Casting Light on Energy Efficiency - Evidence on Consumer Inattention and Imperfect Information

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Abstract

We investigate consumer inattention and imperfect information regarding the financial benefits of energy-efficient lighting using a randomized controlled trial with 1,084 observations. Results suggest that subjects generally know about cost savings of LED bulbs - the central lighting technology of the future - but largely underestimate the magnitude of these savings. As a result, stated willingness-to-pay for an LED bulb increases on average by 2.53€ through the provision of information on expected lifetime costs. Consumers also confound technology attributes of energy-efficient alternatives, which further explains low adoption rates of the LED technology.

Highlights

- We investigate informational and attentional biases in purchase decisions about an innovative lighting technology using a randomized controlled trial with hypothetical choices for a large sample in Germany.
- We find that stated willingness-to-pay for an LED bulb can on average be increased by 2.53€ through the provision of information on expected lifetime costs.
- Consumers are confused about differences between energy-efficient alternatives and falsely assign a negative attribute to LEDs.

Keywords

Imperfect Information, Inattention, Energy Efficiency Gap, Experimental Economics

JEL Codes

D03, D12, D83, Q41, Q48

1. Introduction

Residential lighting is one of the largest electricity end-users in European households and still subject to immense savings potentials, especially when light-emitting diode (LED) bulbs are taken for replacement (De Almeida et al., 2011). Household lighting is also ranked among the most cost-efficient means to reduce externalities from CO_2 emissions (IPCC, 2007). Yet, the adoption of efficient lighting by consumers remains slow, which is particularly puzzling as LED bulbs provide large financial benefits relative to classical alternatives.

Theoretical explanations of this phenome include (rational) inattention to energy efficiency, imperfect information, high discount rates or simply strong preferences for other product attributes.[2] This paper tests for these different causes by using a randomized controlled trial with an information treatment based on Allcott & Taubinsky (2015) for the US market. In their study, the authors find that consumers

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[2] For an overview on potential causes of a so-called “Energy Efficiency Gap” see Gerarden et al. (2015).

undervalue energy-efficient compact fluorescent bulbs (CFL) due to a lack of energy literacy and possibly inattention. To our knowledge, we provide the first related evidence for an even more relevant lighting technology with a focus on the German market.

LEDs are three times more energy-efficient than CFLs and promise even higher cost advantages in the future due to constantly decreasing prices (McKinsey & Company, 2012). In addition, LEDs constitute a closer substitute to traditional incandescent bulbs than CFLs as they include no (potentially health-damaging) mercury content and as they reach full brightness immediately. This differentiation is important as consumers should be less inattentive to differences in energy efficiency when product attributes in other dimensions are similar (Sallee, 2014).

We test for undervaluation of LED bulbs resulting from consumer biases in a randomized controlled trial with hypothetical consumption choices. The analyzed data constitutes a notably large subsample (N=1,084) of a country which is not only the largest economy in the European Union, but also seen as a leader in current energy transformation policies (IRENA, 2015).

2. Experimental Design

Between June and July 2016 people were invited to participate in an online questionnaire via email distributors of German universities and through announcements on social networks. Our sample is consequently drawn from a young and rather well-educated subpopulation. Participation was incentivized through a lottery of cash prizes and vouchers for an online shop.

Upon opening the online questionnaire, subjects were randomly assigned to treatment and control group. The survey started with a short introductory screen (see B.1) and a subsequent screen showing different lamp types in a modern living room (B.2 and B.3). The latter was designed to raise subjects' interest for the survey, which is generally known to increase the reliability of survey responses (Warwick & Lininger, 1975). Participants were then asked to imagine they needed a new light bulb and make hypothetical purchase choices between a 40W incandescent and a 5W LED at varying prices (B.6 and B.7). As depicted in B.7, subjects had to fill in a multiple price list in which the price of the LED increased in ascending order from 0.30€ to 20.30€ while the price of the incandescent was fixed to 1.30€. We define the subjects' *relative* Willigness-to-pay (WTP) for the LED as the average between the two LED prices at which the subject switches from choosing the LED to choosing the incandescent, minus the price of the incandescent bulb.[3]

For individuals in the treatment group, an additional screen prior to the purchase decision appeared (B.4 and B.5) and offered written and graphical information about average differences in electricity and replacement costs between the two bulbs. Following Allcott & Taubinsky (2015), we assume that this intervention eliminates any distortion in consumer choices resulting from inattention to or biased beliefs about the energy efficiency of the two bulbs. Since the only difference between treatment and control group is this information screen, systematic differences in WTP indicate undervaluation of the financial benefits from energy efficiency.

Given that WTP is determined using stated preferences, our estimates are vulnerable to hypothetical bias. Note, however, that estimates from stated preferences are found to be significantly less biased for private goods than for public goods as consumers are more familiar with such products on markets (List & Gallet, 2001).

The survey involved further questions on socioeconomic variables, implicit discount rates, other preferences for light bulbs and psychological characteristics (see B.10 to B.19).

[3] For instance, if the consumer purchased the LED at 3.30€ but switches to the incandescent as soon as the LED costs 4.30€, we define her WTP for the LED as $(3.30€ + 4.30€)/2 - 1.30€ = 2.50€$.

3. Results

The dataset contains 1,084 observations and mostly consists of students (87%). Table A.1 shows that treatment and control group are well balanced in individual covariates and confirms successful randomization.

Table 1 presents basic OLS estimates. We include all subjects with non-censored WTP, meaning that they implicitly revealed their WTP by switching between the incandescent and the LED at some price in the presented price list.[4] The average treatment effect is a statistically significant increase in WTP for the LED bulb of 2.71€. This effect decreases only slightly to 2.53€ when controlling for observable characteristics (Column 2). Our estimates are fairly similar to the incentive-compatible estimate by Allcott & Taubinsky (2015) who find an increase in WTP for CFLs of $2.54 (≈2.02€ at the time of the survey) for the US sample. A larger treatment effect is plausible in our case because LEDs save substantially more energy costs than CFLs and choices in our study were of hypothetical nature.

