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How households in Pakistan take on energy efficient lighting technology

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ABSTRACT

A household survey in Pakistan is used to examine drivers of more efficient compact fluorescent light bulb (CFL) adoption and the impact of CFL adoption on the demand for lighting services. Higher price of a CFL to an incandescent bulb (IB) and limited knowledge about the life span of CFLs versus IBs are found to lower adoption rates by as much as 20%. While CFL adoption increases the technical efficiency of household lighting, the lower cost for lighting services results in estimated rebound effects that decrease potential energy savings by 23% to 35% due to increased brightness and extended hours of use. These findings have important implications for household welfare and cost-benefit tradeoffs for CFL projects.

1. Introduction

Wide scale adoption of more energy efficient technologies can help to bridge the gap between energy supply and demand and combat climate change (Jaffe et al., 2001; Ryan et al., 2012). In developing countries, where finding new sources of energy supply may take years, increasing energy efficiency on a large scale may be the most practical way to reduce the extent to which energy shortages are a major impediment to economic growth. Developing countries, such as Bangladesh, China, India, Pakistan, Philippines, and Vietnam, where energy gaps have been especially severe, have tried to induce energy efficient adoption through programs that distribute millions of free compact fluorescent light bulbs (CFLs) to replace less energy efficient incandescent bulbs (IBs) in domestic households.[1]

Yet, several factors can diminish the long term success of such programs. First, adoption of more energy efficient technologies is often hindered by a combination of market failures, individual preferences, and behavioral biases (Jaffe and Stavins, 1994). Unless policy can address some of these barriers to adoption, long term usage of more energy efficient technology may not be sustainable. The literature addressing the drivers of more energy efficient lighting adoption is still underdeveloped. The few insights from developed countries show that higher education, greater income, and positive environmental attitudes increase adoption of more efficient lighting at the household level (Di Maria et al., 2010; Mills and Schleich, 2010, 2012). These studies, however, may omit key variables driving the adoption decision such as the higher price of more efficient technologies, uncertainty over the quality of technology, and lack of awareness of savings that could be achieved. In particular, evidence suggests that these are major factors leading to lower rates of adoption of improved technologies especially in developing countries (Bhattacharya and Cropper, 2010; Foster and Rosenzweig, 2010). Given that these aspects are important to include in the model they may imply a very different set of recommendations than those suggested by past studies.

Secondly, even if adoption occurs, there may be a rebound effect that results in a much lower amount of energy saved from a switch in technologies than is predicted by models that hold consumer consumption for energy services constant (Sorrell and Dimitropoulos, 2008). This effect arises because adoption of more energy efficient technology decreases the cost of energy services resulting in an increase in the demand for energy services. Past research has documented the rebound effect for a variety of products, population sets, and countries (Greening et al., 2000; Sorrell and Dimitropoulos, 2008; Sorrell et al., 2009). Estimates are shown to vary widely depending on the context and estimation approach. Data limitations have often resulted in rebound effects being computed indirectly based on changes in the price of energy rather than through improvements in energy efficiency. This may result in a different estimate of the rebound effect due to adoption of a particular type of energy service. This is because a change in energy efficiency of one service makes that service cheaper, but also cheaper relative to other types of energy services. In contrast, a decrease in energy price makes all energy services become cheaper while the proportional costs of one energy service compared to another remain the same.

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[1] The World Bank has so far supported residential CFL programs in more than 20 countries from 1994 to 2011 (World Bank, 2011). There are also a number of other initiatives financed directly either by governments or in connection with aid donors.

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In general, studies on the rebound effects that occur for domestic lighting systems are relatively sparse. Existing studies have found rebound effects of 50% utilizing 300 years of aggregate data on consumption of lighting services and their utilization in the UK and 50–80% for kerosene consumption from introduction of a more energy efficient solar lantern in India (Foquet and Pearson, 2011; Roy, 2000). However, a study in Ethiopia, which uses micro-level data to estimate empirically the rebound effect, finds a much smaller rebound effect of 20% 18 months after the distribution of free CFLs (Costalanski et al., 2013).

This paper uses data from a household survey of electrical lighting choices and usage in Pakistan to examine empirical factors related to CFL adoption and the impact that CFL adoption has on the demand for lighting services.[2] It seeks to provide a greater basis for understanding the various aspects that may help or hinder goals of reducing energy demand through adoption of more energy efficient technology in the domestic sector of a large developing country.[3] There are several unique aspects to the analysis. First, the adoption model is able to include variables that capture the relative price of CFLs and perceptions of the lifetime of a CFL compared to an IB that is missing in existing studies. This provides a means for simulating the effect that price subsidies on CFLs and informational campaigns that accompany CFL quality guarantees can have on rates of adoption. Second, an instrumental variable approach is used to better identify the impact of an efficiency increase from CFL adoption on household demand for lighting services usage and brightness capacity. This model is applied not only to the house, but also to different types of rooms. Third, we use the empirical estimates of the impact of CFL adoption on lighting services demand to compute the rebound effect for the average household in the sample. The rebound effects are decomposed into utilization and capacity effects. This reveals how households may value different aspects of lighting when trying to maximize their benefits with the available choices.

The rest of the paper is organized as follows: Section 2 covers the data used for the analysis. Section 3 empirically examines the adoption decision and simulates the effects of different policy levers on the increase in probability to adopt. Section 4 provides the theoretical basis for examining the rebound effect and details how the rebound effect can be estimated through empirical analysis. Finally, Section 5 concludes.

2. Data and descriptive statistics

2.1. Pakistan domestic lighting survey data

Data from the Pakistan Sustainable Energy Efficiency Investment Program (SEEIP) Baseline Domestic Lighting Survey conducted in March and April of 2009 by Gallup Pakistan is used for the analysis. 3253 households from 9 distribution utilities across 58 districts, administrative units, towns and cities were covered by the survey. Areas were chosen based on urban–rural classification, geographical accessibility, and electricity consumption. The sample was stratified to represent domestic customer distribution patterns. Surveying occurred only if an adult and permanent resident was available as a respondent and the house could provide an electricity bill covering the last 12 months.[4]

Table 1
Descriptive statistics of households and respondents.

