandescent lamps (ILs) with new energy efficient compact fluorescent lamps (CFLs) and light emitting diodes (LEDs). The 'rebound' effect of increased lamp luminosity in the transition to energy efficient bulbs is analyzed jointly with the replacement decision to account for household self-selection in bulb-type choice. Results indicate that the EU ban on ILs accelerated the pace of transition to CFLs and LEDs, while storage of bulbs significantly dampened the speed of the transition. Higher lighting needs and bulb attributes like energy efficiency, environmental friendliness, and durability spur IL replacement with CFLs or LEDs. Electricity gains from new energy efficient lighting are mitigated by 23% and 47% increases in luminosity for CFL and LED replacements, respectively. Model results suggest that taking the replacement bulb from storage and higher levels of education dampen the magnitude of these luminosity rebounds in IL to CFL transitions.

1. Introduction

Residential lighting technologies have shown dramatic increases in energy efficiency in recent years. Compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) require about 80% and 85% less electricity compared to incandescent lamps (ILs) and last 6 and 26 times longer, respectively (CLASP, 2013; EC, 2011b; IEA, 2012).[1] Hence, widespread adoption of these technologies has the potential to significantly reduce household electricity consumption, which accounts for about 10% of residential electricity consumption in the EU (Bertoldi et al., 2012). The diffusion of energy-efficient light bulbs has been hampered, however, by several factors, including bulb size and shape (visual appearance), perceived lower lighting quality, limited dimmability, warm-up period before achieving full brightness, environmental and health concerns associated with toxic mercury in CFLs, and higher initial purchase costs (e.g. de Almeida et al., 2013; EC, 2011a,b). Given high initial costs it may not be economically rational to replace ILs with energy-efficient bulbs in rooms where daily usage time tends to be short (e.g. Frondel and Lohmann, 2011; Mills and Schleich, 2010). For instance, a bulb in the attic, storage room or bedroom where the daily usage time is less than 15 min may only pay-off the higher initial purchase cost after more than a decade.

In order to accelerate the transition to more energy-efficient lighting, several countries have implemented bans on imports and domestic sales of incandescent light bulbs since (IEA, 2010). In the EU, where ILs still accounted for more than 50% of the residential lighting stock in 2009 (Bertoldi et al., 2012), Commission Regulation (EC) No 244/2009 imposed an immediate ban of non-clear incandescent lamps along with a gradual phase-out of other incandescent household bulbs. The ban was applied starting in September of 2009 with the highest wattage ILs ($>= 100$ W), and finishing in September of 2012 with the lowest wattage ILs (<60 W).

Little is known though about the role that the bulb ban has played in accelerating household transitions from ILs to energy efficient bulbs. Analyses of the international market for residential lighting suggest that in recent years many households were already making the transition from purchasing ILs to purchasing more energy-efficient CFL and LED bulbs and that the trend was even accelerating (e.g. IEA, 2010;

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* Corresponding author at: 205-A Hutcheson Hall, Blacksburg, Virginia 24061-0401, USA.
E-mail address: bfmills@vt.edu (B. Mills).

[1] In an IL electric current runs through a wire filament and heats the filament until it glows. In a CFL, an electric current passes through a tube containing argon and a small amount of mercury vapor. This generates ultraviolet light that excites a fluorescent coating on the inside of the tube, which emits visible light. An LED is a semiconductor device that produces visible light when an electrical current is passed through it. Since efficacy varies with technology, manufacturer, voltage and wattage, figures on electricity savings can only be approximate.

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McKinsey, 2012). Only two decades ago the vast majority of residential light bulbs were ILs. For example, in 1995 the IL share of all bulbs in the average household in the EU was about 85% (VITO, 2009). By 2007 this share dropped to 54%, while the stock shares of halogens and CFLs were by then 23% and 15%, respectively. Similarly the market share of ILs in the EU decreased from 61% in 2006 to 41% in 2010. For the same period, the market share of CFLs increased from 15% to 23% (Bertoldi et al., 2012; IEA, 2012). More recently, LEDs have rapidly entered the residential light bulb market, and their prices have declined markedly McKinsey (2012). Clearly the ban did not spur transitions among early adopters, but the ban may have forced lagging households to also transition to energy efficient bulbs. On the other hand, households with strong preferences for ILs may have stockpiled ILs prior to implementation of the ban on specific bulb types[2]. Likewise, households often store bulbs to prevent extended loss of lighting services should a bulb suddenly break or in order to lower transaction costs related to purchasing bulbs. Such storage of ILs will slow down the transition towards more energy-efficient bulbs and delay the impact of a ban.

