Free riding and rebates for residential energy efficiency upgrades: A multi-country choice experiment

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Abstract

The cost effectiveness of programs designed to upgrade energy technologies can be significantly affected by free riding. This paper assesses ex ante the effects of free riding on the cost effectiveness of a rebate program promoting the adoption of energy-efficient heating systems, relying on contingent valuation choice experiments carried out through identical representative surveys in eight EU Members States. The analysis distinguishes between strong and weak free riders: strong free riders plan to adopt a new heating system in the next five years anyway; weak free riders decide to purchase once made aware of an attractive technology package (and therefore would not need a rebate to adopt). The mean minimum rebate households require to adopt differs substantially across countries and, on average, amounts to slightly more than half of the heating system's purchasing price, suggesting generally high opportunity costs for premature upgrading of heating systems. The minimum acceptable rebate and weak free ridership vary with income, environmental identity, and with risk and time preferences. At a rebate level that corresponds to half the purchase price of the offered heating system, the share of free riders was estimated at 50 percent for most countries, with the share of weak free riders typically higher than that of strong free riders. Public spending costs per reduced ton of CO_2 differ considerably across countries and only compare to high social costs of carbon.

Introduction

Subsidies to incentivize the adoption of energy efficient technologies are commonly used by governments and energy companies to reach energy savings or greenhouse gas emission goals (de la Rue du Can et al. 2011, 2014; Galleraga et al. 2013, 2016). Surveys of the empirical literature typically conclude that subsidies, such as rebates and subsidized loans, spur the adoption of energy efficient technologies (e.g. Markandya et al. 2014; Datta and Filippini 2016). Subsidies may also help accelerate the replacement of energy-using technologies, such as appliances or heating systems, before they reach the natural end of their working life. Such premature technology upgrades may be required to meet ambitious climate policy targets, particularly for the residential building sector, which is generally considered to represent high potential for energy savings (IEA 2016). In practice, subsidies are often combined with information and communication programs that help customers overcome lack of information on available efficiency upgrades, prohibitive transaction costs, or lack of awareness (e.g., Stern et al. 1986; Blumstein 2010; Allcott and Taubinsky 2015; Gillingham and Palmer 2014).

The design and evaluation of subsidy programs that promote energy efficient technologies are generally complicated by self-selection, rebound effects, moral hazard (consumers deferring adoption to wait for a financial incentive program), and free riding (Hartman 1988; Gillingham et al. 2006; Alberini et al. 2014). Failure to account for these issues results in an overestimation of policy effectiveness (e.g. Joskow and Marron 1992). Free riding, the focus of this study, occurs when subsidies are paid to customers who would have purchased the technology even without the subsidy. Free ridership has been estimated in a variety of ways in previous ex post studies of utility demand side management (DSM) and tax credit programs for residential energy efficiency upgrades in North America (Joskow and Marron 1992; Malm 1996; Loughran and Kulick 2004; Boomhower and Davis 2014) and Europe (Grösche and Vance 2009; Nauleau 2014; Alberini et al. 2014). These studies find that free rider shares among program beneficiaries range from 50 % to 90 %. For governments and utilities, it is rarely feasible to distinguish among beneficiaries who actually needed or did not need the subsidy to engage in energy efficient behavior. Similarly, the economic evaluation literature presumes a non-discrimination principle of incentive allocation: those who allocate the rebate cannot – if not for ethical reasons then for reasons of prohibitive administrative costs – distinguish between free riders and non-free riders when granting subsidies to consumers who purchase eligible efficiency upgrades. In addition, when subsidies are part of a policy package (typically also involving accompanying information programs), evaluations typically cannot identify the effects of individual policies on program effectiveness and program costs. For example, program evaluations typically do not distinguish customers who were planning to invest in an energy efficient technology anyway from customers who were not originally planning to invest in such a technology but decided to do so after being informed.

The overall objective of this paper is to do an ex ante assessment of the effects of free riding on the cost effectiveness of a rebate program incentivizing the premature adoption of energy-efficient heating systems in eight EU Member States. Unlike previous studies, we distinguish the effects of two types of free riders, which we name strong and weak free riders respectively. By strong free riders we mean households that benefit from a rebate but were planning to replace their heating system regardless weak free riders are households that were not originally planning to invest in a heating system but decided to do so after receiving information about an attractive technology package (and therefore only needed awareness of technology, not of the rebate). We effectively separate the effects of providing information from the effects of offering rebates. Further, we explore the factors explaining weak free ridership and the rebate level required to adopt a new heating system. Our findings allow for an analysis of the cost effectiveness of rebate programs across countries, and assess the relevance of each type of free riding for differences in cost effectiveness across countries.

Our empirical analysis relies on contingent valuation choice experiments carried out through representative surveys of 15.000 households in eight EU Members States (France, Germany, Italy, Poland, Romania, Spain, Sweden, United Kingdom). Together, these eight countries account for about 80 % of EU population, energy use, and greenhouse gas emissions. Respondents' choices are used to estimate (for each country) the probability that households upgrade their heating system as a function of the rebate offered and to construct curves for the specific rebate costs (in €/tCO_2) based on free rider shares, which are compared across countries.

The remainder of the paper is organized as follows. The methodology section 2 presents a brief analytical model to evaluate the effectiveness of a rebate policy distinguishing between strong and weak free riders, the multi-country survey, and the choice experiment. The results section 3 shows findings for rebate levels across countries and for the determinants of the rebate level and weak free ridership. Section 3 also includes simulation analyses on the effects of strong and weak free riding on the cost effectiveness of rebates across countries. The final section summarizes and discusses our main findings and identifies some policy implications.

Methodology

In this section, we first present a simple analytical model for evaluating the effectiveness of a rebate policy while distinguishing between strong and weak free riders. Then, we describe our survey, our choice experiment, and the econometric model that we employed to estimate the rebate level and to conduct simulations.

ANALYTICAL MODEL OF REBATE EFFECTIVENESS AND FREE RIDING

The model presented in this section will later be parameterized with econometric estimates based on a contingent valuation survey. Constructing specific rebate cost curves as a function of an offered rebate allows us to simulate the effects of free riding on the cost effectiveness of the rebate program for premature adoption of an energy efficient technology (here: heating).