	Mean	SD
Household characteristics		
Household # workers	1.69	0.85
Household size	6.92	2.99
Main income source: Daily labor	0.34	0.47
Main income source: Farming	0.14	0.34
Main income source: Government/Business/Other	0.34	0.48
Main income source: Private service	0.18	0.38
Property # rooms	2.71	1.41
Property # light points	6.81	5.68
Ownership (vs. rent)	0.91	0.29
Property type: Flat	0.02	0.14
Property type: Single building	0.95	0.23
Property type: Multi building	0.03	0.18
Property construction: Masonry (vs. Adobe/Informal)	0.64	0.48
Respondent characteristics and CFL knowledge		
Female	0.17	0.38
Household head	0.63	0.48
Prior awareness of CFL?	0.89	0.31
How many times do you think a good CFL saver will last compared to an IB?		
Don't know	0.23	0.42
2 times	0.38	0.49
4 times	0.20	0.40
6 times	0.09	0.29
10 times	0.09	0.28
Distance traveled to purchase last bulb >2 km (vs < = 2 km)?	0.20	0.40
Observations	3253	

Note: SD = standard deviation.

The survey collected for each household in the sample the basic demographics of the respondent, house characteristics, and detailed count of lighting equipment. The number of each type of bulb and the associated wattage for each room were recorded through physical visits to the house. Corresponding average hours used per day for each type of bulb in each room over the last month were obtained through self-reports. Up to 7% of the sample was dropped during the analysis because a household had characteristics which were outliers or there were missing data on key variables of interest.

There are some limitations to the data. In general, there are relatively sparse measures related to a household's characteristics that may not provide sufficient controls for adoption and energy usage outcomes. Lighting usage measures are self-reported which may introduce some recall bias into the analysis. While this is probably minimal, as recall is only for the last month of usage, it does prevent the analysis from drawing conclusions for winter or summer periods that have harsher weather conditions causing energy shortages to be more prevalent. The data also did not collect measurements for the quality or efficiency factor of the bulbs. As developing countries often do not impose minimum standards the efficiency factor may vary substantially. While these aspects may serve as a source of measurement error in the analysis, there is still sufficient richness to draw some important insights for understanding factors that affect adoption and energy consumption for lighting in Pakistan.

Table 1 provides selected descriptive statistics of the household and respondent. The average household has 1.7 workers and a household size of 6.9. 34% of the households obtain their main income from daily labor and another 34% from government/private business. Over 91% of households own their homes and 64% have a house constructed from masonry. The average house has 2.7 rooms and 6.8 light points. Thus, the average number of rooms per capita is 0.4. This is well below the 1.6 rooms per capita for OECD countries reflecting a substantially poorer population set (OECD, 2011).

Measures related to a respondent's awareness and beliefs regarding CFLs are also reported.[5] 89% of respondents claim they are aware of

[2] The Pakistan government launched a national program costing $60 million to replace 30 million IBs with CFLS in the residential sector. The Asian Development Bank (ADB) contributed $40 million to the program as a concession loan. For more information about the program see http://pid.adb.org/pid/LoanView.htm?projNo=42051&seqNo=02&typeCd=3. The survey used for this study was conducted in 2009 during the preparation of the loan project.

[3] Pakistan was ranked 134 out 180 countries in terms of its per capita GDP (PPP$) of $2745 in 2011. It is the sixth largest country in the world in terms of population.

[4] The entire area serviced by the 9 distribution utilities was considered and identified in terms of accessibility in which fieldwork could be conducted. Several districts were chosen at random from a set of districts considered accessible for fieldwork in each distribution utility. 45% of interviews were conducted in urban areas and 55% in rural areas. Sampling started from a centralized location and surveying occurred until the quota for the area was exhausted as no existing sample frame was available to draw households for inclusion in the survey.

[5] 51% of respondents also reported buying CFLs in their last light bulb purchase, and 42% cited availability of CFLs as an important determinant to switch from IB to CFLs.

CFLs. However, a large fraction of households are uncertain of how long a quality CFL lasts compared to an IB, while 58% believe it lasts at most 2 to 4 times as long as an IB. In contrast, most quality CFLs in developed countries last 5–13 times longer than an IB. These responses therefore may reflect a combination of lack of awareness and respondent's experience with CFLs in Pakistan that may have been of low quality. Finally, convenience appears to be a strong factor in purchase behavior with 80% of households making their last purchase of lighting within two kilometers of their house.

2.2. Electrical lighting usage and capacity adjusted lighting effects

Lighting usage and lighting capacity measures were constructed for the house as well as for the living room, dining room, and bedroom—the rooms where most lighting services are concentrated in a house.[6] Let n_{irb}, w_{irb}, and h_{irb} represent the number, wattage, and average daily hours of use associated with a given bulb type b for household i in the room (or house) r. Then the average daily usage per bulb (watt-hours), au, average wattage per bulb, aw, and the average daily hours used per bulb, ah, can be constructed as follows:

$$au_{ir} = \frac{\sum_{b \in \{\text{CFL,IB}\}} n_{irb} w_{irb} h_{irb}}{\sum_{b \in \{\text{CFL,IB}\}} n_{irb}} \tag{1a}$$

$$aw_{ir} = \frac{\sum_{b \in \{\text{CFL,IB}\}} n_{irb} w_{irb}}{\sum_{b \in \{\text{CFL,IB}\}} n_{irb}} \tag{1b}$$

$$ah_{ir} = \frac{\sum_{b \in \{\text{CFL,IB}\}} n_{irb} h_{irb}}{\sum_{b \in \{\text{CFL,IB}\}} n_{irb}}. \tag{1c}$$

The average daily usage per bulb is calculated as the sum of total watt-hours of CFL and IB divided by the total number of these types of bulbs. The total watt-hour is equal to the product of the number, wattage and average daily use of the bulbs summed across records. The average wattage per bulb equals the sum of total wattage of CFL and IB divided by the total number of bulbs. The average daily hours used per bulb are the total hours used for bulbs in the room divided by the total number of bulbs. These measures exclude information from other bulb types such as fluorescent tube lamps (FTL) and halogen bulbs as these are typically not interchangeable with IBs. This allows for the measures to more precisely capture lighting usage and lighting capacity that applies between the substitutable technologies of CFLs and IBs.

