Ruhr Economic Papers

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Identifying Free-Riding in Energy-Conservation Programs Using Revealed Preference Data

#99

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Published by

Ruhr-Universität Bochum (RUB), Department of Economics
Universitätsstr. 150, 44801 Bochum, Germany

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Ruhr Economic Papers #99

Responsible Editor: Christoph M. Schmidt

ISSN 1864-4872 (online) – ISBN 978-3-86788-110-4

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Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.

ISSN 1864-4872 (online)
ISBN 978-3-86788-110-4

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Abstract

Identifying the incidence of free-ridership is significant to a range of issues relevant to program evaluation, including the calculation of net program benefits and more general assessments of political acceptability. Estimates of free-ridership in the area of energy policy frequently rely on ex-post surveys that ask program participants whether they would have behaved differently in the absence of program support. The present paper proposes an ex-ante approach to the calculation of the free-rider share using revealed preference data on home renovations from Germany's residential sector. We employ a discrete-choice model to simulate the effect of grants on renovation choices, the output from which is used to assess the extent of free-ridership under a contemporary subsidy program. Aside from its simplicity, a key advantage of the approach is that it bestows policymakers with an estimate of free-ridership prior to program implementation.

JEL Classification: C25, D12, Q4

Keywords: Energy efficiency, residential sector, random utility model, discrete choice simulation

March 2009

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1 Introduction

Industrialized countries are increasingly grappling with the implications of heavy reliance on fossil fuels, including environmental pollution and high import dependency (Frondel and Schmidt 2008). In the European Union, the confluence of volatility in oil markets, political instability in energy-exporting regions, and a surge in world-wide energy demand have stoked concerns of future energy supply shortages. Against this backdrop, a key policy question concerns how to reduce the consumption of fossil fuels, with improvements in energy efficiency frequently cited as a promising solution for achieving cost-effective savings (Balint et al. 2007; ECMT 2007).

Households are seen to afford particularly high potential for energy savings, as the residential sector in Europe typically accounts for upwards of 30% of energy end use. In recent years, European governments have implemented several financial support programs to encourage home retrofits and the replacement of inefficient electric appliances. An important question in gauging the merits of such programs is the extent to which they suffer from free-riding. Free ridership occurs if the subsidized household would have undertaken the energy-conserving activity even in the absence of the subsidy (Train 1994). As Wirl (1997, 2000) argues, if the timing of the subsidy is foreseeable, some households who would undertake a retrofit anyway would wait until the subsidy is released. Thus, not only does the net benefit of the program tend to be limited, but the program might actually have adverse effects on energy conservation.

Despite the potential of free-ridership to seriously undermine the economic efficiency of a program intervention, the issue remains largely absent from contemporary environmental and energy policy discussions in Europe.[1] One reason

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[1] A recent document from an expert group on energy policy commissioned by the German government, for example, is completely devoid of references to free-riding, advocating the unconditional extension of €150 cash bonuses for purchases of new energy efficient appliances (PEPP 2008). This disregard also characterizes the economic recovery plans that shall be launched throughout Europe and the U.S.

for this neglect is the inherent difficulty of assessing which households would have undertaken the energy-conserving activity without the program support. Modern evaluation research is of limited help in this regard, as even recently developed non-experimental evaluation methods are typically predicated on the use of appropriate comparison groups comprising program participants and non-participants (Frondel and Schmidt 2005). Given this condition, it follows that the program itself must have been implemented for its evaluation to proceed. The estimation of the free-rider share thus becomes an ex-post exercise, undertaken after the program funding has been allocated.

Building an econometric model of discrete choice, this paper suggests an *ex-ante* procedure for assessing the extent to which free-ridership threatens to undermine the social benefits of energy conservation programs. Using a rich household-level data set from a survey of 2128 owners of German single-family homes, our key question is whether a given financial incentive would alter the retrofit decision of the homeowner or merely boost the household's income. We begin by estimating a discrete choice model to parameterize the effects of energy savings, costs, and household characteristics in determining the likelihood of one of 16 candidate retrofit measures. To gauge the share of free-riders induced by grants programs with a similar design as one that was recently introduced in Germany, we subsequently use the model estimates to simulate retrofit choices under alternative assumptions about the levels of program support in offsetting costs.