The specific rebate costs are the average CO_2 abatement costs of the rebate program:

$$c = C/\Delta E \qquad (1)$$

C captures total program costs, i.e. the total expenditure for rebate payments, and ΔE is the total additional CO_2 emissions saved by the rebate program. The non-discrimination principle implies that all adopters receive the rebate:

$$C = N_{adopt} \times R = (N_{ia} + N_{wfr} + N_{sfr}) \times R \qquad (2)$$

where R stands for the rebate offered and N_{adopt} is the total number of households adopting, comprised of (i) the number of incentivized adopters N_{ia} i.e. those adopting only if R > 0; (ii) the number of weak free riders $N_{wfr,}$ i.e. those adopting once made aware of an attractive technology package; and (iii) the number of strong free riders N_{sfr}, i.e. those adopting independent of a rebate or additional information. Let the number of strong free riders be defined as:

$$N_{sfr} = N_{pop} \times a \qquad (3)$$

where N_{pop} is the total number of households in the population, and a is the share of strong free riders. Similarly, we denote the number of incentivized adopters:

$$N_{ia}(R) = N_{pop} \times b(R) \text{ , for } R > 0 \qquad (4)$$

where $b(R)$ is the probability of adoption, i.e. Pr(adoption | R); $b(R)$ is a function of the rebate R with $b'(R)>0$ (for $R>0$). The number of weak free riders is then:

$$N_{wfr} = N_{pop} \times b(0) \qquad (5)$$

where $b(0)$ defines the share of weak free riders in the population. Program costs are:

$$C = R \times N_{pop} \, [a + b(0) + b(R)] \qquad (6)$$

The additional CO_2 emissions saved by incentivized adopters can be written as:

$$\Delta E = N_{ia}(R) \times \Delta e \times \gamma = b(R) \times N_{pop} \times \Delta e \times \gamma \quad (7)$$

where Δe is end-use energy savings per replacement, and γ is the CO_2 emissions per unit of energy. We may then rewrite the specific rebate costs from equation (1) as:

$$c = \frac{C}{\Delta E} = \frac{R \times [a + b(0) + b(R)]}{b(R) \times \Delta e \times \gamma} \quad (8)$$

As further detailed in the following subsections, we employ a staged choice structure in a double-bounded willingness-to-accept choice experiment and interval data model estimation to predict the probability of adoption and to estimate *b(R)* and *b(0)*. The double-boundedness increases the precision of the estimate of the acceptable rebate levels.

SURVEY

The survey was implemented by Ipsos GmbH via computer assisted web interviews (CAWI), using existing household panels from Ipsos. A total of 15,000 participants from eight EU countries (France, Germany, Italy, Poland, Romania, Spain, Sweden, United Kingdom) completed the survey. In each country, participants were selected via quota sampling to be representative for that country in terms of gender, age (between 18 and 65 years), and region; only respondents who said that they were involved in their household's investment decisions for utilities, heating, and household appliances were qualified for the survey. Interviews were carried out between July and August 2016. All interviews were translated from the original language (English) to the language of each country by professionals, and back translated subsequently to test for and eliminate any differences that could be attributed to language.

Our survey contained questions on the adoption of energy-efficient technologies, as well as questions designed to assess personality traits and attitudes via established scales. The survey included items that reflect environmental identity,[1] cognitive reflection,[2] willingness to take risk and to wait (patience).[3] Socio-demographic information was gathered both at the beginning of the questionnaire (to ensure that quota requirements were met), and at the end of the questionnaire.

CHOICE EXPERIMENT

The structure of our choice experiment questions is shown in Figure 1. It was adapted from Alberini and Bigano (2015) who employ a similar experiment to evaluate the effectiveness of subsidies toward the replacement of heating systems in Italy. To filter out free riders and to mitigate adverse selection, we asked home-owner respondents who had neither adopted a heating system in the previous 10 years nor were planning to do so in the following 5 years to participate in a simple stated preferences choice experiment.

Note that the number of respondents who answered "yes, I plan to purchase a heating system in the next 5 years" to the first question in Figure 1 (and who had not changed their heating system in the previous 10 years) reflects the number of strong free riders N_{sfr}: those are the households who were planning to purchase anyway, with or without the rebate program. We assume that these households will realize their planned behavior and benefit from a rebate.

For the subsample of respondents who did not answer "yes" to the first question, the choice experiment proposed a cost of €2.000 for the heating system and one randomly assigned combination of total savings and savings duration: savings and duration varied randomly between €200, €400, €600, or €800 and 10, 15, or 20 years, respectively, resulting in 12 different offering combinations. Each respondent only saw one of these offerings, which they could either accept or reject. Respondents who rejected the initial offer were offered, at random, one of six rebates and were asked if they accepted the offer at the given rebate level. Rebates varied randomly among €100, €200, €300, €500, €800, or €1000. Since the values for the level of the rebate, savings, and duration were randomly assigned to participants, our design mimics a randomized controlled experiment.

The choice options yielded three types of respondents:

- *Type 1 (observed weak free riders)*: Respondents who accepted the initial offering. For this type of respondent, the latent reservation incentive (i.e., the unobserved, minimum rebate level a household is willing to accept) is between -∞ (or negative disposable income) and 0. These are therefore observed weak free riders, i.e., households who were not planning to purchase a heating system but decided to do so when informed about the existence of an attractive technology option.
- *Type 2 (incentivized adopters)*: Respondents who rejected the initial offering but accepted when the rebate was offered. For this type of respondent, the latent reservation incentive is between 0 and the offered rebate.
- *Type 3 (non-adopters)*: Respondents who rejected the initial offering and the rebate. For this type of respondent, the latent reservation incentive is between the offered rebate and ∞.

ECONOMETRIC MODEL

We use an adapted double-bounded willingness-to-pay approach (Cameron and James 1986; Hanemann *et al.* 1991) to estimate the probability of adoption as a function of the rebate offered. Similar to Alberini and Bigano (2015), the adaptation reflects a focus on willingness-to-accept a subsidy rather than on willingness-to-pay.