Lumen-adjusted measures of the average daily lighting output per bulb, alu, and average lighting intensity per bulb, alw, corresponding to Eqs. (1a)–(1b) are also constructed to capture the amount of lighting services provided by IBs and CFLs. Let l denote the lighting capacity in lumens generated per hour. It is assumed that there is a linear relationship where bulb wattage can be multiplied by a factor σ to obtain l. To yield the same level of lighting output an IB is assumed to consume approximately $m(q)$ times the amount of energy of a CFL with quality q. Thus,

$$l^{cfl} = \sigma w^{cfl} = m(q)\sigma w^{ib} = m(q) l^{ib}. \tag{2}$$

For the lumen adjusted measures, the coefficient σ is a constant factor and eliminated in the variable construction so that only the wattage of light bulb is used to construct the variables to proxy for lighting services as follows:

$$alu_{ir} = \frac{\sum_{b \in \{\text{CFL}\}} n_{irb} m(q) w_{irb} h_{irb} + \sum_{b \in \{\text{IB}\}} n_{irb} w_{irb} h_{irb}}{\sum_{b \in \{\text{CFL}\}} n_{irb} + \sum_{b \in \{\text{IB}\}} n_{irb}} \tag{3a}$$

$$alw_{ir} = \frac{\sum_{b \in \{\text{CFL}\}} n_{irb} m(q) w_{irb} + \sum_{b \in \{\text{IB}\}} n_{irb} w_{irb}}{\sum_{b \in \{\text{CFL}\}} n_{irb} + \sum_{b \in \{\text{IB}\}} n_{irb}}. \tag{3b}$$

The difference between Eqs. (3a)–(3b) and the counterparts in Eqs. (1a)–(1b) is that the wattage of CFL bulbs is multiplied by a factor of $m(q)$. This adjustment results in very different interpretations of the two sets of variables. Actual usage is reflected by the first set, whereas the second set proxies for lighting services. For high quality CFLs in developed countries the amount $m(q)$ typically ranges between 4 and 6 depending on the quality.[7] However, in developing countries there may be a wide range due to the absence of manufacturing standards and quality controls. As the data does not capture the efficiency factor of the CFLs to a standard IB, we develop a strategy to proxy for the efficiency factor based on the price paid by the household for their last CFL and their beliefs regarding the length of time a CFL versus an IB lasts. A conservative approach is taken which assumes that the efficiency factor ranges between 3 and 5 times that of an IB. The efficiency factor of 3 was identified as a lower bound from evidence that the price of a CFL was at least 3 times the price of an equivalent IB in Pakistan. The approach used for determining the efficiency factor, detailed in Appendix 1, ultimately results in an average efficiency factor of CFLs to IBs of 3.4. Given that prices and beliefs are a good reflection of bulb quality this approach may resolve some of the error in the estimation that arises from not having a direct measure of the efficiency factor. However, since there are no clear measures of what an appropriate lower bound is in terms of the efficiency factor of a CFL in Pakistan, or any developing country, additional efficiency factors were created to check the robustness of the results. For example, we also considered an efficiency factor that instead ranged between 2 and 5 times that of an IB resulting in an average efficiency factor of 2.7.

Table 2 presents descriptive statistics on lighting in the house, living room, dining room and bedroom. There are 3023 valid household observations. 1019, 681, and 2444 households reported presence of lighting in the living room, dining room, and bedroom. As the average number of rooms across the sample is less than 3, the difference in observations indicates that many households do not have all 3 rooms. For households where some combination of dining, living and sleeping occurs in a single room, enumerators were asked to categorize these rooms under a single room type.

64% of houses contain at least one CFL bulb while the penetration rate was 74%, 64% and 57% in the living room, dining room and bedroom. The living room has the highest CFL penetration potentially due to a combination of both the functionality and amount of time spent in the room. The average number of CFLs per house is 2.8 while for IBs it is 2.6. The data suggest that CFLs are more prevalent than IBs on both the extensive margin (penetration) and intensive margin (proportion of bulbs) in the overall house and the main rooms of a typical household in Pakistan. People tend to use more CFLs than IBs in the living and dining rooms, but not in the bedrooms.

The sample mean of the average energy consumption of one bulb, computed with formula (1a), is 205, 205, 188 and 231 watt-hours for the overall house and in the living, dining and bedrooms, respectively.

[6] This aggregation occurs to better capture aspects of the lighting system and trade-offs in utilization and capacity of lighting that could not be observed at a per-bulb level.

[7] Energy Star (2012) states that the minimum standard for a CFL to receive an Energy Star designation in the US is to have an energy efficiency which is 4 times that of an equivalent IB.

Table 2
Lighting of the house and by room.

Variable	House		Living room		Dining room		Bedroom	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CFL in room	0.64	0.48	0.74	0.44	0.64	0.48	0.57	0.50
# IB	2.58	2.78	0.48	0.74	0.54	0.73	0.91	1.11
# CFL	2.77	3.99	1.08	0.95	0.97	1.05	1.00	1.44
Avg. daily use per bulb (watt-hrs)	204.73	174.27	204.88	183.63	188.37	196.48	231.40	226.77
Avg. wattage per bulb	52.75	28.46	42.31	28.99	44.83	29.11	53.33	33.49
Avg. hrs used per watt	3.77	1.87	4.93	2.40	4.14	2.43	4.29	2.41
Avg. daily lighting services per bulb	341.06	209.80	474.30	310.21	390.41	306.40	406.16	279.46
Avg. lighting intensity per bulb	85.05	27.76	93.22	34.94	90.75	38.90	91.41	32.37
Observations	3023		1019		681		2444	

Note: SD = standard deviation.

The energy consumption per bulb can be decomposed into average wattage per bulb and average daily use in hours per bulb as represented by formulas (1b) and (1c). The means of average wattage and hours of daily use per bulb are 52.8 wattage and 3.8 h for the entire house, 42.3 wattage and 4.9 h for the living room, 44.8 wattage and 4.1 h for the dining room, and 53.3 wattage and 4.3 h for the bedrooms. On average, the living room has the longest daily use of lighting, while the bedroom has significantly higher wattage per bulb than the other 2 room types. The latter, however, does not hold when we account for the different lighting capacities of CFL and IB of the same wattage.

The virtual average watt-hours and wattage per bulb defined by formulas (3a) and (3b) are presented in the bottom of Table 2. The means of these virtual lumen-adjusted variables are about 60% to 130% higher than the corresponding actual watt hours and wattage variables. This illustrates the substantial energy savings that can be achieved with CFLs if households pursue the same level of lighting. The average wattage per bulb in the bedroom is 20–25% higher than those in the living and dining rooms. However, lighting capacity per bulb, as measured by the virtual average wattage, is similar across rooms. On the other hand, people still seem to prefer a brighter bedroom since there are 2 bulbs on average in the bedroom, while only 1.5 bulbs exist in other room types. One explanation is that the bedroom is generally bigger than living or dining rooms in Pakistan.