The remainder of the paper is outlined as follows. After a brief survey of the literature on free-riding in section 2, section 3 describes the data, discusses the model specification and catalogues the estimation results. Section 4 illustrates a procedure for simulation from which the policy implications are derived. Section 5 concludes.

2 Previous Literature

The paper builds on a handful of earlier studies of household energy consumption behavior. Joskow and Marron (1992) and Eto et al. (1995) conduct a meta-analysis of free ridership by surveying evaluations of demand-side management (DSM) programs conducted by U.S. utilities. With respect to residential programs, the authors uncover a wide range of estimates, varying from zero to up to 50% of free riders. However, most of the reviewed evaluations are based on simple survey questions that ask the respondents whether they would have hypothetically reached the same decision in absence of the DSM program. Due to the nature of these questions, the calculated free rider share may therefore be susceptible to a hypothetical- or response bias.[2]

Malm (1996) circumvents these difficulties by analyzing the revealed choice of high-efficiency heating system purchases among different clusters of consumers. He derives a share of 89% of households that would have bought the efficient equipment even in the absence of a subsidy. Cameron (1985) was among the first to analyze retrofit choices using a nested logit model. She finds that these choices are inelastic with respect to investment cost, and hence awarded grants will not have a sizable effect in enhancing residential energy efficiency.

More recently, Grösche and Vance (2009) develop an error components model to investigate the problem of free-ridership. Abstracting from the possible existence of hidden costs, including transaction costs and emotional stress, they designate potential free-riders as those whose estimated willingness-to-pay (WTP) is higher than the observed investment cost, and find a free-rider share approaching 50%. Drawing on the same data set, the present paper takes a different route for identifying potential free riders. First, the model specification employed is more flexible, allowing for differential effects of household-level socioeconomic variables

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[2] To the extent that program participants feel committed to justify the existence of the DSM program the bias would yield an underestimation of the true free-rider share.

Table 1: Description of the choice set

	Sample Means		Means pertaining to retrofitting households		
	Cost	ΔQ	Households	Cost	ΔQ
No renovation			799		
Roof	12.45	6.68	75	11.02	5.11
Window	6.59	2.86	87	7.03	3.64
Façade	10.90	7.28	20	11.73	9.28
Heating	2.40	3.28	300	2.39	4.00
Roof, Window	19.04	9.53	84	17.54	13.70
Roof, Façade	21.03	13.95	13	19.42	15.62
Roof, Heating	14.85	9.26	81	15.84	11.97
Window, Façade	17.49	10.13	24	18.09	13.87
Window, Heating	8.99	5.86	202	9.32	7.59
Façade, Heating	13.31	9.81	20	14.87	13.24
Roof, Window, Façade	27.62	16.81	37	28.42	23.59
Roof, Window, Heating	21.44	11.83	168	21.80	17.78
Roof, Façade, Heating	23.43	15.79	20	24.76	23.34
Window, Façade, Heating	19.89	12.39	50	18.81	15.90
Roof, Window, Façade, Heating	30.02	18.36	148	32.90	27.31

In total 2128 households from western Germany. Investment cost are measured in 1000€, energy savings (ΔQ) are measured in MWh.

across each retrofit option. Second, by contrasting simulated retrofit probabilities under different hypothetical support schemes to calculate free-ridership, the analysis facilitates a nuanced investigation of how the share of free-riders changes with increases in the program subsidy.

3 Empirical Framework

3.1 Data

The data are drawn from a sample of 2128 single-family home owners from western Germany, surveyed in 2005 as part of the German Residential Energy Consumption Survey.[3] Four different retrofit measures are surveyed: roof insulation, façade insulation, windows replacement, and heating-equipment replacement. These measures and any possible combination, including the option not to undertake a retrofit, form a choice set with $K = 16$ elements from which the household chooses. Table 1 lists the 16 available options along with the number of households that actually chose the option. In total, 63% of the households retrofitted their homes between 1995 and 2004. The table further gives an overview of the average investment costs and energy savings corresponding to each option.

Cost and energy savings were not surveyed but are technical estimates, which are calculated based on the individual characteristics of the homeowner's dwelling. This information was derived for each candidate retrofit measure. Cost are expressed in € while energy savings are expressed in kilowatt-hours, and are computed as the reduction of the building's primary energy demand following a renovation.[4] Comparing the averages for the complete sample and the averages pertaining to the retrofit measures actually chosen shows that the subgroup of retrofitting households consistently exhibit either lower investment cost, higher energy savings, or both. This demonstrates that households take these aspects into account when deciding on a retrofit measure.