We assume that a household i has a reservation rebate level R_i^*. Were it offered a rebate $R_i \geq R_i^*$, it would adopt the technology; a rebate $R_i < R_i^*$ would lead to rejection. R_i^* is a function of both the technology package and characteristics of the household. It can be written as:

$$R_i^* = \alpha + \boldsymbol{x}_i\boldsymbol{\beta} + \boldsymbol{z}_i\boldsymbol{\delta} + \varepsilon_i \quad (9)$$

1. We use the four-item scale of the environmental identity scale developed by Whitmarsh and O'Neill (2010). Participants were asked to rate the following items on a scale from 1 (Strongly disagree) to 5 (Strongly agree): (1) To save energy is an important part of who I am. (2) I think of myself as an energy conscious person. (3) I think of myself as someone who is very concerned with environmental issues. (4) Being environmentally friendly is an important part of who I am.

2. Cognitive reflection tests (CRT) assess individual ability to suppress an intuitive and spontaneous wrong answer in favor of a correct answer (Frederick, 2005). To measure cognitive reflection we use the following items: (1) A bat and a ball cost 1.10€ in total. The bat costs €1.00 more than the ball. How much does the ball cost? (2) If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? (3) In a lake, there is a patch of lily pads. Every day, the patch doubles in size. It takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?

3. We measured time and risk preferences on one-item scales validated by Falk et al. (2016) and Dohmen et al. (2010). Participants were asked to rate the following items on a scale from 1 (Not at all willing) to 5 (Very willing): (1) How willing are you to give up something that is beneficial for you today in order to benefit more from that in the future? (2) In general, how willing are you to take risks?

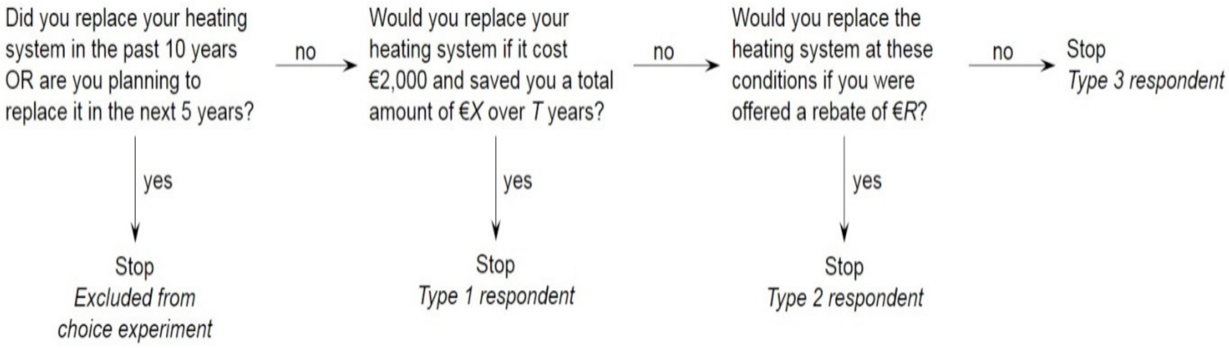

Figure 1. Structure of the choice experiment questions.

where x_i defines the technology package consisting of the annual savings s_i and the duration of the savings t_i; z_i is a set of covariates describing a household's characteristics (see Table 1); ε_i is the normally distributed error term with standard deviation σ.

R_i^* cannot be observed, but it can be estimated in a double bounded contingent valuation model. The probability that R_i^* lies between the lower (R_i^L) and upper bound (R_i^U) obtained from the household's responses in the choice experiment is written as the following interval data model:

$$Pr\left(R_i^L < R_i^* \leq R_i^U\right) \qquad (10)$$

$$= Pr(R_i^L < \alpha + \boldsymbol{x}_i\boldsymbol{\beta} + \boldsymbol{z}_i\boldsymbol{\delta} + \varepsilon_i \leq R_i^U)$$

$$= Pr\left(\left(R_i^L - (\alpha + \boldsymbol{x}_i\beta + \boldsymbol{z}_i\delta)\right)/\sigma\right) < \varepsilon_i/\sigma$$

$$\leq Pr\left(\left(R_i^U - (\alpha + \boldsymbol{x}_i\beta + \boldsymbol{z}_i\delta)\right)/\sigma\right)$$

$$= \Phi\left(\left(R_i^U - E(R_i^*)\right)/\sigma\right) - \Phi\left(\left(R_i^L - E(R_i^*)\right)/\sigma\right) = \Phi^U - \Phi^L$$

where Φ denotes the standard normal cdf, and $E(R_i^*)$ is the expected value of the threshold subsidy level. For the three types of respondents (Figure 1), Φ^U and Φ^L are as follows:

For type 1 respondents,

$$\Phi^U = \Phi\left(\left(0 - E(R_i^*)\right)/\sigma\right) = \Phi\left(-E(R_i^*)/\sigma\right)$$

and $\Phi^L = \Phi(-\infty) = 0.$

For type 2 respondents,

$$\Phi^U = \Phi\left(\left(R_i - (R_i^*)\right)/\sigma\right)$$

and $\Phi^L = \Phi\left(\left(0 - E(R_i^*)\right)/\sigma\right) = \Phi\left(-E(R_i^*)/\sigma\right).$

For type 3 respondents,

$$\Phi^U = \Phi(\infty) = 1$$

and $\Phi^L = \Phi\left(\left(R_i - E(R_i^*)\right)/\sigma\right).$

We used a maximum likelihood procedure to estimate the coefficients α, β, and δ. With these coefficients, we can then predict the probability of adoption for the sample and obtain the free rider shares. Given data availability, we slightly redefine the share of strong free riders compared to equation (3) as:

$$a = N_{out} / N_{sample} \qquad (11),$$

with N_{out} the number of people stating an intention to adopt a new heating system in the next five years and N_{sample} the full sample size. The predicted share of adopters for any rebate equal to or greater than zero can then be written as follows:

$$b(0) = Pr(adoption \mid R_i = 0) \times \left[N_{exp}/N_{sample}\right] \qquad (12)$$

$$= \Phi\left(\left(0 - E(R_i^*)\right)/\sigma\right) \times \left[N_{exp}/N_{sample}\right]$$

$$b(R) = Pr(adoption \mid R_i > 0) \times \left[N_{exp}/N_{sample}\right] \qquad (13)$$

$$= \Phi\left(\left(R_i - E(R_i^*)\right)/\sigma\right) \times \left[N_{exp}/N_{sample}\right]$$

N_{exp} is the size of the subsample eligible for the choice experiment, i.e. those who had not and were not planning to adopt within the given timeframe. The full sample N_{sample} is equal to $N_{exp} + N_{out}$. Note that equation (12) yields the predicted weak free riders. Unlike observed weak free riders, equation (12) allows us to calculate weak free riding independent of the range of subsidies offered in the choice experiment.