3. CFL adoption

3.1. Model of CFL adoption

Investigating factors related to CFL adoption by households can help in informing appropriate policy levers to increase rates of adoption and understanding the long-term effectiveness of projects which distribute CFLs for free. To investigate the factors determining adoption of CFLs, A_i^{cfl}, we run a simple probit model for household i as follows:

$$\Pr\left(A_i^{cfl} = 1 | p_i, z_i, x_i\right) = \Phi\left(\gamma p_i + z_i'\delta + x_i'\beta + D_i\right). \quad (4)$$

In this model, p_i captures the price ratio between a CFL to an equivalent IB for the last reported prices for bulb purchases by households in an area. z_i is a series of dummy variables indicating the households beliefs of how long a CFL lasts compared to an IB. x_i is a vector of variables controlling for household characteristics such as household ownership, household size, number of rooms, construction of the house and property type as well as the households main source of income. These are meant to proxy for household level of wealth in the absence of measures of household income or expenditures. Average area level income was created utilizing the Pakistan Health Income and Expenditure Survey (HIES) 2007–2008 and included in the model as an additional proxy for wealth. A respondent's gender and age were also included to capture idiosyncracies in responses. Finally, disco dummies, D_i, are also included to capture differences in electricity provision and price dictated by differences in the 9 different distribution utilities as these aspects are likely to affect a household's assessed benefits of adopting or utilizing more efficient technology.

In this model φ and δ represent the coefficients on the variables of interest. The marginal effect representing the change in the probability of adoption due to a change in p_i is therefore $\gamma\phi(.)$ where the standard normal density, ϕ, is taken at the mean of all variables included in the model. A few additional characteristics reflecting a household's awareness of CFLs and purchasing behavior were also included in variants of the model specification. However, these were not found to be significant or highly correlated with existing variables and ultimately eliminated. Standard errors are clustered at the area level to capture unobserved within area correlations.[8] Models were run for the house and each of the 3 main rooms.

Table 3 shows marginal effect estimates for the various factors affecting the adoption decision. Household CFL adoption is found to be significantly related to the price of CFL versus IB with a 1 unit increase in the price ratio effectively decreasing the probability of CFL adoption by 2.8%. The inclusion of variables on the respondent's knowledge regarding the life of a CFL versus IB shows that this factors significantly into the adoption decision. In particular, a respondent who does not know how long a CFL lasts compared to an IB versus a respondent who reports that a CFL lasts at least 4 times that of an IB is 63% less likely to be in a household that has adopted a CFL. In general, the probability of adoption rises with the respondents reported belief about the length of time a CFL lasts compared to an IB. However, both price effects and differences in beliefs in regards to CFLs are not statistically significant for the individual rooms.

The number of bulbs in a room, ownership, and house construction are generally statistically significant factors related to adoption. However, more sturdy housing construction and a greater number of light points, which most likely proxies for wealth, are the main variables which are consistently and positively related to CFL adoption across the house and rooms. The models generally reveal the importance of including measures that can capture the price trade-offs of the various technologies (CFLs versus IBs) and aspects related to the beliefs or perceptions of the relative quality of the available technology. While this study has a more rough level of controls for household wealth and electricity services provided than Mills and Schleich (2010) and Di Maria et al (2010), both price and beliefs are likely important variables to include in models assessing more efficient technology adoption independent of other more refined control measures. We expect this to be especially true for developing countries where the variation in and access to quality CFLs can create uncertainty that diminishes the perceived returns to adoption. In general, the inclusion of the price and belief

[8] Mills and Schleich (2010) draw on the marketing literature by using a double hurdle model to investigate the adoption and intensity of adoption decision for CFLs. We do not focus on this model here to make a clearer connection between CFL adoption and the rebound effect. However, using this formulation we found that the importance of coefficients such as reported knowledge of CFLs does change between the first hurdle and second hurdle, but remains significant.

Table 3
Marginal effect estimates of household CFL adoption.

Variable	House	Living room	Dining room	Bedroom
Ratio price CFL to IB (per watt)	−0.028***	−0.002	0.000	−0.027***
	[0.004]	[0.005]	[0.008]	[0.005]
Perceived life of CFL vs IB: Don't know (vs 4 times)	−0.629***	−0.442***	−0.473***	−0.580***
	[0.026]	[0.060]	[0.073]	[0.025]
Perceived life of CFL vs IB: 2 times (vs 4 times)	−0.091***	0.043	0.057	−0.098***
	[0.027]	[0.034]	[0.058]	[0.031]
Perceived life of CFL vs IB: 6 times (vs 4 times)	0.065*	0.042	0.100	0.021
	[0.036]	[0.043]	[0.066]	[0.044]
Perceived life of CFL vs IB: 10 times (vs 4 times)	0.127***	0.147***	0.266***	0.207***
	[0.033]	[0.028]	[0.043]	[0.040]
# Bulbs [house/room]	0.034***	0.179***	0.258***	0.095***
	[0.004]	[0.022]	[0.038]	[0.013]
HH size	0.004	−0.004	−0.006	0.004
	[0.004]	[0.005]	[0.007]	[0.004]
Main income source: Farming	−0.081**	0.034	−0.194**	−0.093**
	[0.033]	[0.046]	[0.089]	[0.037]
Main income source: Government/Business/Other	0.034	0.065**	0.112**	0.063**
	[0.024]	[0.032]	[0.055]	[0.030]
Main income source: Private Service	−0.020	0.057*	0.169***	0.072**
	[0.030]	[0.034]	[0.054]	[0.034]
Property: # Rooms	0.044***	0.011	0.016	0.019*
	[0.011]	[0.012]	[0.017]	[0.011]
Ownership (vs Rent)	0.003	0.021	0.223***	0.062
	[0.037]	[0.049]	[0.077]	[0.044]
Property type: Multi bldg (vs single building)	0.073	0.024	0.080	0.210***
	[0.056]	[0.058]	[0.084]	[0.060]
Property construction: Masonry (vs Adobe/Informal)	0.153***	0.097**	0.194***	0.167***
	[0.024]	[0.042]	[0.067]	[0.028]
Average City log (HH per capita income)	0.092*	0.037	−0.043	0.103*
	[0.048]	[0.068]	[0.097]	[0.062]
Observations	3129	1051	689	2505

Note: Standard errors in brackets.
DISCO dummies, respondent characteristics, distance to last bulb purchase >2 km included but not shown. Standard errors clustered by city.
Omitted dummies are life CFL versus IB: 4 times; Main income: Daily labor;
Property: Rent; Property type: Single building; Property Construction: Informal/Adobe;
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

variables accounts for more than half of the variance explained by the model with R-squared changing from 0.19 to 0.38 after inclusion, further reflecting their importance.