Slow diffusion may not be the only constraint inhibiting electricity savings from energy efficient bulbs. Savings may be lower than expected from a strictly engineering-economic assessment due to 'rebound effects' (e.g. Brookes, 1990; Frondel et al., 2008, 2012; Greening et al., 2000; Khazzoom, 1980, 1987, 1989; Madlener and Alcott, 2009; van den Bergh, 2011; or Sorrell, 2007). Since purchasing energy-efficient light bulbs means lower costs of lighting services, households may respond by letting bulbs burn longer, using more bulbs for additional lighting services, or increasing the luminosity of bulbs purchased, thereby increasing the demand for lighting services.[3] In addition to this direct rebound effect, indirect and economy-wide rebound effects may also exist. Indirect rebound effects reflect additional energy use associated with higher expenditures for other goods and services based on cost savings. Macroeconomic (or economy-wide) rebound effects are typically the result of productivity improvements and radical innovations resulting in additional applications of energy-using technologies and economic growth (i.e. a macroeconomic growth effect). Income effects and economy-wide rebound effects associated with lighting are typically, in the short to medium term, small since the share of lighting in total electricity consumption and the expenditures for lighting as a fraction of disposable income are rather small (e.g. Chitnis et al., 2013; Fouquet and Pearson, 2012). Several empirical studies find direct rebound effects of energy efficient lighting, including Greening et al. (2000), de Almeida (2008), Chitnis et al. (2013), and Schleich et al. (2014), but with the exception of Fouquet and Pearson (2006, 2012), and Schleich et al. (2014), these studies focus on the rebound effects from longer burn time only. In particular, relying on data for several hundred years, Fouquet and Pearson (2006, 2012) find that total consumption of lighting services increased substantially over time in response to cheaper and better lighting services and in response to growing incomes.[4] Schleich et al. (2014) use the same dataset as this study and calculate the rebound effects for energy efficient lighting in terms of both burn-time and luminosity.[5] However, the factors that drive household choice of energy efficient bulbs and the factors associated with increases in luminosity are not explored.

Studies exploring the relation between household adoption of energy efficient bulbs and socio-economic factors include Scott (1997) and di Maria et al. (2010) for Ireland, Kumar et al. (2003) for India and Mills and Schleich (2010) for Germany, but only Kumar et al. (2003) find a strong positive correlation (for income and education), while di Maria et al. (2010) highlight the role of environmental awareness. Existing studies though are based on data collected either in the 1990s or early 2000s and CFLs and LEDs have improved markedly as substitutes for ILs since then. Similarly, no empirical analysis has been undertaken on the actual impact of the EU ban, particularly when accounting for the pre-ban existence of a market shift away from ILs.

In this paper, we examine three fundamental questions related to the efficacy of the EU ban on ILs. 1) Did the ban appreciably increase the rate of adoption of energy efficient CFL and LEDs? 2) What other factors are associated with the switch from ILs to energy efficient lamps? 3) What are the factors associated with increases in lamp luminosity observed with the changeover to energy efficient lamps?

These questions are addressed using a 2012 representative survey with more than 1600 documented choices of how private households in Germany replaced ILs. The paper represents, to our knowledge, the first attempt to analyze factors associated with household decisions to adopt energy efficient bulbs after the implementation of the EU ban and to document factors associated with concurrent changes in bulb luminosity.

The remainder of the paper is organized as follows. Section 2 presents the paper's theoretical and empirical framework. Section 3 presents the statistical model and data. Section 4 presents the results and Section 5 concludes and distills policy implications.

2. Theoretical and empirical framework

2.1. Theory

A utility maximizing household needs to replace an IL. The household makes two choices: 1) what bulb type to replace the initial IL with and 2) the wattage of the replacement bulb relative to the initial IL bulb. Assume that household utility associated with bulb replacement can be captured from net income after replacement, y, and lighting luminosity L (●) that has a bulb-type i specific relationship with wattage, w, represented as $L^i(w)$[6]

$$U\left(y, L^i(w)\right) \quad \text{where } i = \text{IL}, \ \text{CFL}, \ \text{LED}.$$

Net income after replacement depends on base income, y^0, bulb-type and wattage specific costs of purchase, $B^i(w)$, and bulb-type specific variable costs of bulb use, $C^i(w)$

$$y = y^0 - B^i(w) - C^i(w).$$

Given a bulb type, maximization of utility subject to the income constraint yields the optimal choice of bulb wattage w^* where

$$\frac{\partial U}{\partial L^i(w^*)} \frac{\partial L^i(w^*)}{\partial w^*} = \frac{\partial U}{\partial y}\left[\frac{\partial B^i(w^*)}{\partial w^*} + \frac{\partial C^i(w^*)}{\partial w^*}\right]. \tag{1}$$

The marginal utility of the luminosity associated with increased wattage equals the marginal utility of income associated with the variable and fixed costs of the increased bulb wattage.

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[2] Such stockpiling was observed in several European countries in the first half of 2009, notably Germany (Kanter, 2009; Spiegel Online International, 2009).

[3] Some increases in household welfare likely occur from the increased duration or intensity of lighting use.

[4] For example, lighting demand increased by a factor of 500 over the last three centuries in the UK. Fouquet and Pearson (2012) estimate the own price elasticity of lighting demand for the early twenty-first century in the UK at around −0.5. While this may only be a crude estimate for the size of the rebound effect in lighting demand assuming unsatiated lighting needs, it provides some evidence that the effect is not negligible (see also Borenstein, 2013).

[5] Schleich et al. (2014) employ discrete indicators of increases and decreases in burn time. But recall data on changes in burn-time are inherently more difficult to collect and this study does not attempt to examine factors associated with those discrete changes.

[6] Utility from all other goods not influenced by the bulb decision is assumed constant, as is bulb burn time.