Table 1

OLS Estimates of Treatment Effect

	Dependent variable: Relative willingness-to-pay for the LED bulb	
	(1)	(2)
Treatment	2.705	2.532
	(0.248)***	(0.256)***
Observables	No	Yes
Constant	3.735	2.562
	(0.127)***	(1.194)**
R^2	0.13	0.19
N	932	932

*Notes: Robust standard errors are in parentheses. Significance levels are given by * p<0.1; ** p<0.05; *** p<0.01.*

Figure 1 provides a comparison of demand curves for LED bulbs between control and treatment group. At the typical relative market price of these two bulbs (approximately 6€ in Germany) the share of consumers choosing the LED more than doubles from 19 to 45 percent as a result of the information treatment.

In order to identify whether our treatment effect results from increased information about or just inattention to energy efficiency, we ask all subjects additional questions on energy literacy. Subjects were asked which of the two bulbs had lower operating costs (B.10) and how much lower these costs were for 15 years of usage (B.11 and B.12). The results in column (1) and (2) of Table A.2 are obtained by using probit regressions to regress the binary variables "Belief: LED is cheaper" and "Belief: LED saves 120€" on the treatment. The first dependent variable is equal to 1 if the subject correctly answered the LED was cheaper than the incandescent, and zero otherwise. Analogously, the second variable takes on the value 1 if the subject answered "120€" on the question regarding how much the LED saves compared to the incandescent, and zero if she chose any other answer. Being part of the treatment

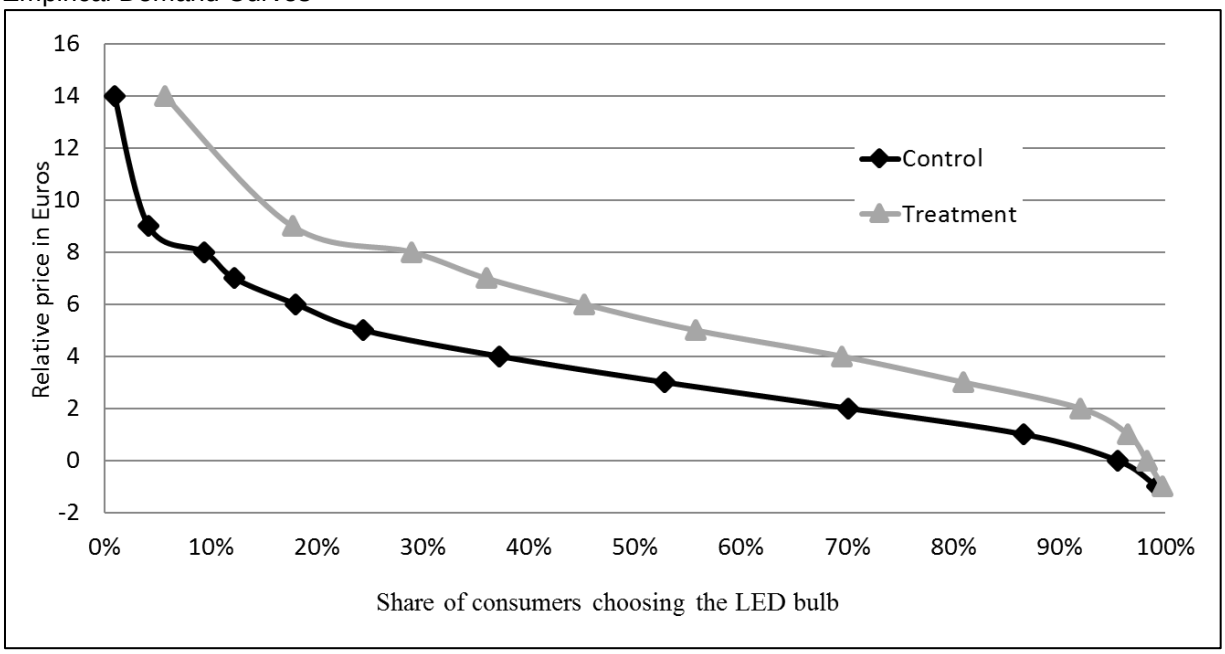
[4] Of the entire sample, 152 subjects preferred the same bulb at any given price and had to type in its minimum/ maximum WTP for the LED in an additional field (B.8). Given that these specific subjects were able to state an arbitrarily large WTP, we analyze this subsample carefully. If we include these subjects, the average treatment effect increases to 7.82€. However, the median treatment effect only increases to 3.27€, indicating that this drastic increase in the average treatment effect is driven by a few subjects who reported an exceptionally large WTP.

group increased the probability of answering that LEDs are less expensive in usage by 3.1 percentage points. While this effect is highly significant from a statistical perspective, its economic magnitude is relatively small. Even in the control group, 95 percent of subjects answered that using the LED was cheaper. Much larger differences exist when it comes to the accuracy of savings beliefs. Column (2) implies that the treatment increased the probability of giving the "correct" answer on expected cost differences by 25.2 percentage points for the treatment group. Only 16 percent in the control group had savings beliefs which were equal to the estimated average savings of around +120€. Consumers appear to know LEDs have lower usage costs in general, but have biased beliefs about the magnitude of the financial savings.

Figure 2 illustrates the density functions of savings beliefs between treated and non-treated subjects. The density function of the control group is centered around values closer to zero and involves a notably larger variance.

Figure 1

Empirical Demand Curves



Notes: The relative price is defined as the price of the LED minus the price of the incandescent.