3.2. The effect of price subsidies and informational campaigns on CFL adoption

Inclusion of the relative price of CFLs versus IBs and a respondent's beliefs regarding the life of CFLs versus IBs in the model provides a means to investigate how price subsidies and informational campaigns may change the probability of adoption. Table 4 provides the simulated results. The predicted adoption rate is 73% at the mean values of variables included in the model. The average price of a 25-watt CFL is 158 rupees (~$1.58 US) compared to 16 rupees for a 75 watt IB (~$0.16 US). This results in an effective price ratio of a low quality CFL to IB (efficiency factor of 3) of 10. Considering a subsidy which decreases the price by 25%, about 40 rupees (~$0.40 US) for each 25 watt CFL, this is expected to result in an adoption rate of 80% which is a 7 percentage point increase over the baseline. Likewise, a 50% subsidy, worth 80 rupees for each 25 watt CFL, would result in an adoption rate of 85% which is a 12 percentage point increase over the baseline.

Imposing a high quality guarantee accompanied with an informational campaign on the lifetime of a CFL versus an IB however may encourage higher adoption rates than price subsidies on CFLs. This is because uncertainty over the quality may be preventing households from assessing the economic benefits that could be gained from adopting more efficient CFLs. Assuming that a guarantee could be provided that the lifespan of a CFL is 4 times that of an IB and all households become totally informed, then the estimated number of adopters becomes 88%. This is a 15 percentage point increase in adopters over the baseline. Furthermore, an informational campaign which guarantees households that the lifespan of CFLs is at least 10 times that of IBs and all households become totally informed, is predicted to raise adoption to 94%. This is a 22 percentage point increase in the percentage of adopters over the baseline. An examination of these effects is less for the living room and dining room, but larger for the bedroom where the proportion of households that have adopted CFLs is smaller. In the context of investment projects that distribute quality CFLs, such projects may help households to resolve some of the uncertainty of quality or knowledge about CFLs in comparison to IBs and thus may have significant spillover effects in increasing overall CFL adoption rates.

Table 4
Simulations of CFL adoption in the house.

Variable	House	Living room	Dining room	Bedroom
Baseline average	73%	82%	72%	60%
Decreasing price ratio of CFL to IB from ~8.8 to 6.8	80%	–	–	66%
Decreasing price ratio of CFL to IB from ~8.8 to 4.8	85%	–	–	72%
Raising awareness that CFLs will last at least 4 times as long as IBs	88%	85%	77%	76%
Raising awareness that CFLs will last at least 6 times as long as IBs	91%	87%	84%	78%
Raising awareness that CFLs will last at least 10 times as long as IBs	94%	95%	95%	90%

Note: Predictions for simulations based on coefficient estimates in Table 4. Average rates in sample population used for all other variables.
Price ratio changes for living room and dining room not shown due to lack of precision on estimates for price-ratio for these rooms.

These simple simulations likely provide an upper bound on the maximum increase that a price subsidy or awareness campaign can have on adoption rates. This is partly because the model in equation (4) has a relatively sparse specification that lacks explicit controls for household income, education, and the quality or efficiency factor of the bulb at different price points. Therefore, the main variables of interest on the price of CFLs to IBs and beliefs regarding CFLs may simply be capturing some of these omitted aspects that are less easily changed. In this case, the models are likely to overestimate the relevancy of changes in these variables on adoption outcomes.

4. Rebound effect in electrical lighting usage

While adoption of CFLs may improve the technical efficiency of a household's lighting system, the rebound effect predicts less energy savings than what would be achieved if an IB is replaced with an equivalent capacity CFL and the household does not change its demand for energy services. An empirical approach is used to estimate the impact that CFL adoption has on the demand for lighting services. This effect is decomposed into a capacity and utilization effect. Before continuing with the empirical analysis the theoretical concept of the rebound effect is presented to form a basis for understanding how to calculate the rebound effect from empirical estimates.

4.1. Theoretical concept

The direct rebound effect implies that efficiency improvements in one type of energy services may lead to an increase in effective income of consumers and thus higher demand for this and other types of energy services. It also reduces the prices of intermediate and final goods that use this type of energy services as inputs in production, and thus may increase consumption of these goods. These effects are termed indirect and economy wide rebound effects, respectively (Greening et al., 2000; Sorrell and Dimitropoulos, 2008). The existence of rebound effects suggests that estimating the economic benefits of energy efficiency improvements must go beyond simple engineering calculations.

While the different rebound effects differ in the mechanisms, most studies focus on the direct rebound effect. Following Greening et al. (2000) and Sorrell and Dimitropoulos (2008), the energy efficiency (ε) of an energy service is defined as:

$$\varepsilon = \frac{S}{E}, \tag{5}$$

where S is the amount of energy service produced per unit of device, such as lighting output measured by lumen-hours; and E is the amount of energy input, captured by watt-hours, used to produce S.

Since $\frac{\partial \varepsilon}{\varepsilon} = \frac{1}{\varepsilon}\left(\frac{\partial S}{E} - \frac{S \partial E}{E}\right) = \frac{\partial S}{S} - \frac{\partial E}{E}$, the efficiency elasticity of demand for energy is

$$\eta_\varepsilon(E) \equiv \frac{\varepsilon \partial E}{E \partial \varepsilon} = \frac{\varepsilon \partial S}{S \partial \varepsilon} - 1. \tag{6}$$

Thus, if the demand for energy services moderately increases due to energy efficiency improvements, i.e. $1 > \frac{\varepsilon}{S}\frac{\partial S}{\partial \varepsilon} > 0$, the efficiency elasticity of demand for energy would be smaller than 1 in absolute value. This implies that higher energy efficiency would not lead to a proportional reduction in energy consumption. It is also possible that the demand for energy services may be elastic with respect to energy efficiency improvements, i.e. $\frac{\varepsilon}{S}\frac{\partial S}{\partial \varepsilon} > 1$, so that the efficiency elasticity of demand for energy would be positive implying an increase in energy consumption in response to energy efficiency improvements.

$$1 + \eta_\varepsilon(E) = \frac{\varepsilon \partial S}{S \partial \varepsilon} \equiv \eta_\varepsilon(S). \tag{7}$$

For example, if energy consumption decreases by 7% in response to a 10% increase in energy efficiency, the efficiency elasticity of demand for energy is −0.7. Thus, the rebound effect is 30%, equal to the efficiency elasticity of demand for energy service.