Results

We first present our econometric findings on rebate levels across countries as well as determinants of the reservation rebate level and weak free ridership respectively. Using econometric parameter estimates we then carry out simulations to provide for further insight into the impact of different types of free riders on the cost effectiveness of rebates (for upgrading heating systems) across countries.

ECONOMETRIC RESULTS FOR RESERVATION REBATE LEVELS

To simply estimate the mean and median reservation rebate level, all variables of the technology package x_i and household characteristics z_i are dropped from equation (9). Results for this reference model appear in Table 2. In the *all countries* model, where data from all countries are pooled, the mean and median reservation rebate is €1,064. For the individual models, which only use country-specific observations, we find the lowest mean and median reservation rebates for Romania and Poland, and the highest for France, Germany, and Sweden. In the *all countries* model and in most individual models, the mean and median reservation rebate corresponds to slightly more than half the heating system's purchasing price of €2,000, suggesting generally high opportunity costs for premature heating system replacement.

Table 1. Description of covariates.

Variable	Description
Income	Dummy (=1, if respondent education level is above country median income level)[a]
Education	Dummy (=1, if respondent education level is above country median education level)[a]
Gender	Dummy (= 1 if respondent is male)
Age	Age of respondent in years
HHsize	Number of household members
ENV_ID	z-score based on responses to environmental identity scale items
CRT	z-score based on responses to "Cognitive Reflection Test" items
WTRisk	z-score based on responses to item scale eliciting willingness to take risk
WTWait	z-score based on responses to item scale eliciting willingness to wait

Table 2. Results for reference model (standard errors in parentheses).

	All countries	FR	DE	IT	PL	RO	ES	SE	UK
Rebate	1,064***	1,317***	1,299***	869***	651***	438***	1,137***	1,649***	1,078***
	(26.07)	(94.73)	(90.05)	(65.85)	(47.32)	(57.21)	(71.66)	(164.7)	(54.47)
Sigma	1,232***	1,475***	1,349***	1,185***	928***	806***	1,357***	1,270***	1,022***
	(32.88)	(116.9)	(105.1)	(92.75)	(68.44)	(91.14)	(92.71)	(102.7)	(60.05)
N	7,681	1,123	1,059	868	1,014	359	1,282	901	1,075

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

ECONOMETRIC RESULTS FOR DETERMINANTS OF RESERVATION REBATE AND WEAK FREE RIDERSHIP

Table 3 reports results for the *all countries* model, when all variables of the technology package x_i and household characteristics z_i are included in equation (9). The household characteristics comprise both the socio-demographic and attitudinal variables described in Table 1. As expected, the reservation rebate is higher when the *savings* offered are higher. On average, each additional € of energy cost lifetime *savings* lowers the reservation rebate by about €0.14. *Duration* exhibits the expected positive sign, but is not statistically significant at conventional levels.

Regarding the relationships between different household characteristics and reservation rebate level, Table 3 suggests that the reservation rebate is negatively related to *income*. Hence, weak free ridership (i.e., respondents with predicted $R^* \leq 0$) is positively related to income. Households with above median income require a rebate which is about €97 lower than the rebate that households with an income less than or equal to the median need. The coefficients of *education* and *gender* are not statistically significant at conventional levels. Older respondents require a higher rebate, almost €4 for each additional year. The coefficient on *HHsize* suggests that each additional household member lowers the rebate by almost €57. As intuitively expected, a higher *environmental identity* translates into a lower rebate. Interestingly, respondents with a higher *cognitive reflection* score (CRT) demand a higher rebate and are less prone to be weak free riders. Arguably, respondents with a high cognitive reflection score who stated that they did not intend to adopt a new heating system (within the next 5 years) grounded their statement in rational decision-making based on sufficient

Table 3. Correlation of reservation rebate with socioeconomic and attitudinal variables in all countries model (standard errors in parentheses).

Savings	-0.136	*	(0.08)
Duration	4.025		(4.51)
Income	-97.3	**	(48.32)
Education	-7.133		(37.69)
Gender	-39.04		(34.38)
Age	3.576	***	(1.38)
HHsize	-56.84	***	(12.66)
ENV_ID	-107.9	***	(18.45)
CRT	119.6	***	(17.99)
WTRisk	-126.2	***	(19.19)
WTWait	-111.8	***	(18.68)
FR	1.296		(65.37)
IT	-180.3	**	(70.03)
PL	-298.6	***	(66.84)
RO	-461.4	***	(89.62)
ES	1.265		(63.22)
SE	63.71		(71.56)
UK	41.96		(66.00)
Rebate	1,230	***	(122.90)
Sigma	1,154	***	(30.70)
N	7,681		

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

information; altering this decision would lead to a relatively high welfare loss, thus requiring a higher rebate for compensation. Finally, respondents with a higher *willingness to take risks* and *to wait* require a lower rebate and are less prone to be predicted weak free riders. Thus, most household characteristics exhibit expected relationships with the reservation rebate, and hence with predicted weak free ridership.[4, 5]

SIMULATIONS

We perform simulations to gain further insights into the role of weak and strong riders on cost effectiveness of the rebate and into differences across countries. For these simulations, we use the results of the interval data model estimations presented in Table 2, but we assume that the reservation rebate in each country depends on *savings* as suggested by the *all countries* model shown in Table 3.

Rebate effectiveness (incentivized adopters)

Figure 2 plots the probability of adoption as a function of the rebate level Pr(adoption | R_i) for each country. Higher rebates increase adoption probability at a rate of between 3.4 percentage points in Sweden and 9 percentage points in Romania per €200 increase (i.e. 10 % of the proposed purchase price)[6]. Steeper curves reflect larger changes in adoption rates in response to a change in the rebate level. Thus, the results show that raising a rebate by a given amount would lead to particularly large increases in the share of incentivized adopters in Italy, Romania, Poland, or the UK, and to relatively small increases in France, Germany, Spain, or Sweden.

Free riders

The curves' intercepts with the ordinate in Figure 2 depict the predicted share of weak free riders in the subsample participating in the experiment N_{exp}, i.e. the share of those whose reservation rebate is zero or lower. Accordingly, the average weak free rider share is around 20 percent of the subsample, lowest for Sweden (11.70 %), the UK (17.09 %) and Germany (19.33 %), and highest for Romania (28.30 %), Poland (26.61 %) and Italy (26.30 %). The shares of strong free riders are reported in Table 4.