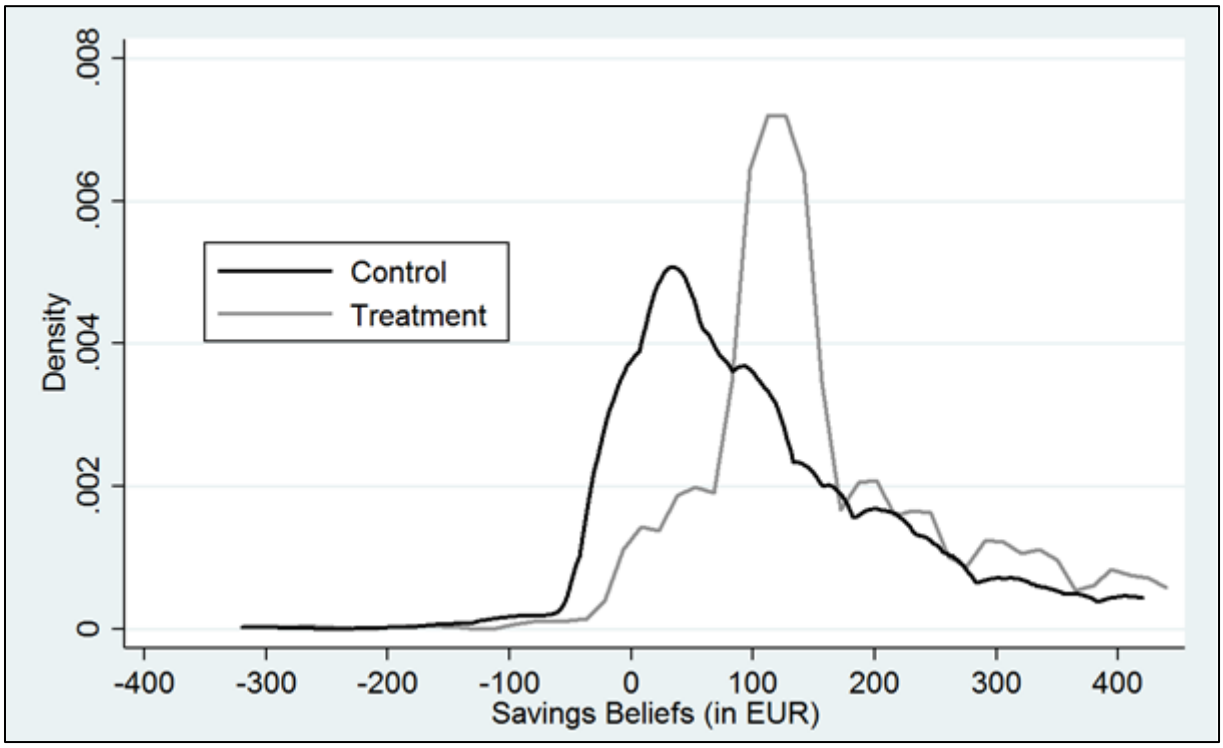
In addition, we asked subjects about the importance of factors that have influenced their hypothetical purchase decision using a Likert-Scale (B.14). Results are used as regressors for WTP in Table A.3. Consumers who put a high emphasis on the bulb's CO_2 emissions, its energy consumption and its lifetime have a significantly higher WTP for the LED, unlike consumers who focus on the initial purchase price. Interestingly, consumers who placed high importance on the time until the bulb reaches full brightness also show a significantly lower WTP for the LED. Note, however, that both incandescents and LEDs immediately reach full brightness. A long warm-up time is characteristic for CFLs and found to be an unpopular feature among consumers in other studies (Rasmussen et al., 2007; Wall & Crosbie, 2009). Since LEDs are relatively new on the lighting market, this may suggest that consumers confound LEDs with CFLs or assume energy-efficient bulbs to need more time to warm up in general. The finding that consumers appear to have biased beliefs about differences *between* energy-efficient technologies is a non-negligible result since it could translate into other markets for energy-using durables.

Another hypothesis to be tested is that consumers who discount future utility at larger rates should be less inclined to purchase the LED, as energy savings are benefits accruing in the future. We address this conjecture by asking consumers whether they hypothetically prefer receiving 100€ today or varying amounts between 100€ and 200€ in one year (see B.13). The discount rate is defined as $i = \left({}^{switching\ point}/_{100€}\right) - 1$, where the *switching point* is the average of the two monetary amounts in one year at which the consumer switches from preferring money today to money in the future. Column

1 in Table A.4 regresses WTP for the LED on the implicit discount rate and finds that an increase in the discount rate by 10 percentage points is associated with a statistically significant decrease in average WTP of 0.11€. The average discount rate of the analyzed sample is 23%. Economic intuition is supported by columns (2)-(4), where we find evidence that purchase decisions of subjects with higher discount rates are less influenced by the bulbs' energy costs, its lifetime and its final disposal.

Figure 2

Density Functions of Savings Beliefs



Notes: The figure illustrates the Epanechnikov kernel density functions of savings beliefs elicited by questions B.11 and B.12.

4. Conclusion

Our work provides evidence for significant undervaluation of LED bulbs in Germany resulting from biased beliefs about financial benefits of energy efficiency. Given that we have analyzed a subsample with an above-average educational level, these effects are likely to be even larger for the entire population. Additional results suggest that consumers with higher discount rates are more likely to favor incandescents and that the adoption of LEDs may further be hampered as consumers are confused about differences between energy-efficient alternatives.

Our results are also relevant from a political perspective since the European Union considers LEDs as the most important alternative to traditional incandescents and established the "European LED Quality Charter" to improve consumer acceptance of LED bulbs (European Commission, 2012). The presented findings provide ground for a discussion on information policies as adequate means to promote the adoption of energy-efficient lighting and its associated benefits regarding externality reductions.

Acknowledgments

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Appendix A: Additional Tables

Table A.1 Balance of Observables between Treatment and Control Group

	Treatment Group Mean (1)	Control Group Mean (2)	Difference (Treatment – Control) (3)
Conservative	0.119 (0.324)	0.0962 (0.295)	0.0230 (0.0188)
Social democrat	0.223 (0.416)	0.222 (0.416)	0.000628 (0.0253)
Liberal	0.119 (0.324)	0.131 (0.338)	-0.0120 (0.0202)
Leftist	0.121 (0.327)	0.145 (0.353)	-0.0240 (0.0207)
Right-wing	0.00586 (0.0764)	0 (0)	0.00586 (0.00319)
Ecological	0.172 (0.378)	0.156 (0.363)	0.0163 (0.0225)
Other political affiliation	0.0195 (0.139)	0.0157 (0.125)	0.00380 (0.00799)
Not interested in politics	0.0977 (0.297)	0.107 (0.309)	-0.00899 (0.0185)
Statement on political affiliation denied	0.123 (0.329)	0.128 (0.334)	-0.00458 (0.0202)
Tenant	0.889 (0.315)	0.890 (0.313)	-0.00119 (0.0191)
Homeowner	0.0938 (0.292)	0.0822 (0.275)	0.0116 (0.0172)
Homeowner and tenant	0.0176 (0.132)	0.0280 (0.165)	-0.0104 (0.00914)
Customer of “green electricity”	0.270 (0.444)	0.299 (0.458)	-0.0294 (0.0275)
German basic school diploma (“Hauptschule”)	0 (0)	0.00175 (0.0418)	-0.00175 (0.00185)
German middle school diploma	0.00391 (0.0624)	0.00524 (0.0723)	-0.00134 (0.00413)