3.2 Model Specification

Similar to Grösche and Vance (2009), we choose the conditional logit model as the empirical point of departure, and explore the implications of estimating a more general form of the model by including error components. In the general

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[3] Households located in the former German Democratic Republic are excluded in this paper as there was an extensive wave of publicly supported refurbishment in the 1990s following the country's reunification.

[4] The calculation comprises information of the respective living space, the building's age and the original insulation standard, and draws on regional information concerning material cost and craftsman wages. Further details on the data assembly are provided in Grösche and Vance (2009).

case, the utility U_{ij} of household i for alternative j is defined as:

$$\begin{aligned} U_{ij} &= V_{ij} + \sum_{h\in\{1,2\}} \psi_h \mu_{jh} + \epsilon_{ij} \\ &= \boldsymbol{\alpha}_j' \boldsymbol{z}_i + \beta_1 C_{ij} + \beta_2 \Delta Q_{ij} + \sum_{h\in\{1,2\}} \psi_h \mu_{jh} + \epsilon_{ij}. \qquad (1) \end{aligned}$$

V_{ij} denotes deterministic utility, which is comprised of alternative-specific attributes (costs and energy savings, C and ΔQ) as well as characteristics of the household, contained in the vector $\boldsymbol{z}_i$. The elements of this vector include the household's income, its energy consumption, and its access to information on renovation options, the latter of which is proxied by a measure of the number of certified home auditors within a 20 kilometer radius.[5] As each of these variables is measured at the household level, the identification of this effects necessitates interaction with an alternative-specific variable. For this purpose, we create for each of the 16 retrofit candidates interactions with an indicator vector $\boldsymbol{\alpha}_j'$, including an alternative-specific constant term.

The error structure of the model is comprised of three components. The first is the usual random-utility error term that augments the deterministic utility associated with each alternative. The other two components pertain only to subsets of the alternatives, but apply equally to all alternatives within the subset, thereby imposing a particular correlation structure across the utility of different choice alternatives (Brownstone and Train 1999). Correspondingly, two dummy variables, $\mu_{jh}, h \in \{1,2\}$, capture unobserved variance specific to these two sets of alternatives, respectively. The error components $\psi_h \sim N(0, \sigma^2_{\psi_h})$ are specified as normally distributed random parameters with zero mean. In specifying this correlation structure, the aim was to capture latent effects whose influence

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[5] To derive this measure we drew upon a list of certified home auditors and their addresses published by the German government. We read the data as a map-layer into a Geographical Information System and overlaid this with a layer of household locations. We then created a circular buffer around each household having a radius of 20 kilometers and generated a count of auditors within this buffer. As a final step, we divided this count by the number of homes (excluding apartment complexes) within the buffer. The variable thus created serves to capture the relative availability of expert guidance on retrofits within the vicinity of the household.

could otherwise violate the assumption of independence of irrelevant alternatives implied by the standard conditional logit model. The presented specification incorporates two overlapping error components. As in Cameron's (1985) nested logit analysis, one error component clusters all alternatives that consist of any retrofit activity and thus distinguishes the binary decision concerning whether to retrofit. The second error component groups 13 of the retrofit combinations involving the roof and façade, as these tend to produce annoying levels of dirt and disarray.

Assuming the remaining error terms ϵ_{ij} in equation (1) to be identically and independently distributed as Gumbel (or Type I extreme value), the choice probabilities of the error-component logit model are equal to:

$$P_i(j) = \frac{e^{V_{ij}+\sum_h \psi_h \mu_{hj}}}{\sum\limits_k e^{V_{ik}+\sum_h \psi_h \mu_{hk}}}. \tag{2}$$

If neither of the two latent effects turn out to be relevant, meaning that $\sigma^2_{\psi_1} = \sigma^2_{\psi_2} = 0$, then equation (1) collapses to the conditional logit choice probabilities.