To further explore the relative effects of the different types of free riders, Figure 3 plots the shares of both weak and strong free riders among all adopters at any given rebate level. The share of total free riders starts at 100 % for a zero rebate and drops as higher rebates incentivize additional adopters, while the total number of weak and strong free riders does not vary with the rebate. However, even at a rebate of €1,000 – which corresponds to half the purchase price of the heating system – the share of free riders remains high, i.e. around 50 percent in most countries, and is even higher in Italy and Romania. At this rebate level, about half the total rebate expenditure (and in Romania almost three quarters) would go to free riders. Notably, the decomposition of total free riders differs substantially across countries.

Figure 3 implies that for most countries the share of weak free riders is greater than (or equal to as in Italy) the share of strong free riders. Romania is an exception (see Table 4).[7] As expected, as the rebate increases, total program costs increase, but the share of the rebate expenditures going to free riders decreases.

CO_2 emissions and rebate cost effectiveness

For further elaboration, we simulate the effects of the rebate on CO_2 emissions. To do so, we need to make additional assumptions. We therefore standardize as many parameters across countries as possible, to allow us to isolate the effects of differences in free riding on the cost effectiveness of the rebates. To calculate the CO_2 emissions per adoption of a heating system, we first assume that the old and the new systems are gas fired.[8] We then translate the energy cost savings into kWh-savings (i.e. Δe in equation (7)) using a price of €0.05/kWh.[9] Similarly, employing a CO_2-factor of 0.2 kg/kWh (corresponding to γ in equation (7)) then yields the CO_2 savings per € of energy expenditures saved. For simplicity, we assume a total lifetime *savings* of €1000 per adoption of a new gas-fired heating system.[10] Table 4 lists the parameter values used in the subsequent simulations.

To calculate cost effectiveness, we divide the CO_2 emissions saved by incentivized adopters (i.e. without CO_2 emissions saved by weak or strong free riders) by the rebate expenditures (see equations (7) and (8)). Figure 4 shows these specific rebate costs as a function of the rebate level for all countries. The dotted line denotes average expenditures without considering expenditures for weak or strong free riders. Since we assume identical savings, gas prices, and CO_2 factors for all countries, this line is linear and identical across countries. The dashed line captures the specific rebate costs, when expenditures for weak free riders are also accounted for. Therefore, the difference between the dashed line and the dotted line reflects additional expenditures for weak free riders. Thus, if weak free riders could be identified and transformed into (non-incentivized) adopters (e.g. via low-cost targeted information programs) and excluded from receiving rebates, then the average (and total expenditures) of the rebate program would be substantially lower in all countries, especially in France and Spain.

The solid line reflects specific rebate costs, when expenditures for both strong and weak free riders are included. The difference between the solid and the dashed lines corresponds to

4. As a "robustness check", we ran a simple binary response model, where the dependent variable was set to 1 for observed weak free riders (i.e. Type 1 in Figure 1) and to 0 for incentivized adopters (i.e. Type 2) and non-adopters (i.e. Type 3). Qualitatively, the findings are similar to those reported in Table 2.

5. In addition to the all countries model presented in Table 3, we ran individual country models. While there is heterogeneity in findings across countries, they are rather consistent. For example, the coefficient associated with savings was found to be negative and statistically significant for four countries. For two of the remaining countries the p-value was between 0.1 and 0.2, thus generally providing (at least weak) evidence for rational choices in most countries.

6. For Italy, the estimated rate is 5.8 percentage points, and thus very close to the 6-percentage point probability increase for an equivalent raise that was found by Alberini and Bigano (2015) for heating systems in Italy.

7. Romanians (particularly in urban areas) are increasingly switching from district heating systems to individual systems because the existing systems are old, inefficient, and have a high carbon footprint (NEEAP Romania, 2015, pp. 134).

8. In our survey, the share of gas-fired heating systems among all heating system replacements in the last ten years ranges from about 78 % in the UK to around 3 % in Sweden. Gas-fired heating systems are also the most common replacement type in France, Germany, Italy, and Spain.

9. This figure is very close to actual gas prices during the first half of 2016 for six of the eight countries included in this study (Eurostat, 2016b). Only gas prices in Poland (€0.032/kWh) and Romania (€0.018/kWh) differed markedly from that value.

10. Additional simulations carried out as a "sensitivity analysis" suggest that using €500 as savings leads to qualitatively very similar findings as using €1,000 .

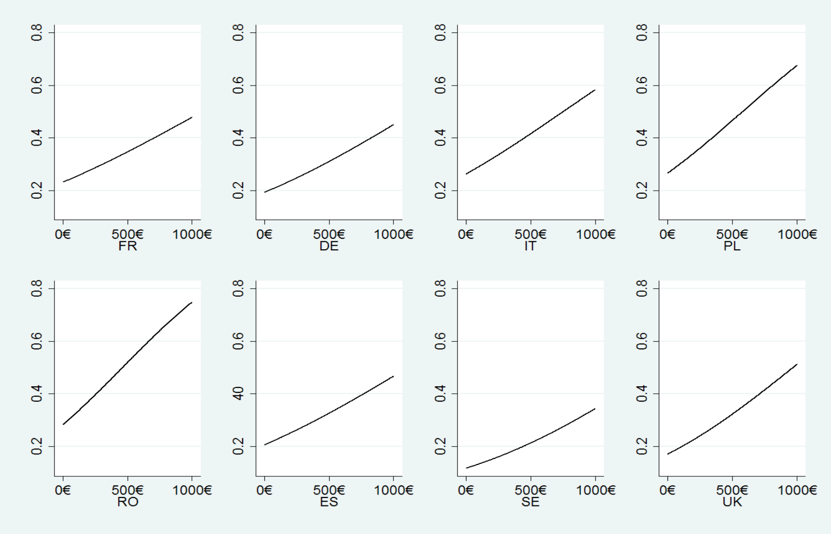

Figure 2. Estimated probability of adoption as a function of the rebate (in €).