("Realschule")			
German high school diploma ("Abitur")	0.637 (0.481)	0.626 (0.484)	0.0108 (0.0294)
Apprenticeship	0.0313 (0.174)	0.0385 (0.192)	-0.00721 (0.0112)
University degree	0.322 (0.468)	0.322 (0.468)	0.000587 (0.0285)
Statement on education denied	0.00586 (0.0764)	0.00699 (0.0834)	-0.00113 (0.00488)
Don't know education degree	0 (0)	0 (0)	0 (0)
Female	0.576 (0.495)	0.570 (0.496)	0.00624 (0.0301)
Male	0.424 (0.495)	0.430 (0.496)	-0.00624 (0.0301)
Searching for employment	0.00195 (0.0442)	0.00175 (0.0418)	0.000205 (0.00261)
Employed	0.127 (0.333)	0.105 (0.307)	0.0221 (0.0194)
Pupil	0.00195 (0.0442)	0.00699 (0.0834)	-0.00504 (0.00412)
Student	0.869 (0.338)	0.879 (0.326)	-0.0102 (0.0202)
Occupation not specified	0 (0)	0.00699 (0.0834)	-0.00699 (0.00369)

Notes: Column (1) and (2) have standard deviation in parentheses. Column (3) has standard errors in parentheses. Significance levels are given by * $p<0.1$; ** $p<0.05$; *** $p<0.01$.

Table A.2 Effect of Treatment on Savings Beliefs

	Belief: LED is cheaper (marginal effects obtained from probit regression)	Belief: LED saves 120€ (marginal effects obtained from probit regression)	Median Savings Beliefs (in EUR)
	(1)	(2)	(3)
Treatment	0.031 (0.012)**	0.252 (0.023)***	50.000 (4.243)***
Constant			70.000 (2.916)***
N	1,084	1,084	1,084

Notes: Results in column (1) and (2) are marginal effects obtained from probit regressions. Estimates from column (3) are obtained through quantile regressions. Standard errors are in parentheses. Significance levels are given by * p<0.1; ** p<0.05; *** p<0.01.

Table A.3 Association of Factor Importance and Willingness-to-pay

	Dependent variable: Relative willingness-to-pay for the LED bulb								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Design of the bulb	0.106 (0.084)								
Brightness		0.322 (0.123)***							
CO2-emissions			0.265 (0.095)***						
Energy costs				0.673 (0.119)***					
Purchase price					-0.859 (0.126)***				
Lifetime						0.538 (0.121)***			
Mercury content							0.212 (0.095)**		
Disposal								0.094 (0.102)	
Warm-up time									-0.217 (0.097)**
Constant	4.520 (0.284)***	3.525 (0.528)***	4.088 (0.326)***	2.191 (0.492)***	8.158 (0.514)***	2.740 (0.500)***	4.267 (0.329)***	4.546 (0.295)***	5.633 (0.360)***
R^2	0.00	0.01	0.01	0.03	0.05	0.02	0.01	0.00	0.01
N	880	913	816	904	926	891	724	751	848

Notes: Results are obtained from OLS regressions. Robust standard errors are in parentheses. Significance levels are given by * p<0.1; ** p<0.05; *** p<0.01.

Table A.4 Association of Discount Rates, Willingness-to-pay and Factor Importance

	Relative willingness-to-pay for the LED bulb	Importance of Bulb's Energy costs	Importance of Bulb's Lifetime	Importance of Bulb's Disposal
	(1)	(2)	(3)	(4)
Implicit discount rate ($= i \times 100$)	-0.011 (0.006)*	-0.005 (0.002)***	-0.004 (0.002)**	-0.006 (0.002)**
Observables	No	No	No	No
Constant	5.112 (0.204)***	4.156 (0.052)***	4.144 (0.052)***	2.717 (0.076)***
R^2	0.00	0.01	0.01	0.01
N	879	853	839	707

Notes: Results are obtained from OLS regressions. The average discount rate of the total sample is 23%. Robust standard errors are in parentheses. Significance levels are given by * p<0.1; ** p<0.05; *** p<0.01.

Appendix B: Instructions

All instructions were translated from German to English.