3.3 Coefficient Estimates and Model Fit

Table 2 presents the results of the conditional and the error components logit model. For brevity, the estimated interaction terms are presented in the appendix (table 4), though it is noted here that the sign, magnitude, and significance of most of the coefficients are similar across the two models. This also applies to the coefficients on *Cost* and *Energy Savings* presented in table 2. While the estimates from the error components model are uniformly higher, their relative magnitude is roughly the same.

Regarding the question of model fit, a comparison of the log-likelihoods suggests that the partitioning of the choice set using error components improves performance. The likelihood-ratio-chi-square statistic is 26.2 with two degrees of freedom, implying a statistically significant improvement in fit. Moreover, the

Table 2: Estimation Results of Logit Models

	Conditional Logit		Conditional Logit with Error Components	
	$\hat{\beta}$	s.e.	$\hat{\beta}$	s.e.
Cost (C_{ji})	-0.109^{*}	0.012	-0.155^{*}	0.015
Energy Savings (ΔQ_{ji})	0.193^{*}	0.010	0.277^{*}	0.017
Standard deviation for error components				
Renovation at all			0.007	1.156
Annoying renovation			2.053^{*}	0.349
Log-Likelihood	-4176.4		-4163.3	

*Significant at the 1% level. Detailed results for the alternative specific constants and the interaction effects with the households specific vector $\boldsymbol{z}_i$ are presented in table 4 in the appendix.

standard deviation on “annoying” alternatives is also significant, indicating that the utilities of the respective retrofit alternatives are correlated.

Irrespective of the specification chosen, we clearly see that the cost of the retrofit measure exerts a negative effect on its attractiveness, while the associated energy savings tend to increase the probability that the measure is chosen. The appendix reveals that, if anything, the effect of higher access to information is to raise the likelihood of the most comprehensive retrofit action, while households displaying a higher consumption of energy tend to stay away from this alternative. Household incomes do not seem to be important correlates of the decision, though. In the subsequent simulations, our results will illustrate the effect of subsidized cost on predicted probabilities.

4 Policy Implications

4.1 Simulation Setup

The most recent financial support program of the German government to encourage retrofits allows households to not only apply for loans, but also provides grants for covering renovation expenses. Up to 10% of the investment cost are awarded, reaching a maximum of €5000 per dwelling. The question emerges as to what extent the grants induce renovation activities beyond those that would have otherwise occurred in their absence.

To clarify this issue, we simulate the effect of introducing a grant that effectively reduces the investment cost of the considered retrofit options. For example, a specific household receives a grant of θC_{ij} and has to bear a cost of $(1-\theta)C_{ij}$ on its own. In order to gauge the associated effect on its retrofit decision, we use the fitted model parameters to compute revised probabilities $P_i(j|\theta)$ for each element j in the retrofit choice set. We start with a grant of $\theta = 0\%$ and sequentially increase the quota in steps of 5 percentage points up to $\theta = 50\%$ of investment cost.

In each scenario, the simulated number of sampled households $N_{j|\theta}$ that would choose the respective option j arises due to:

$$N_{j|\theta} = \sum_{i=1}^{I} P_i(j|\theta), \tag{3}$$

where $I = 2128$ denotes the number of sample households.

We calculate the program expenses that accrue in each scenario by multiplying the household-specific grant θC_{ij} for a specific retrofit option with its revised probabilities to choose this option. Summation among the whole choice set and among all households gives the simulated program expenses:

$$Exps(\theta) = \sum_j \sum_i P_i(j|\theta)\ \theta C_{ij}. \tag{4}$$

The energy savings $Sav(\theta)$ – measured as the reduction in annual primary energy demand arising in each scenario – are calculated in a like manner, by multiplying the household- and option-specific energy savings ΔQ_{ij} by the individual revised choice probabilities:

$$Sav(\theta) = \sum_j \sum_i P_i(j|\theta)\ \Delta Q_{ij}. \tag{5}$$

Because equation (5) does not control for the autonomous energy savings that occur even in the absence of grants, $Sav(\theta)$ represents gross energy savings in the specific scenario. Comparing $N_{j|\theta}, Exps(\theta)$ and $Sav(\theta)$ with the situation of zero grants, we can approximate the extent to which a specific grant triggers additional benefit.