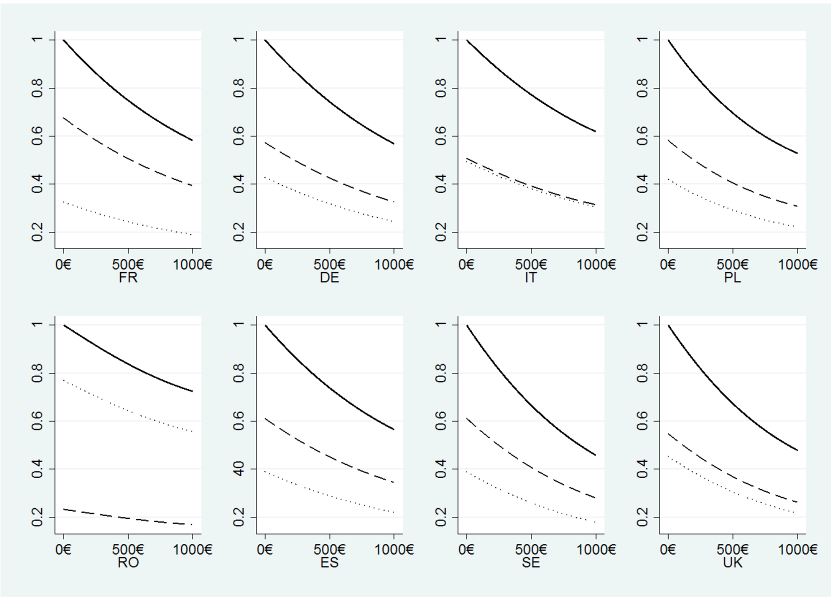

Figure 3. Shares of free riders as a function of rebate level. Note: solid line: total share of free riders; dashed line: share of weak free riders; dotted line: share of strong free riders.

Table 4. Parameter assumptions for the simulations.

	FR	DE	IT	PL	RO	ES	SE	UK
Sample size[a]	1,248	1,212	1,090	1,208	696	1,451	969	1,227
# of households[b] (in 1,000)	28,920.4	40,257.8	25,788.6	14,113.4	7,469.7	18,376.0	5,099.8	28,218.5
Gas price[c] (€/kWh)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CO_2 factor (kg-CO_2/kWh)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Savings(in €)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Share of strong free riders (%)[d]	10.01	12.62	20.36	16.05	48.41	11.64	6.91	12.38

[a] Subsample of homeowners, who stated that they did not purchase a new heating system during the past ten years and who live in a dwelling built before the year 2000 (corresponds to N_{sample} in the analytical model).[b] Eurostat (2016a). [c] Eurostat (2016b). [d] Share of strong free riders in the subsample.

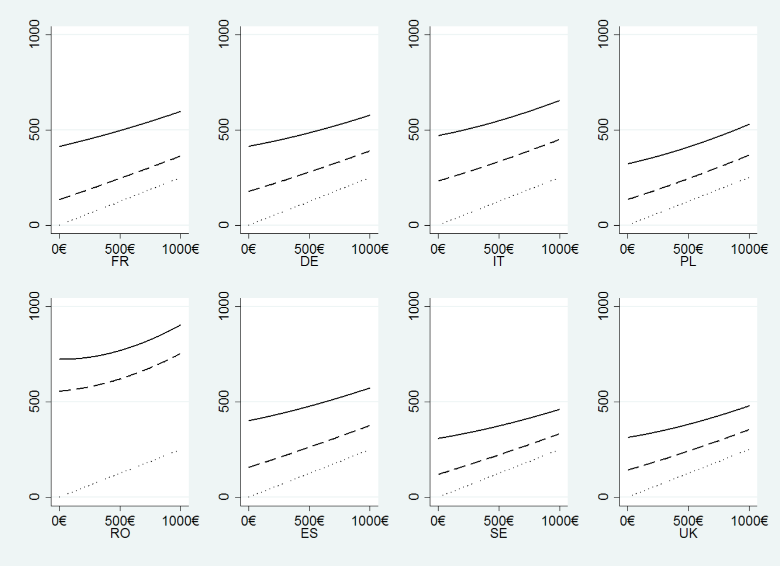

Figure 4. Specific rebate costs (in €/tCO_2) as a function of rebate level. Note: solid line: CO_2 reduction of free riders not credited to rebate; dashed line: CO_2 reduction of strong free riders not credited to rebate; dotted line: CO_2 reduction of all free riders credited to rebate.

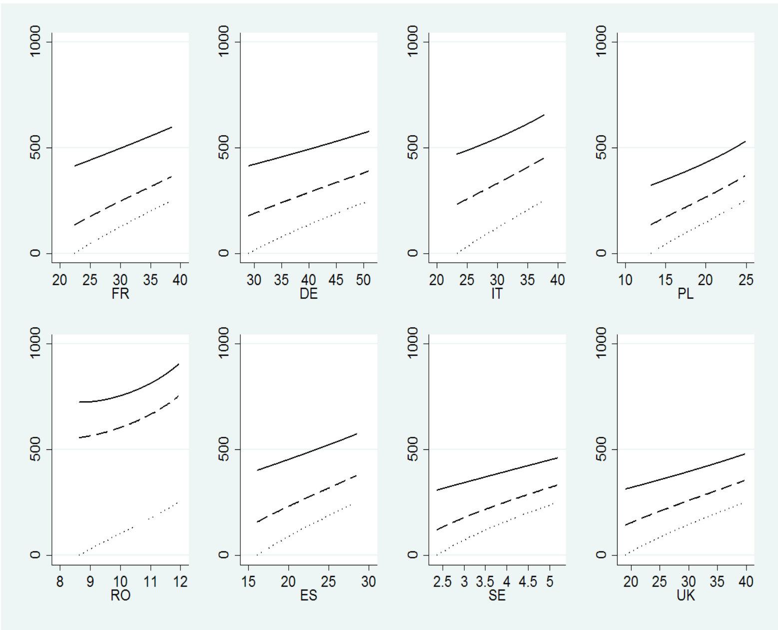

Figure 5. Specific rebate costs (in €/tCO_2) as a function of abated emissions (in Mt). Note: solid line: CO_2 reduction of free riders not credited to rebate; dashed line: CO_2 reduction of strong free riders not credited to rebate; dotted line: CO_2 reduction of all free riders credited to rebate.

the additional expenditures for strong free riders. For a rebate of €1000 , the specific rebate costs for most countries are just above €500/tCO_2. Figure 2 suggests that at a rebate of €1000 (in most countries) at least half of the subpopulation would replace its heating system. Due to a high share of strong free riders, the specific rebate costs are particularly high for Romania (even though the mean reservation rebate was low). In comparison, we also note that for countries that exhibit relatively high levels of the mean rebate (e.g. Sweden), the specific rebate costs may be rather low if the shares for weak and strong free riders in these countries are low.