Figure B.1: Introduction Screen

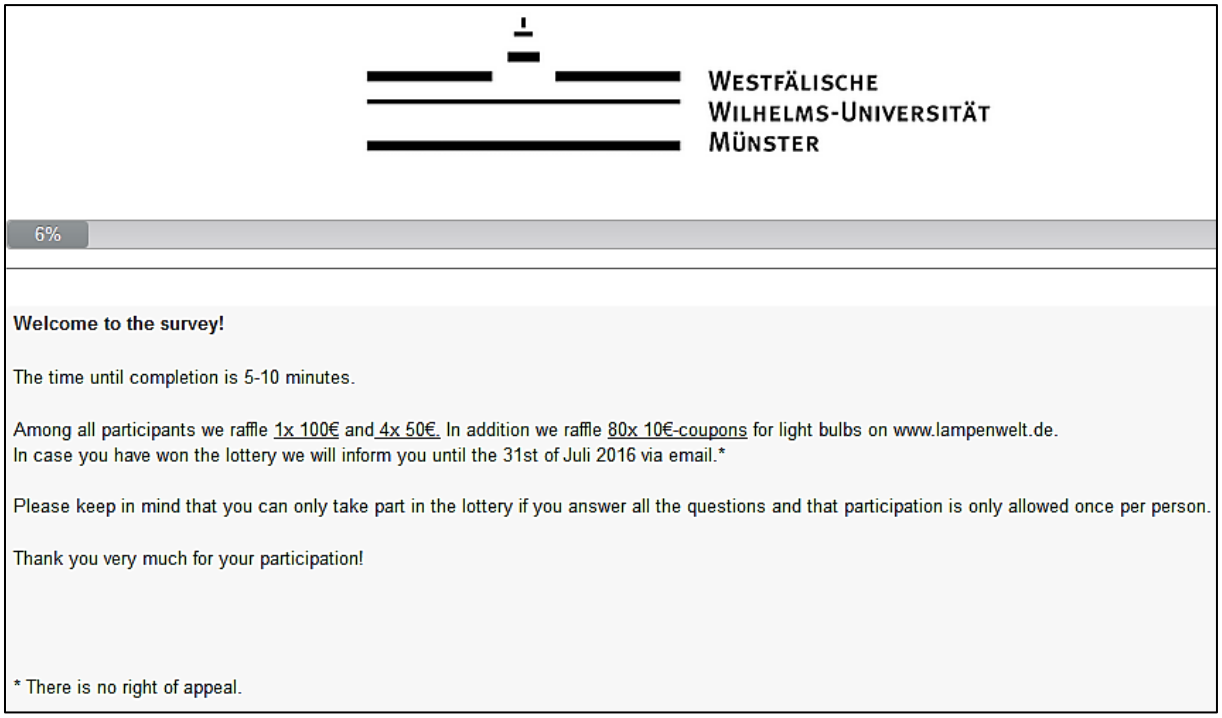


Figure B.2: Distraction Screen 1 (Top of Screen)

The following picture depicts a living room with different types of lamps.

source: www.lampenwelt.de

Which of the following lamps is most appealing to you?

- ○ A
- ○ B
- ○ C
- ○ D
- ○ E
- ○ F
- ○ G
- ○ H
- ○ I

Figure B.3: Distraction Screen 1 (Bottom of Screen)

Which of the following lamps do you already own? You can select more than one.

- ☐ A
- ☐ B
- ☐ C
- ☐ D
- ☐ E
- ☐ F
- ☐ G
- ☐ H
- ☐ I
- ☐ None

Figure B.4: Treatment Screen (Top of Screen)

You will now receive information regarding the electricity costs and lifetime of a 40 Watt incandescent light bulb and a 5 Watt LED light bulb.

Electricity costs

The LED light bulb uses less electricity than the incandescent light bulb. The average electricity costs after one year are:

- 8€ for an incandescent light bulb
- 1€ for an LED light bulb

The following graph illustrates the average electricity costs after one year:

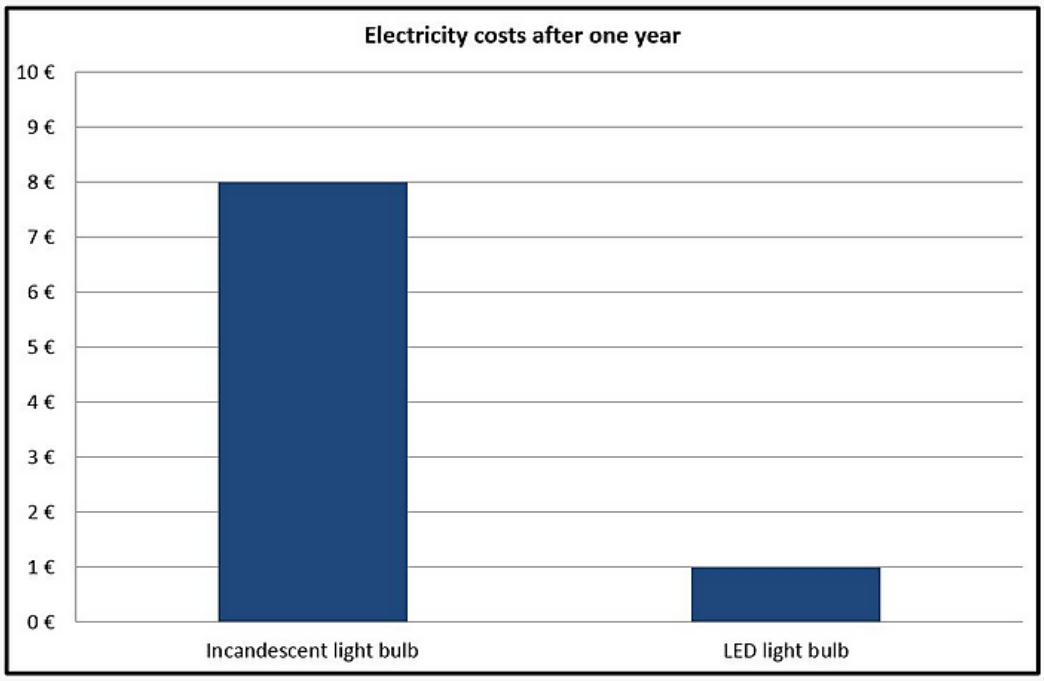


Figure B.5: Treatment Screen (Bottom of Screen)

Lifetime

The LED light bulb has a longer lifetime than the incandescent light bulb:

- Incandescent light bulbs have an average lifetime of 1 year and then need to be replaced.
- LED light bulbs have an average lifetime of 15 years and then need to be replaced.

Total costs

For a usage period of 15 years the expected total costs would amount to:

- 138.20€ for the incandescent light bulb. This is made up of 120€ electricity costs and 18.20€ for the yearly replacement of the light bulb.
- 15€ for the LED light bulb. There are 15€ electricity costs and no replacement costs.