4.2 Simulation Results

As we empirically observe the revealed choices of the sampled households in the scenario with zero grants, this scenario can serve as a benchmark for the predictive power of the two logit models. In this regard, we find that the conditional logit model performs better than the error component model. Table 3 gives a detailed summary of the simulation results for the conditional logit model. The *simulated* shares of households $1/I \cdot N_{j|\theta}$ exactly coincides with the *actual* observed shares, depicted in the first column of table 3. By contrast, the simulated shares from the error component logit model deviate slightly from the observed shares.[6] We therefore rely on the simulations performed by the conditional logit model for further analysis , and report the simulation results of the error component model in table 5 in the appendix.

The upper panel of table 3 shows the simulated share $1/I \cdot N_{j|\theta}$ for each retrofit option. It can be seen that the fraction of households declining a retrofit decreases with the introduction of grants: With zero grants, about 38% of the households abstain from renovation; this share decreases to 35% when a grant of 10% of investment cost is awarded. A more generous grant of as much as 50% of the investment cost causes the share of refraining households to decline to 26%. Turning to the retrofit decisions, we observe an apparent shift to more expensive choices with increasing grants. In the absence of financial support,

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[6] For instance, the actual percentage of households foregoing any renovation is 38% instead of 43% that are computed by the error component logit model. As a consequence, the error component logit model simulates autonomous energy savings that underestimate the autonomous savings calculated from the actual observed shares.

Table 3: Simulation Results for the Conditional Logit Model

		Simulated share of households $1/I \cdot N_{j\|\theta}$ *in %, given a grant of* $\theta =$										
	actual	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
No renovation	38	38	36	35	34	33	31	30	29	28	27	26
Roof	4	4	4	4	4	4	4	3	3	3	3	3
Window	4	4	4	4	4	4	4	4	4	4	4	4
Façade	1	1	1	1	1	1	1	1	1	1	1	1
Heating	14	14	14	13	13	12	12	12	11	11	10	10
Roof, Window	4	4	4	4	4	4	5	5	5	5	5	5
Roof, Façade	1	1	1	1	1	1	1	1	1	1	1	1
Roof, Heating	4	4	4	4	4	4	4	4	4	4	4	4
Window, Façade	1	1	1	1	1	1	1	1	1	1	1	2
Window, Heating	9	9	10	10	10	10	10	10	9	9	9	9
Façade, Heating	1	1	1	1	1	1	1	1	1	1	1	1
Roof, Window, Façade	2	2	2	2	2	2	2	3	3	3	3	3
Roof, Window, Heating	8	8	8	9	9	9	10	10	11	11	11	12
Roof, Façade, Heating	1	1	1	1	1	1	1	1	1	1	1	1
Window, Façade, Heating	2	2	2	3	3	3	3	3	3	3	3	4
Roof, Window, Façade, Heating	7	7	8	8	9	10	11	11	12	13	14	15
Gross Energy Savings $Sav(\theta)$, MWh	15704	15704	16395	17087	17775	18458	19134	19801	20458	21103	21736	22356
Net Energy Savings, MWh			692	1383	2072	2755	3431	4097	4754	5399	6033	6653
Program Expenses $Exps(\theta)$, 1000€			998	2088	3273	4554	5930	7403	8972	10638	12402	14263

Results for $I = 2128$ sampled households from western Germany. 1 MWh = 1000 kWh.

the exchange of the heating equipment is the modal retrofit choice. As financial support increases, this option becomes less popular, with the combination of all four retrofits (roof, windows, façade, and the exchange of the heating equipment) emerging as the favored option. The respective share $1/I \cdot N_j$ increases from 7% to 15%.

The lower panel reflects the impacts of the individual choices on the gross and net energy-savings, and on the program expenses. For instance, with zero grants, about 799 households (37.6% of the sample) abstain from renovation, while the remaining 1329 (=2128-799) households retrofit their homes in some way, yielding autonomous energy savings of 15,704 MWh. Raising the grant to 10% of investment cost, 745 households (35.0%) still do not undertake maintenance, while the remaining 1383 households choose one of the 15 retrofit options. The gross energy-savings amount in this scenario to 16,395 MWh. Deducting the autonomous savings yields net energy-savings of 692 MWh. Assuming that each implemented retrofit is financially supported, nearly one million euros are paid as subsidy to the retrofitting households.

The implications of the grants program on expenses and energy savings are summarized in figure 1. The solid line denotes $Sav(\theta)$, and the circle depicts the gross energy-savings of a grant of 10%. The dotted horizontal line renders the autonomous energy savings of 15,704 MWh. The net energy-savings in each scenario is the space between the solid and the dotted horizontal line.