It is assumed that the amount of energy service required is the product of the size or capacity of the device (C) for provision of energy service and the utilization of the device (U), i.e. $S = CU$. For lighting, the capacity can be measured in lumens a bulb generates while utilization is captured by the number of hours a bulb is used. Thus,

$$\frac{\varepsilon \partial S}{S \partial \varepsilon} = \frac{\varepsilon \partial C}{C \partial \varepsilon} + \frac{\varepsilon \partial U}{U \partial \varepsilon}. \tag{8}$$

This shows that the direct rebound effect can be decomposed into two effects: the enlarged capacity of the energy device and prolonged use of the device in response to an improvement in energy efficiency.[9]

4.2. Empirical estimates of the rebound effect

The relationship between household adoption of CFLs and demand for lighting services can be investigated empirically and used to estimate the size of the rebound effect for the average household.

The empirical regression model used is:

$$y_i = \beta_0 + \beta_1 \mathrm{CFL}_i + X_i' B + D_i + \varepsilon_i. \tag{9}$$

In this model i indexes the household and the dependent variable y_i is log of *au*, *aw*, *ah*, *alu* or *alw*. The right had side variables include CFL which is equal to 1 if there are one or more CFLs in the house or room, and 0 otherwise; X_i is a vector of respondent and household characteristics such as main income sources, household size and number of workers, number of rooms, property type, etc; and D_i is a dummy for the disco electricity distribution utilities which are included to control for potential supply side effects such as electricity price variations across regions and quality of energy supplied.

In this model, β_1 is the key parameter of interest. However, estimation of β_1 is subject to potential endogeneity bias arising from unobserved factors such as environmental attitude of the household, availability of various energy efficient technologies, and knowledge. These variables are likely to both affect the CFL adoption decision and a household's observed usage of lighting resulting in bias in the coefficient of interest. Therefore an instrumental variable approach is used where CFL adoption is instrumented using the respondent's CFL knowledge and the price ratio of CFL to IB in the area. The validity of the identification approach for estimating the effects of β_1 relies on the proposed instruments having a high correlation with CFL adoption, but having little explicit impact on the usage of lighting services. It is found that exclusion restrictions of the proposed instruments generally hold as endogeneity tests reveal that these variables do not enter independently in the main lighting services equations. Robust standard errors are estimated clustering errors by area to account for heterogeneity and intra-area correlations among the model residuals. The models are run for the house and several key rooms as different room types have different usage and burden of usage that are related to preferences for lighting.

Table 5 reports estimates for β_1 using a standard regression (OLS) model (even-numbered columns) and instrumental variables (IV) model (odd-numbered columns) for different dependent variables and rooms. Columns 1 through 6 display estimates for the actual average watt-hours, wattage and daily hours of use per bulb. Columns 7 through 10 display corresponding variables adjusted to account for lighting capacity. The estimates for the entire house, living, dining and bedrooms are displayed in the top, second, third and bottom panels, respectively. Due to space limitations, the estimated coefficients for other control and dummy variables are omitted in the table.

The OLS and IV models show some differences in the magnitude and significance of the impact of the adoption decision on energy choices and lighting. As IV is considered the valid approach discussion focuses on estimates from these models. On average, rooms that have adopted CFLs consume about 76% to 95% less watt-hours per bulb per day (column 2) than those with no CFLs in the rooms. The reduction is largely attributable to the reduction in average wattage of bulbs (column 4) with coefficient estimates statistically significant at the 1% level. Dining rooms that have adopted CFLs use 27% (~1.3 h) more every day compared to those that have not adopted CFLs (column 6). This differs with the smaller and less statistically significant estimates for the house, living room and bedroom.

When the dependent variables are adjusted to capture lighting capacity or amount of lighting services used by households, some contrasting estimates are obtained. Adopting CFLs increases the average lumen adjusted daily watt-hours per bulb and average lumen adjusted wattage of each bulb. The effects are statistically significant at the 1% level for the rooms and the 10% level for the household. These results point to the existence of rebound effects across different rooms. It also reflects that enhanced lighting capacity per bulb may be another channel, besides prolonged use, that causes the rebound effect.

To calculate the size of the rebound effect in household lighting requires using the sample statistics and the estimates on the variable for CFL adoption specified in equation (9). Let $\beta_1(y)$ be the coefficient estimate of β_1 when the dependent variable is $\log(y)$. Thus,

$$\beta_1(au) = \frac{\partial E}{E \partial \mathrm{CFL}} \tag{10a}$$

[9] The intermediate steps for deriving the capacity and utilization effect come from noting the following mathematical relationships:

$$\frac{\varepsilon}{S}\frac{\partial (CU)}{\partial \varepsilon} = \frac{\varepsilon}{S}\left(U\left(\frac{\partial C}{\partial \varepsilon}\right) + C\left(\frac{\partial U}{\partial \varepsilon}\right)\right) = \frac{\varepsilon}{S}\left(\left(\frac{S}{C}\right)\left(\frac{\partial C}{\partial \varepsilon}\right) + \left(\frac{S}{U}\right)\left(\frac{\partial U}{\partial \varepsilon}\right)\right).$$

Table 5
Effects of CFL adoption on consumption of lighting energy and services.