The next graph illustrates these accrued total costs after 15 years:

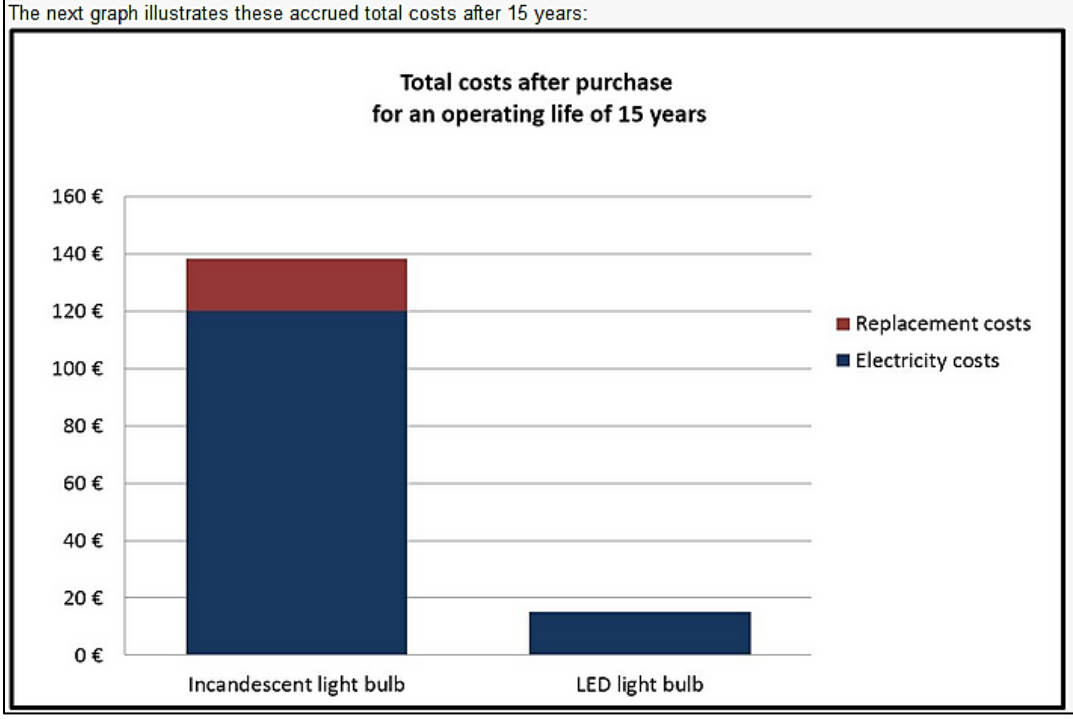
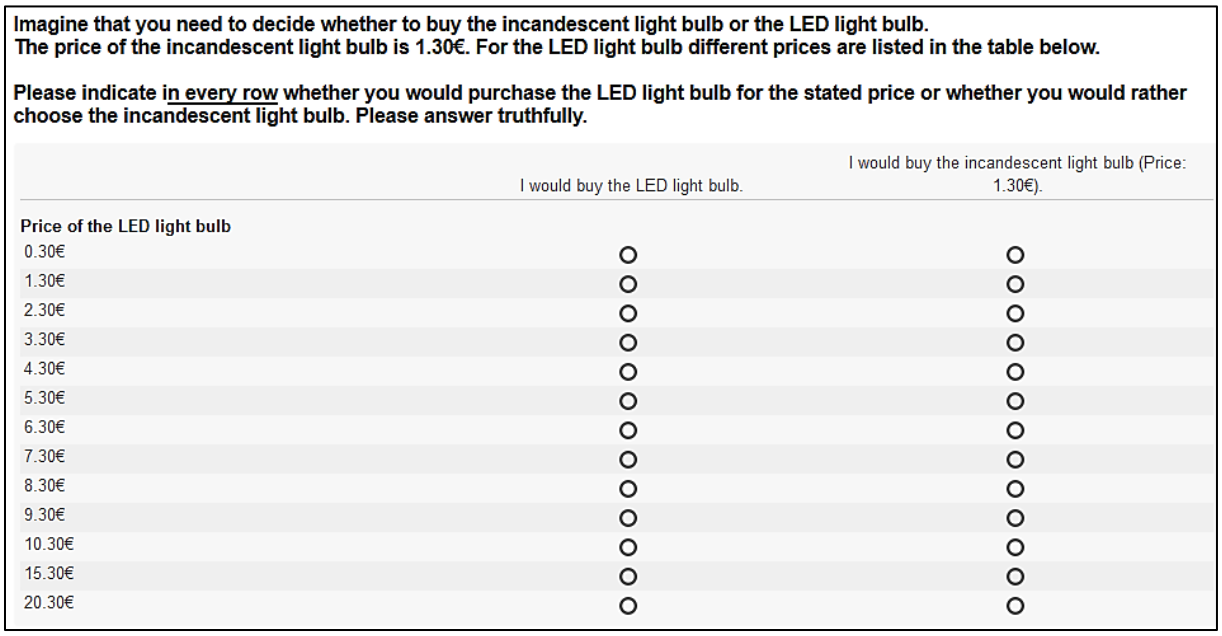


Figure B.6: Purchase Decision (Top of Screen)

Imagine that you need a new light bulb and that you can choose between the following two products:

	Incandescent light bulb	LED light bulb
Socket	E27	E27
Watt	40 W	5 W (replacing 40 W)
Luminosity	415 Lumen	470 Lumen
Color	2700 Kelvin	2700 Kelvin
Picture		

Figure B.7: Purchase Decision (Bottom of Screen)

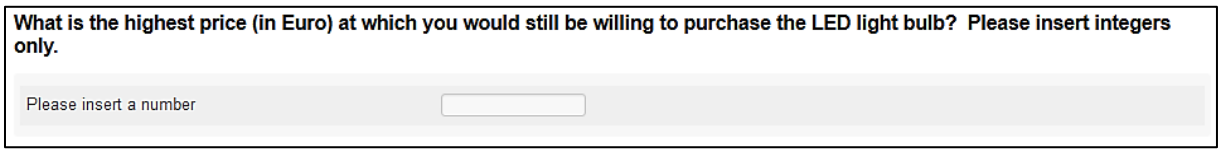


Imagine that you need to decide whether to buy the incandescent light bulb or the LED light bulb.
The price of the incandescent light bulb is 1.30€. For the LED light bulb different prices are listed in the table below.

Please indicate in every row whether you would purchase the LED light bulb for the stated price or whether you would rather choose the incandescent light bulb. Please answer truthfully.