The dashed line in figure 1 depicts the program expenses $Exps(\theta)$ triggering the program net savings. Contrary to the linear development of $Sav(\theta)$, the expenses rise at an increasing, non-linear rate. The explanation for this finding is rooted in the shift away from inexpensive but effective refurbishments towards more expensive retrofit options, together with the increasing popularity of renovation in general.[7]

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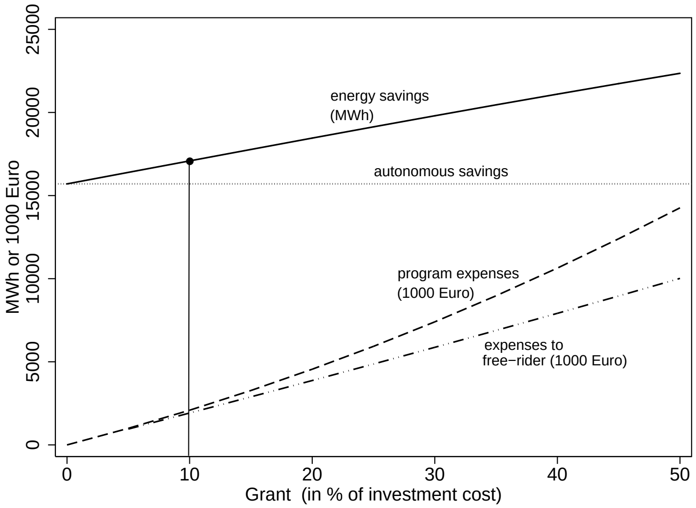
[7] As can bee seen in table 3, an exchange of the heating equipment alone becomes a less frequent choice in favor of additionally renovating the complete building shell. However, table 1

Figure 1: Effects of a Grant Introduction



The disproportionate rise in program expenses relative to the energy savings yield increasing expenses per net saved kWh. Using the figures reported in the last two rows in table 3, we can calculate the "average price" associated with each kWh. For instance, a grant of 10% yields program expenses of €2.088 million, while the net savings amount to 1,383 MWh. Hence, each kWh net savings is worth €1.51. Upgrading the grant to 50% is associated with the average price rising to €2.14 per kWh. This trend stresses that as more of the cost is covered by the grant, more expensive retrofit options are "purchased".

As figure 1 indicates, the autonomous savings are a considerable part of the gross savings, especially with small scaled grants. Consequently, the success of the grants program suffers if a fairly large amount of the program expenses is assigned to households that would undertake a retrofit irrespective of the grants. Given

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reports that on average 3.28 MWh/€2,400 = 1.44 kWh energy savings arise for this option per invested €. On the other hand, retrofitting the complete building shell and the heating equipment yields 18.36 MWh/€30,020 = 0.61 kWh energy savings per invested €.

that the program authority cannot identify such households, there is an incentive to free ride on the grant. While we cannot pinpoint the extent to which such free-riding takes place, we can examine the case in which every retrofit measure receives financial support to glean insights into whether the subsidy program generates *additional* energy savings. The dashed-dotted line in figure 1 provides the extent to which the grants program may suffer from misspent funds. It illustrates the amount of program expenses assigned to free-riders. With a grant of 10%, it almost coincides with the dashed line of program expenses $Exps(\theta)$. In this scenario, not less than 92% of the expenses may be awarded to free-riders. Expanding the program causes this quota to drop, as the program gradually induces net benefits, but even when covering 50% of the investment cost, some 70% of the public disbursements do not induce net energy savings. A sizable grant is thus not a sensible option to address the challenge of free-riding. To the contrary, such an expansion would mean that the public pays a rising price for privately conserved energy. In this regard, the simulation seriously calls into question the efficacy of the program in inducing energy savings that would have already occurred in the program's absence.

5 Conclusions

Free-riding is a problem of outstanding importance for programs that support residential energy conservation. Quantification of free-riding, however, is complicated by the fact that the program authority cannot identify whether a certain household would undertake an energy-conserving activity without program support. Typical evaluation approaches require that the subsidy program itself must have been implemented for its evaluation to proceed, which can generally only occur after the program funding has already been allocated. By contrast, this paper suggests an ex-ante procedure for assessing the extent of free-riding prior to the funding decision.