Dependent variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	log Avg. W.h.	log Avg. W.h.	log Avg. wattage	log Avg. wattage	log Avg. hour	log Avg. hour	log Lum-Adj W.h.	log Lum-Adj W.h	log Lum-Adj. wattage	log Lum-Adj wattage
CFL in house	−0.734***	−0.766***	−0.773***	−0.840***	0.040	0.074	0.086	0.232**	−0.011	0.095*
	[0.062]	[0.108]	[0.038]	[0.061]	[0.044]	[0.077]	[0.061]	[0.107]	[0.030]	[0.056]
Observations	3023	3010	3023	3010	3023	3010	3023	3010	3023	3010
R-squared	0.280	0.276	0.509	0.503	0.118	0.117	0.130	0.103	0.178	0.117
CFL living room	−0.918***	−0.948***	−1.134***	−1.095***	0.216***	0.148	0.268***	0.385**	0.046	0.239**
	[0.088]	[0.178]	[0.058]	[0.108]	[0.059]	[0.129]	[0.087]	[0.173]	[0.050]	[0.099]
Observations	1019	1019	1020	1020	1019	1019	1019	1019	1020	1020
R-squared	0.428	0.428	0.692	0.691	0.148	0.146	0.290	0.289	0.294	0.289
CFL dining room	−1.020***	−0.926***	−1.054***	−1.193***	0.035	0.267*	0.201**	0.496***	0.148**	0.209***
	[0.090]	[0.144]	[0.081]	[0.089]	[0.052]	[0.145]	[0.083]	[0.151]	[0.063]	[0.064]
Observations	681	681	681	681	681	681	681	681	681	681
R-squared	0.517	0.515	0.693	0.685	0.305	0.283	0.338	0.256	0.209	0.103
CFL bedroom	−0.871***	−0.883***	−1.028***	−1.028***	0.158**	0.146	0.223**	0.365***	0.051	0.200***
	[0.107]	[0.131]	[0.063]	[0.063]	[0.063]	[0.108]	[0.107]	[0.135]	[0.057]	[0.063]
Observations	2444	2432	2445	2433	2444	2432	2444	2432	2445	2433
R-squared	0.354	0.349	0.670	0.668	0.163	0.162	0.141	0.107	0.145	0.017
HH Char.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Disco dummy	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes: Standard errors in brackets. Lum-Adj = lumen adjusted; W.H. = watt-hours.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

$$\beta_1(alu) = \frac{\partial S}{S\partial \text{CFL}} \quad (10b)$$

$$\beta_1(alw) = \frac{\partial C}{C\partial \text{CFL}} \quad (10c)$$

$$\beta_1(ah) = \frac{\partial U}{U\partial \text{CFL}}. \quad (10d)$$

The average percentage of efficiency improvement from adopting CFLs is

$$\frac{\partial \varepsilon}{\varepsilon\partial \text{CFL}} = \frac{\partial S}{S\partial \text{CFL}} - \frac{\partial E}{E\partial \text{CFL}} = \beta_1(alu) - \beta_1(au). \quad (11)$$

The efficiency elasticity of energy demand can be obtained as follows,

$$\eta_\varepsilon(E) = \frac{\varepsilon\partial E}{E\partial\varepsilon} = \frac{\frac{\partial E}{E\partial \text{CFL}}}{\frac{\partial\varepsilon}{\varepsilon\partial \text{CFL}}} = \frac{\beta_1(au)}{\beta_1(alu) - \beta_1(au)}. \quad (12)$$

The rebound effect is then,

$$\eta_\varepsilon(S) = 1 + \eta_\varepsilon(E) = \frac{\beta_1(alu)}{\beta_1(alu) - \beta_1(au)}. \quad (13)$$

The rebound effect can then be decomposed into a capacity effect and a utilization effect:

$$\eta_\varepsilon(C) = \frac{\varepsilon\partial C}{C\partial\varepsilon} = \frac{\frac{\partial C}{C\partial \text{CFL}}}{\frac{\partial\varepsilon}{\varepsilon\partial \text{CFL}}} = \frac{\beta_1(alw)}{\beta_1(alu) - \beta_1(au)} \quad (14a)$$

$$\eta_\varepsilon(U) = \frac{\varepsilon\partial U}{U\partial\varepsilon} = \frac{\frac{\partial U}{U\partial \text{CFL}}}{\frac{\partial\varepsilon}{\varepsilon\partial \text{CFL}}} = \frac{\beta_1(ah)}{\beta_1(alu) - \beta_1(au)}. \quad (14b)$$

Table 6 shows the estimates of the rebound effects for the house and the rooms. The first four rows present estimates of β_1 that are used for calculating the rebound effects. The estimates suggest that if a household switches to CFLs they will improve efficiency of their lighting system by 100%–140%. The efficiency elasticity of energy demand reflecting the response of energy demand to efficiency improvements in lighting through CFLs is between −77% and −65% with the corresponding rebound effects ranging between 23% and 35%. This means that for every 10% of energy efficiency improvement due to advanced lighting technology, 2.3–3.5% of potential energy savings will be offset by the households consuming more lighting services by either making rooms brighter or leaving lights on longer. As a result, a 10% increase in lighting efficiency results in about 6.5–7.7% increase in actual energy savings. The dining room is found to have the largest rebound effect registered at 35%.

Decomposition of the rebound effect into a capacity effect and a utilization effect yields interesting variations across room types. The last

Table 6
Energy efficiency improvement and rebound effects.

	House	Living room	Dining room	Bedroom
$\beta_1(au)$	−0.766	−0.948	−0.926	−0.883
$\beta_1(alu)$	0.232	0.385	0.496	0.365
$\beta_1(alw)$	0.095	0.239	0.209	0.2
$\beta_1(ah)$	0.074	0.148	0.267	0.146
$\frac{1}{\varepsilon}\frac{\partial\varepsilon}{\partial \text{CFL}}$	0.998	1.333	1.422	1.248
$\eta\varepsilon(E)$	−0.768	−0.711	−0.651	−0.708
Rebound effect	0.232	0.289	0.349	0.292
Capacity effect	0.095	0.179	0.147	0.160
Utilization effect	0.074	0.111	0.188	0.117

Note: Rebound effect estimates and computations based on estimates from Table 2 and 5.

two rows of Table 6 show that the capacity effect contributes more to the rebound effect than the utilization effect except for the dining room. For the living room, adoption of CFLs results in the average household increasing their lighting capacity by 18% and extending the daily utilization by 11%. In the bedroom the average household increases lighting capacity by 16% and utilization by 12%. In the dining room, however, the capacity effect (15%) is four percentage points smaller than the utilization effect (19%) from CFL adoption. This result suggests a higher propensity for a household to leave lights on longer or spend more time in the dining room due to the increased efficiency of lighting from CFL adoption. This stark difference between the dining, living and bedrooms demonstrates the importance of lighting to a household's domestic activities, and the extent to which people's choice of lighting services, made possible by the technology, is shaped by different characteristics of these activities.