Figure 5 displays specific rebate costs as a function of abated emissions for each country. The shapes of the curves and the interpretation of our findings on the impact of weak and strong free riders are like those in Figure 4. In addition, the differences in the shapes of the curves across countries in Figure 5 suggest that cooperation among countries to achieve a given aggregate CO_2 emission level would yield sizeable reductions in public expenditure. From a public spending perspective and depending on the aggregate target, it appears preferable to prioritize implementation of the rebate program in the UK, Sweden, and Poland[11].

11. At present, there is no aggregate EU (or national) emission target for particular activities like space heating. So, this finding should rather be illustrative of the efficiency gains that cooperation across countries might involve.

Discussion and conclusions

For countries and energy companies to achieve ambitious energy and climate policy targets, it is crucial to account for free riding when assessing the cost effectiveness of programs (such as rebates incentivizing technology replacement) designed to support customer conversion to energy efficient technologies. Relying on contingent valuation choice experiments carried out through identical representative surveys in eight EU Members States, we ex ante assess the effects of free riding on the cost effectiveness of a rebate program that incentivizes the adoption of energy-efficient heating systems in these countries. Conceptually and empirically, we distinguish between what we name strong and weak free riders: strong free riders are households planning to adopt a new heating system even without any information or rebate program; weak free riders only need to be made aware of an attractive technology package to decide to adopt (and therefore do not need the rebate program). In contrast, incentivized adopters are those adopters who only purchase because of the rebate program.

We find that mean and median reservation rebates for incentivized adopters differ substantially across countries. On average (across countries), this rebate corresponds to slightly more than half the heating system's purchasing price of €2,000, suggesting a generally high opportunity cost for the premature replacement of a heating system. The reservation rebate and weak free ridership vary substantially across socio-economic groups. We find significant positive correlations of the reservation rebate with income and environmental identity, hence negative correlations of predicted weak free ridership with these household characteristics. Interestingly, and typically not considered in the extant literature, our results also suggest that risk and time preferences affect the reservation rebate. More risk-averse and less patient respondents require higher rebates and are thus less likely to be weak free riders.

Further, our simulation results suggest that the propensity to adopt a new heating system varies considerably across countries. Raising the rebate by a given amount would most effectively increase adoption rates in Romania and Poland, and least effectively in Germany and Sweden. At a rebate level of €1000, which corresponds to half the purchase price of the offered heating system, the share of free riders is estimated at 50 percent for most countries, but is substantially higher for Italy and Romania. The decomposition of total free riders, however, differs across countries. We find that for most countries, the share of weak free riders is higher than the share of strong free riders. In general, our ex ante estimates of free ridership, based on hypothetical technology and incentive offerings, are broadly consistent with the ex post results in the literature on free ridership within the context of residential energy efficiency improvements, which tend to find free rider shares of 50 % or more.

Our analyses provide some guidance for policy making. First, simulation results imply that for a rebate of €1,000, the specific rebate costs for most countries are just above €500/tCO_2. Thus, public spending on rebates for premature heating system replacement as a CO_2 emissions reduction instrument compares to high social costs of carbon only. In addition to the high opportunity costs associated with premature technology replacement, this figure also reflects high shares of strong and weak free riders. Due to a large share of strong free riders, the specific costs are particularly high for Romania (even though the reservation rebate in that country is low). In contrast, despite high reservation rebates, specific rebate costs are low in some countries (like Sweden) owing to their lower share of free riders.

Second, rebates for heating system upgrades appear to be an effective means for governments or energy companies to reach energy and emission targets. The European Union (EU) for example, has set a 20 % energy savings target by 2020 in the Energy Efficiency Directive (EED) (2012/27/EU). The EED further requires Member States to lower annual energy sales to final customers by 1.5 percent each year until 2020. Member States may pass on this responsibility to energy retail companies and/or take policy measures themselves. The European Commission "Winter Package" proposal for an updated EED (COM (2016)/761 final) includes a new 30 % energy savings target for 2030 and suggests continuing this commitment to year over year improvement through 2030 and beyond. While effective, our findings further suggest that such rebate programs would be rather costly, because of high shares of free riders.

Third, substantial differences in the shapes of the specific rebate cost curves illustrate that if countries were to achieve a common CO_2 emission reduction target (as in the EU for example), coordinated measures (here: rebates) would yield sizeable reductions in public expenditure.

Fourth, our findings on weak free ridership attest to the role of attention-getting efforts in increasing program participation (Stern et al. 1986). While a combination of policies may increase adoption compared to a single policy, the cost effectiveness of a non-discriminatory subsidy policy suffers from a parallel instrument's effectiveness. Our results suggest that in most countries (especially in France and Spain), rebate expenditures would be much lower if low-cost programs – involving communication and information for example – could turn weak free riders into (non-incentivized) adopters. Thus, rather than implementing rebate and information programs simultaneously, these programs should be introduced sequentially: first information programs to address the weak free riders by helping to overcome information-related barriers, and then rebate programs to reach those households that require financial incentives to prematurely replace their heating system. Of course, realizing a sequential approach might be challenging in practice, raising fairness and equity questions. For example, policy makers would have to announce the rebate program only after the information program had been implemented.

Finally, we want to point out some limitations of our study. Our findings rely on stated rather than observed behavior and conceal underlying factors that could motivate respondents' choices. The hypothetical nature of contingent valuation, however, is the price paid for ex ante empirics. Further, and as argued by Alberini and Bigano (2015, p. 78), the hypothetical bias associated with stated preferences experiments is likely to be small compared to a potential free rider bias. An additional limitation is that we ignored program administration costs (Eto *et al.* 2000) and did not account for rebound effects (e.g. Sorrell and Dimitropoulos 2008), which can lead to negative absolute savings in appliance subsidy programs (Galarraga *et al.* 2013).