For a recently implemented grants program in Germany, we investigate the extent to which the program suffers from free-riding. Using a revealed-preference data set of 2128 households from western Germany, we analyze the individual and choice alternative attributes that determine the decision process. Starting with the standard conditional logit model, we augment the model's flexibility by imposing a correlation structure among the utility of the alternatives with the error components logit model. Because of its superior predictive accuracy, the estimates from the conditional logit model are subsequently used to simulate the introduction of grants on the household's retrofit decision.

With respect to the social benefits triggered by the grants program, the results are disillusioning. Under the current program design, the grants lower the investment costs by up to 10%. The simulation shows that the program induces relatively small energy savings beyond the savings that would occur in absence of the grants. However, the program essentially subsidizes each implemented retrofit. This means that in the worst case under which every eligible household behaves rationally and hence applies for the grant, a remarkable share of 92% of the program expenses will be awarded to free-riders. This disclosure is in line with Wirl's (1997, 2000) analytical conclusion, which calls into question the general effectiveness of such programs.

Our findings are of special interest in Europe, given that the European Union's recent Directive on Energy End-Use Efficiency requires that member states introduce political measures to decrease energy end-use by 9%. Our results raise serious scepticism as to whether such political measures can meet the basic expectation that public money is well spent. While energy policy should pay attention to the current challenges of energy supply security and climate protection, the results presented here suggest that policy-makers take heed of free-rider effects in designing public programs to promote energy efficiency in the residential sector.

Data Appendix

Table 4: Detailed Regression Results

		Conditional Logit		Conditional Logit with Error Components	
		$\hat{\beta}$	*s.e.*	$\hat{\beta}$	*s.e.*
Cost (C_{ij})		-0.109^{**}	0.012	-0.155^{**}	0.015
Energy Savings (ΔQ_{ji})		0.193^{**}	0.010	0.277^{**}	0.017
No renovation	Constant	2.246^{**}	0.377	3.140^{**}	0.475
	Income	0.004	0.008	0.002	0.009
	Information Access	-0.028^{**}	0.008	-0.034^{**}	0.011
	Energy Consumption	0.017^{*}	0.008	0.018	0.010
Roof	Constant	-0.094	0.509	0.179	0.568
	Income	0.009	0.012	0.007	0.013
	Information Access	-0.003	0.010	-0.006	0.012
	Energy Consumption	0.005	0.012	0.012	0.014
Window	Constant	-0.039	0.470	0.955	0.528
	Income	-0.009	0.012	-0.011	0.012
	Information Access	-0.025	0.014	-0.032^{*}	0.015
	Energy Consumption	0.036^{**}	0.009	0.037^{**}	0.010
Façade	Constant	-1.803^{*}	0.859	-1.523	1.120
	Income	0.021	0.019	0.018	0.021
	Information Access	-0.046	0.035	-0.051	0.044
	Energy Consumption	0.012	0.019	0.015	0.025
Heating	Constant	0.588	0.397	1.412^{**}	0.472
	Income	0.005	0.009	0.002	0.010
	Information Access	-0.031^{**}	0.010	-0.036^{**}	0.012
	Energy Consumption	0.029^{**}	0.008	0.028^{**}	0.009
Roof, Window	Constant	0.614	0.471	0.965	0.495
	Income	-0.013	0.012	-0.014	0.012
	Information Access	-0.017	0.013	-0.022	0.016
	Energy Consumption	0.011	0.011	0.018	0.011
Roof, Façade	Constant	-1.668	1.023	-1.674	1.404
	Income	0.011	0.024	0.011	0.029
	Information Access	-0.010	0.027	-0.011	0.055
	Energy Consumption	-0.034	0.028	-0.033	0.028
Roof, Heating	Constant	-1.003^{*}	0.473	-0.737	0.472
	Income	0.014	0.011	0.013	0.011
	Information Access	-0.015	0.013	-0.018	0.016
	Energy Consumption	0.026^{**}	0.009	0.030^{**}	0.010