Nevertheless, it is possible that the capacity and utilization rebound effects may simply be a construction of the assumption that the efficiency factor of a CFL to an IB ranges between 3 and 5 and can be determined based on relative price of CFL and a respondent's beliefs on the life of a CFL versus an IB. To examine the robustness of the results, we further relaxed the assumption and tested variations where the efficiency factor instead ranged from 2 to 5. The estimated rebound effect was larger for the dining room at 37% while the rebound effect for the living room was 3 percentage points smaller at 26%. It also resulted in a lower weight being placed on the capacity effect compared to the utilization effect for the house and rooms by about 2 percentage points. We also explored another scenario where the efficiency factor was a constant 4 for all households. The results resulted in a smaller range for the rebound effect across the house and different rooms of 27 to 34%. Inevitably there is some error introduced in the process of computing the rebound effect. However, the overall rebound effect of 23% from the CFL adoption for households in Pakistan, based on watt-hours of consumption, is close in range to the 20% rebound effect found from free distribution of CFLs utilizing household micro-level data in Ethiopia by Costalanski et al. (2013).

5. Conclusion

Increasing energy efficiency offers a solution that reduces the need for energy while maintaining or even increasing the consumption of energy services. Thus, programs that induce wide scale increases in more energy efficient technology, such as those that replace CFLs with IBs, have a potential to make a major impact on energy shortfalls. If these programs are sufficiently successful, not only will electricity not be an impediment to economic growth, but environmental quality may improve if overall energy consumption is reduced.

Yet, the evidence reveals that uncertainty over the quality of CFLs and the high relative price of CFLs compared to IBs makes it difficult for CFLs to effectively compete with IBs. This may potentially be a challenge toward ensuring continued improvements in energy efficiency of lighting systems. This may be a major reason why there is underinvestment in more efficient lighting technologies despite lower energy costs paying for the difference in the price of the CFL bulb within months of replacing an IB. Unless there are sufficient informational campaigns and quality guarantees that can be placed on CFL bulb purchases, households may continue to purchase IBs. Resolving the uncertainty over the quality of CFLs may do more for energy efficient adoption in the long run than subsidizing the price of more efficient CFLs.

However, energy efficient adoption is less effective at closing the gap in energy shortages due to the rebound effect. Our study finds that potential energy savings that could be achieved through CFL adoption that increases energy efficiency is reduced by as much as 34%. Incorporating and updating estimates of rebound effects are ultimately crucial for policy planning of energy supply and climate change scenarios. If rebound effects are greatly underestimated, shortfalls and impediments to economic growth may worsen and increased environmental degradation may occur without additional complementary policies designed to reduce energy consumption or increase energy supply.

The rebound effect that occurs from increases in lighting usage or brightness of a room is potentially a luxury, with only minimal economic benefits, that arises because of the reduction in the cost of lighting services. Therefore, combining informational campaigns that encourage adoption by reducing uncertainty over the quality of CFLs with campaigns which pressure households to be more cognizant of their energy consumption may be helpful in reducing the size of the rebound effect. Such campaigns have been shown to have a positive effect in increasing energy efficiency and reducing wasteful energy consumption (Allcott and Mullainathan, 2010; Herberich et al, 2011; Reiss and White, 2008). Future research relying on a broader range of data therefore has an important role in improving our understanding of the size of the rebound effect and how it differs over the distribution of households so targeted policies can be designed that ensures that goals for reducing energy demands are met.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2013.07.006.

References

Allcott, H., Mullainathan, S., 2010. Behavior and energy policy. Energy 237, 1204–1205.
Bank, World, 2011. Climate Change and the World Bank Group: Phase II — The Challenge of Low-carbon Development (Washington DC).
Bhattacharya, S., Cropper, M., 2010. Options for energy efficiency in India and barriers to their adoption. Resources for the Future Discussion Paper 10–20. Washington DC.
Costalanski, P., Elahi, R., Iimi, A., Kitchlu, R., 2013. Impact evaluation of free-of-charge CFL bulb distribution in Ethiopia. World Bank Policy Research Working Paper 6383. Washington D.C.
Di Maria, C., Ferreira, S., Lazarova, E., 2010. Shedding light on the light bulb puzzle: the role of attitudes and perceptions in the adoption of energy efficient light bulbs. Scot. J. Polit. Econ. 57 (1), 48–67.
Foquet, R., Pearson, P., 2011. The long run demand for lighting: elasticities and rebound effects in different phases of economic development. BC3 Working Paper Series 2011-06. Basque Centre for Climate Change (BC3), Bilbao, Spain.
Foster, A., Rosenzweig, M., 2010. Microeconomics of technology adoption. Annual review of economics. Annu. Rev. 2 (1), 395–424.
Greening, L., Greene, D., Difiglio, C., 2000. Energy efficiency and consumption – the rebound effect – a survey. Energy Policy 28 (6–7), 389–401.
Herberich, D., List, J., Price, M., 2011. How Many Economists Does it Take to Change a Light Bulb? A Natural Field Experiment on Technology Adoption, Working Paper.
Jaffe, A., Stavins, R., 1994. The energy paradox and the diffusion of conservation technology. Resour. Energy Econ. 16 (2), 91–122.
Jaffe, A., Newell, R., Stavins, R., 2001. Energy-efficient Technologies and Climate Change Policies: Issues and Evidence. Climate Change Economics and Policy: An RFF Anthology, ed. M. Toman. RFF Press, Washington DC.
Mills, B., Schleich, J., 2010. Why don't households see the light? Explaining the diffusion of compact fluorescent lamps. Resource and Energy Economics 32, 363–378.
Mills, B., Schleich, J., 2012. Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: an analysis of European countries. Energy Policy 49, 616–628.
OECD, 2011. Chapter 4: housing conditions. How's Life?: Measuring Well-Being.OECD Publishing, Paris.
Reiss, P., White, M., 2008. What changes energy consumption? Prices and public pressure. RAND J. Econ. 39 (3), 636–663.
Roy, J., 2000. The rebound effect: some empirical evidence from India. Energy Policy 28 (6–7), 433–438.
Ryan, L., Selmet, N., Aasrud, A., 2012. Plugging the energy efficiency gap with climate finance. International Energy Agency Insights Series 2012 Paris.
Sorrell, S., Dimitropoulos, J., 2008. The rebound effect: microeconomic definitions, limitations and extensions. Ecol. Econ. 65, 636–649.
Sorrell, S., Dimitropoulos, J., Sommerville, M., 2009. Empirical estimates of the direct rebound effect: a review. Energy Policy 37 (4), 1356–1371.
Star, Energy, 2012. Lighting Choices to Save You Money from. http://energy.gov/energysaver/articles/lighting-choices-save-you-money (Retrieved May 18, 2013).