	I would buy the LED light bulb.	I would buy the incandescent light bulb (Price: 1.30€).
Price of the LED light bulb		
0.30€	○	○
1.30€	○	○
2.30€	○	○
3.30€	○	○
4.30€	○	○
5.30€	○	○
6.30€	○	○
7.30€	○	○
8.30€	○	○
9.30€	○	○
10.30€	○	○
15.30€	○	○
20.30€	○	○

Figure B.8: Question on Maximum Willingness-to-pay if larger than 20.30€

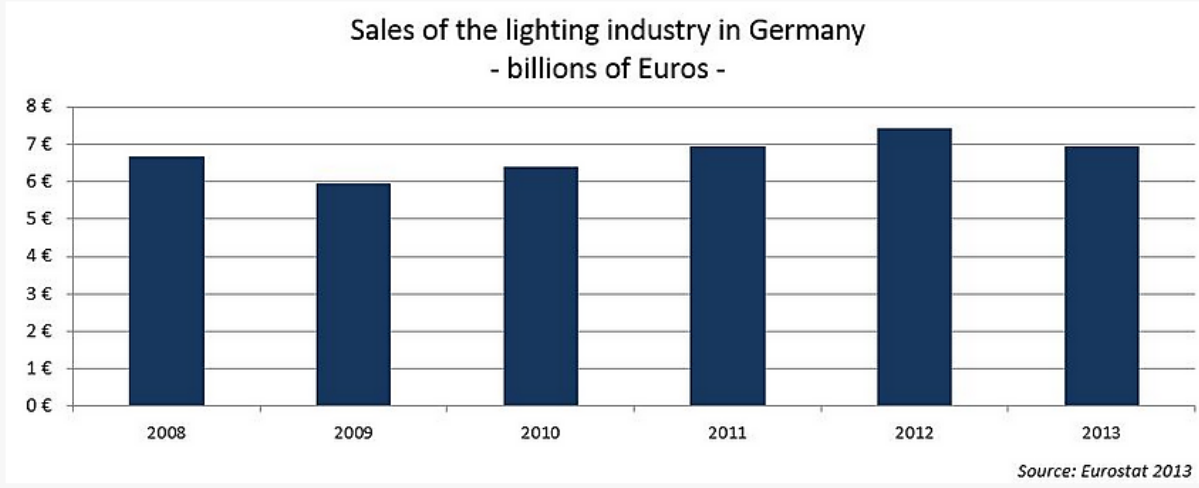


What is the highest price (in Euro) at which you would still be willing to purchase the LED light bulb? Please insert integers only.

Please insert a number

Figure B.9: Distraction Screen 2

The following graph illustrates the sales trend in the lighting industry in Germany between 2008 and 2013.



Which year shows the highest sales?

- ○ 2008
- ○ 2009
- ○ 2010
- ○ 2011
- ○ 2012
- ○ 2013

Figure B.10: First Question on Savings Beliefs

15,000 hours of light are equivalent to an average operating life of 15 years. For these 15,000 hours of light, do you think it is cheaper or more expensive to use an LED light bulb instead of an incandescent light bulb?

- ○ Cheaper
- ○ More expensive

Figure B.11: Second Question on Savings Beliefs if Answer to First Question was “Cheaper”

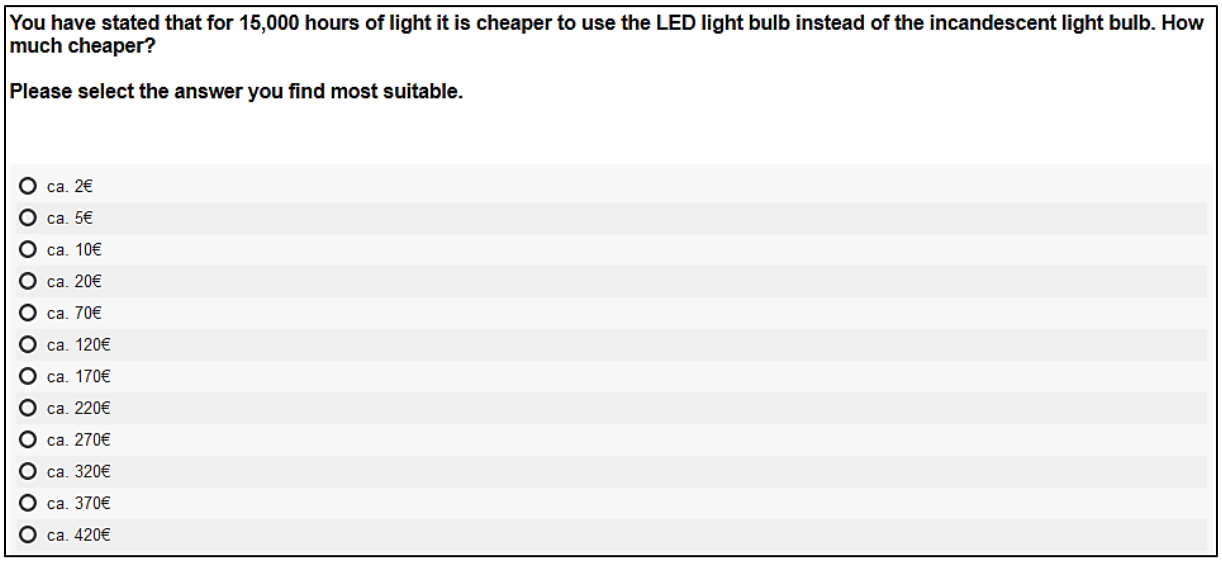


Figure B.12: Second Question on Savings Beliefs if Answer to First Question was “More Expensive”