Finally, the choice experiment setting eliminates the reality of uncertainty of future savings (Farsi 2014) and hides the extent to which respondents account for additional, 'hidden' costs (e.g. transaction costs) when taking the survey. Grösche and Vance (2009) showed how such hidden costs may reduce free ridership. Yet, because our chosen method allows for ex ante predictions, we could effectively separate the effects of weak free riding from the effects of monetary incentives, and obtain results on free riding shares that are consistent with those found with ex post evaluations.

References

Alberini, A., Bigano, A., 2015. How effective are energy-efficiency incentive programs? Evidence from Italian homeowners. *Energy Economics* 52, S76–S85. doi:10.1016/j.eneco.2015.08.021.

Alberini, A., Bigano, A., Boeri, M., 2014. Looking for free riding: energy efficiency incentives and Italian homeowners. *Energy Efficiency* 7, 571–590. doi:10.1007/s12053-013-9241-7.

Allcott, H., Taubinsky, D., 2013. The lightbulb paradox: Using behavioral economics for policy evaluation. NBER Working Paper 19713.

Blumstein, C., 2010. Program evaluation and incentives for administrators of energy efficiency programs: can evaluation solve the principal/agent problem? *Energy Policy* 38, 6232–6239.

Boomhower, J., Davis, L.W., 2014. A credible approach for measuring inframarginal participation in energy efficiency programs. *Journal of Public Economics* 113, 67–79. doi:10.1016/j.jpubeco.2014.03.009.

Cameron, T.A., James, M.D., 1986. Utilizing "closed-ended" contingent valuation survey data for preliminary demand assessments. UCLA Economics Working Papers.

Datta, S., Filippini, M., 2016. Analysing the impact of ENERGY STAR rebate policies in the US. *Energy Efficiency* 9 (3), 677–698.

Dohmen, T., Falk, A., Huffman, D., Sunde, U., 2010. Are risk aversion and impatience related to cognitive ability? *American Economic Review* 100 (3), 1238–1260.

Eurostat, 2016a. Data Explorer: Number of private households by household composition, number of children and age of youngest child. Download: http://appsso.Eurostat.ec.Europa.eu/nui/show.do?dataset=lfst_hhnhtych&lang=en.

Eurostat, 2016b. Natural gas price statistics (Series 2016 S1). Download: http://ec.Europa.eu/Eurostat/statistics-explained/index.php/Natural_gas_price_statistics.

Eto, J., Kito, S., Shown, L., Sonnenblick, R., 2000. Where did the money go? The cost and performance of the largest commercial sector DSM programs. *The Energy Journal* 21, 23–49.

Falk, A., Dohmen, T., Becker, A., Huffman, D., Sunde, U., 2016. The preference survey module: A validated instrument for measuring risk, time, and social preferences. IZA Discussion Paper No. 9674.

Frederick, S., 2005. Cognitive reflection and decision making. *Journal of Economic Perspectives*, 19 (4), 25–42.

Galarraga, I., Abadie, L.M., Kallbekken, S., 2016. Designing incentive schemes for promoting energy-efficient appliances: A new methodology and a case study for Spain. *Energy Policy* 90, 24–36. doi:10.1016/j.enpol.2015.12.010.

Galarraga, I., Abadie, L.M., Ansuategi, A., 2013. Efficiency, effectiveness and implementation feasibility of energy efficiency rebates: The "Renove" plan in Spain. *Energy Economics* 40, S98–S107. doi:10.1016/j.eneco.2013.09.012.

Gillingham, K., Newell, R. and Palmer, K., 2006. Energy efficiency policies: A retrospective examination. *Annual Review of Environment and Resources* 31, 161-192.

Gillingham, K., Palmer, K., 2014. Bridging the energy efficiency gap: Policy insights from economic theory and empirical evidence. *Review of Environmental Economics and Policy* 8, 18–38. doi:10.1093/reep/ret021.

Grösche, P., Vance, C., 2009. Willingness to pay for energy conservation and free-ridership on subsidization: Evidence from Germany. *The Energy Journal* 30, 135–153.

Hanemann, M., Loomis, J., Kanninen, B., 1991. Statistical efficiency of double-bounded dichotomous choice contingent valuation. *American Journal of Agricultural Economics* 73, 1255–1263.

Hartman, R.S., 1988. Self-selection bias in the evaluation of voluntary energy conservation programs. *Review of Economics and Statistics* 70 (3), 448–458.

IEA, 2016. World Energy Outlook 2016. International Energy Agency, OECD, Paris.

Joskow, P.L., Marron, D.B., 1992. What does a Negawatt really cost? Evidence from utility conservation programs. *The Energy Journal* 13, 41–74. doi:10.5547/ISSN0195-6574-EJ-Vol13-No4-3.

Loughran, D.S., Kulick, J., 2004. Demand-side management and energy efficiency in the United States. *The Energy Journal* 25 (1), 19–43.

Malm, E., 1996. An actions-based estimate of the free rider fraction in electric utility DSM programs. *The Energy Journal* 17 (3), 41–48.

Markandya, A., Labandeira, X., Ramos, A., 2014. Policy instruments to foster energy efficiency. In: Ansuategi, A., Delgado, J., Galarraga, I. (eds): Green energy and efficiency. An economic perspective. Springer, Heidelberg.

Nauleau, M.L., 2014. Free-riding on tax credits for home insulation in France: An econometric assessment using panel data. *Energy Economics* 46, 78–92.

NEEAP Romania, 2015. National energy efficiency action plan 2014. The Official Journal of Romania. Download: https://ec.Europa.eu/energy/sites/ener/files/documents/NEEAP%20Romania_en%20version.pdf.

de la Rue du Can, S., Shah, N., Phadke, A., 2011. Country review of energy-efficiency financial incentives in the residential sector. LBNL Report 5033E. Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division. Berkeley, California.

de la Rue du Can, S., Leventis, G., Phadke, A., Gopal, A., 2014. Design of incentive programs for accelerating

penetration of energy-efficient appliances. *Energy Policy*. 72, 56–66.
Sorrell, S., Dimitropoulos, J., 2008. The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics* 65 (3), 636–649.
Stern, P.C., Aronson, E., Darley, J.M., Hill, D.H., Hirst, E., Kempton, W., Wilbanks, T.J., 1986. The effectiveness of incentives for residential energy conservation. *Evaluation Review* 10, 147–176.
Whitmarsh, L., O'Neill, S. (2010): Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *Journal of Environmental Psychology* 30 (3), 305–314.

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