Table 4: Detailed Regression Results

		Conditional Logit		Conditional Logit with Error Components	
		$\hat{\beta}$	*s.e.*	$\hat{\beta}$	*s.e.*
Window, Façade	Constant	-0.354	0.755	-0.023	0.782
	Income	-0.023	0.019	-0.027	0.026
	Information Access	-0.053	0.036	-0.059^{*}	0.029
	Energy Consumption	0.013	0.017	0.017	0.025
Window, Heating	Constant	0.731^{*}	0.362	1.532^{**}	0.415
	Income	0.001	0.008	-0.001	0.008
	Information Access	-0.017^{*}	0.008	-0.022^{**}	0.008
	Energy Consumption	0.019^{*}	0.008	0.020^{*}	0.008
Façade, Heating	Constant	-1.956^{**}	0.408	-1.750^{**}	0.426
	Income	0.001	0.008	-0.001	0.008
	Information Access	-0.017^{*}	0.008	-0.022^{**}	0.008
	Energy Consumption	0.019^{*}	0.008	0.020	0.008
Roof, Window, Façade	Constant	-1.883^{**}	0.365	-1.836^{**}	0.371
	Income	0.001	0.008	-0.001	0.008
	Information Access	-0.017^{*}	0.008	-0.022^{**}	0.008
	Energy Consumption	0.019^{*}	0.008	0.020^{*}	0.008
Roof, Window, Heating	Constant	0.482	0.336	0.920^{**}	0.352
	Income	0.001	0.008	-0.001	0.008
	Information Access	-0.017^{*}	0.008	-0.022^{**}	0.008
	Energy Consumption	0.019^{*}	0.008	0.020^{*}	0.008
Roof, Façade, Heating	Constant	-2.663^{**}	0.396	-2.674^{**}	0.407
	Income	0.001	0.008	-0.001	0.008
	Information Access	-0.017^{*}	0.008	-0.022^{**}	0.008
	Energy Consumption	0.019^{*}	0.008	0.020^{*}	0.008
Window, Façade, Heating	Constant	-0.889^{*}	0.357	-0.622	0.379
	Income	0.001	0.008	-0.001	0.008
	Information Access	-0.017^{*}	0.008	-0.022^{**}	0.008
	Energy Consumption	0.019^{*}	0.008	0.020^{*}	0.008
	Standard deviation for error components				
Renovation at all				0.007	1.156
Annoying renovation				2.053^{**}	0.349
Log-Likelihood		-4176.4		-4163.3	

** Significant at the 1% level. * Significant at the 5% level.

Table 5: Simulation Results for the Error Component Logit Model

		Simulated share of households $1/I \cdot N_{j\|\theta}$ *in %, given a grant of* $\theta =$										
	actual	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
No renovation	38	43	42	40	39	38	37	36	35	33	32	31
Roof	4	3	3	3	3	3	3	3	2	2	2	2
Window	4	4	4	4	4	4	4	4	4	4	4	4
Façade	1	1	1	1	1	1	1	1	1	1	1	1
Heating	14	15	14	14	13	12	12	11	11	10	10	9
Roof, Window	4	3	3	3	3	4	4	4	4	4	4	4
Roof, Façade	1	1	1	1	1	1	1	1	1	1	1	1
Roof, Heating	4	3	3	3	3	3	3	3	3	3	3	3
Window, Façade	1	1	1	1	1	1	1	1	1	1	1	1
Window, Heating	9	10	10	10	10	10	10	10	10	10	10	10
Façade, Heating	1	1	1	1	1	1	1	1	1	1	1	1
Roof, Window, Façade	2	2	2	2	2	2	2	3	3	3	3	3
Roof, Window, Heating	8	6	7	7	8	8	8	9	9	9	10	10
Roof, Façade, Heating	1	1	1	1	1	1	1	1	1	1	1	1
Window, Façade, Heating	2	2	2	2	2	2	2	2	2	3	3	3
Roof, Window, Façade, Heating	7	6	7	8	9	10	11	12	13	14	15	16
Gross Energy Savings $Sav(\theta)$, MWh	15704	14387	15205	16031	16859	17685	18504	19313	20109	20890	21655	22401
Net Energy Savings, MWh			818	1644	2472	3298	4117	4926	5722	6503	7268	8014
Program Expenses $Exps(\theta)$, 1000€			890	1882	2980	4183	5493	6910	8433	10063	11799	13641

Results for $I = 2128$ sampled households from western Germany. 1 MWh = 1000 kWh.

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