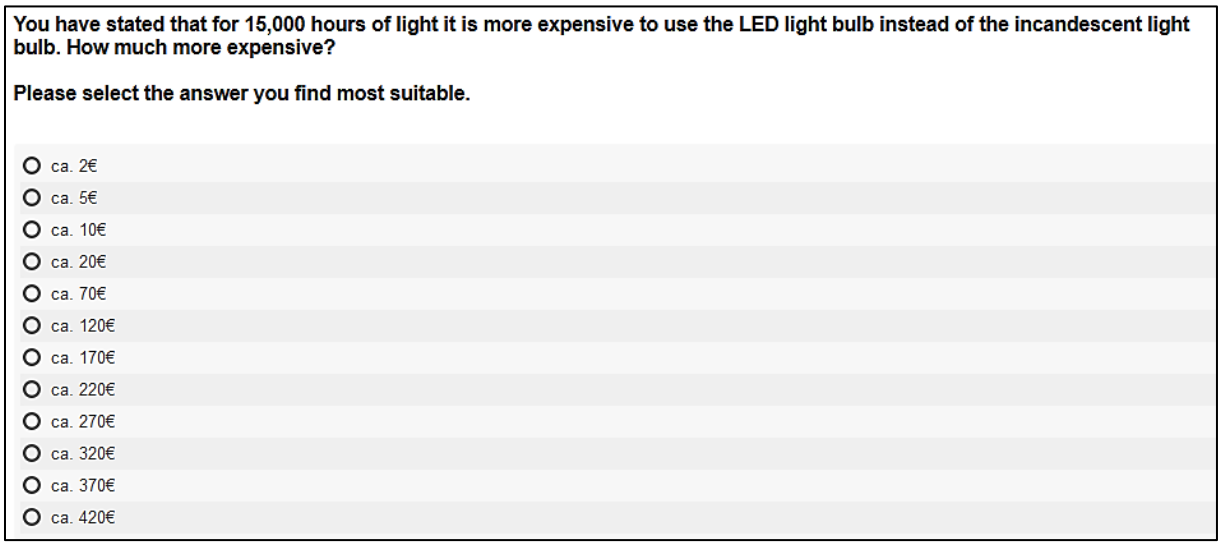


Figure B.13: Question to elicit Implicit Discount Rates

Imagine that you could either receive 100€ today or an alternative amount of money in one year. In both cases the payment would be guaranteed.

Please indicate in every row whether you would choose the money today or the alternative amount of money in one year.

	I take the money today.	I take the money in one year.
100€ today or 100€ in one year	○	○
100€ today or 110€ in one year	○	○
100€ today or 120€ in one year	○	○
100€ today or 130€ in one year	○	○
100€ today or 150€ in one year	○	○
100€ today or 170€ in one year	○	○
100€ today or 200€ in one year	○	○

Figure B.14: Question on Importance of Factors influencing the Purchase Decision

How important were the following factors for your decision between the LED and the incandescent light bulb?
Please rate each factor on a scale from 1 to 5.
If you have not been aware about a factor when you made your decision, please answer with "don't know".

	1 (absolutely not important)	2	3	4	5 (very important)	don't know
Design of the light bulb	○	○	○	○	○	○
Luminosity	○	○	○	○	○	○
CO2 emissions	○	○	○	○	○	○
Energy costs	○	○	○	○	○	○
Purchase price	○	○	○	○	○	○
Lifetime	○	○	○	○	○	○
Mercury content	○	○	○	○	○	○
Disposal of the light bulb	○	○	○	○	○	○
Time until the light bulb reaches full brightness	○	○	○	○	○	○

Figure B.15: Question on Political Affiliation

Which political affiliation would you assign yourself?

- ○ no statement
- ○ conservative
- ○ social democrat
- ○ liberal
- ○ left
- ○ right
- ○ green
- ○ other
- ○ I am not interested in politics

Figure B.16: Elicitation of Psychological Characteristics

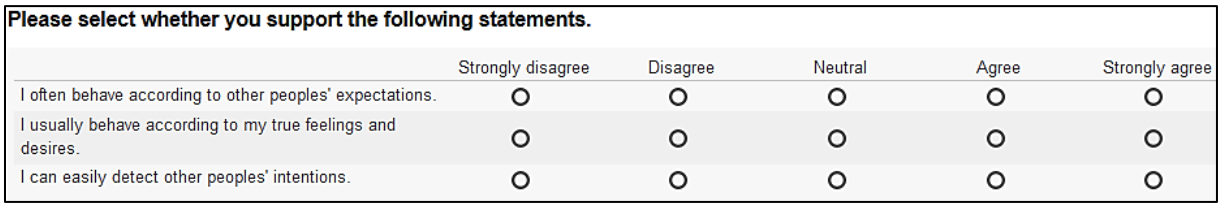


Figure B.17: Question on Home-ownership

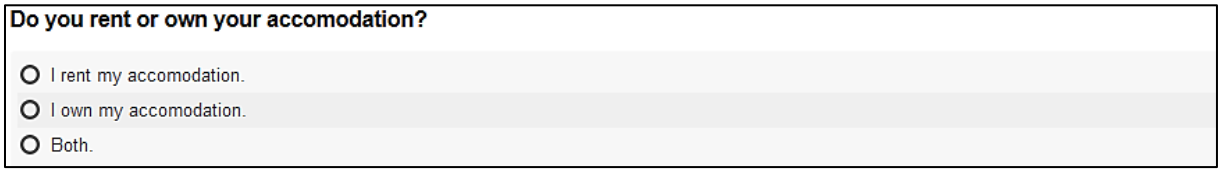


Figure B.18: Invitation to participate in the Lottery after completing the Survey

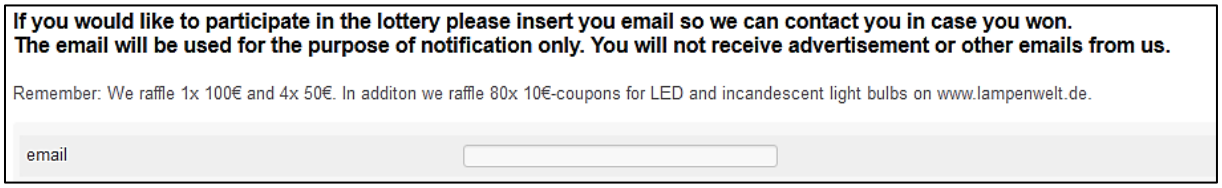


Figure B.19: Final Screen after completing the survey