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Identifying Free-riding in Home Renovation Programs Using Revealed Preference Data

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Summary

Identifying free-ridership is significant to several issues relevant to program evaluation, including the calculation of net program benefits and assessments of political acceptability. Despite the potential of free-ridership to seriously undermine the economic efficiency of a program intervention, for instance to foster energy efficiency, the issue remains largely absent from contemporary environmental and energy policy discussions in Europe. One reason for this neglect is the inherent difficulty of assessing which households would have undertaken the energy-conservation activity even without the program. This paper proposes a procedure to calculate the free-rider share using revealed preference data on home renovations from Germany's residential sector. We employ a discrete-choice model to analyze the effect of grants on renovation choices, the output from which is used to assess the extent of free-ridership under a subsidy program very akin to an implemented grants program in Germany. Our empirical results suggest only very moderate energy savings induced by the program, making free-riding a problem of outstanding importance.

1 Introduction

Industrialized countries are increasingly grappling with the challenges posed by heavy reliance on fossil fuels, including environmental pollution and high import dependency. Against this backdrop, a key policy question concerns how to reduce the consumption of

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fossil fuels, with improvements in energy efficiency frequently cited as a promising solution for designing programs that maximize social benefits (IEA 2009). Households are seen to afford particularly high potential for energy savings, as the residential sector in industrialized countries typically accounts for upwards of 30 % of energy end use. In recent years, European governments have consequently implemented several financial support programs to encourage home retrofits and the replacement of inefficient electric appliances.¹

In the face of tight budgetary constraints, a fundamental question in gauging the merits of energy efficiency programs is the extent to which free-riding undermines the program's success in yielding the desired energy conservation. Free ridership occurs if the subsidized household would have undertaken the energy-conserving activity even in the absence of the subsidy (Train 1994), implying a selection effect in program participation.

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. Germany's state-owned KfW Foerderbank, for example, currently provides soft loans and investment grants in order to encourage retrofits. It has calculated that about € 5.3 billion in public funds were extended to home owners in 2009, reducing the annual energy demand by 2.6 billion kWh (Clausnitzer et al. 2010) for a cost of € 1.96 for every saved kWh. Such calculations implicitly assume that all energy savings are causally linked to the program, and neglect the incidence of free-riding.

One reason for this neglect is the inherent difficulty of assessing which households would have undertaken the energy-conservation activity even without the financial support. Only a handful of earlier studies tackle this issue by exploring free-ridership in energy-efficiency programs. 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

Loughran and Kulick (2004) circumvent these difficulties by evaluating DSM programs with panel data from U.S. utilities on retail electricity sales. Their results suggest that the program expenditures reduce electricity sales, which is argued to be at least partially due to efficiency enhancements. However, the estimated effect appears to be much lower than that reported by the respective utilities, and Loughran and Kulick (2004) suspect that the utilities generally do not fully control for selection bias. Malm (1996) analyzes the revealed choice of high-efficiency heating system purchases among different clusters

¹ To this end, the EU directive (2006/32/EC) on Energy End-Use Efficiency and Energy Services requires European member states to reduce end-energy consumption by 9 % between 2008 and 2016 (compared to a base period 2001-2006), and stipulates that they initiate policy measures to increase energy efficiency.

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.

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.

Banfi et al. (2008) estimate willingness-to-pay (WTP) for energy-saving measures in residential buildings, using data of stated preferences within a discrete-choice framework. They find that the WTP is typically higher than the associated investment cost. Using the same data set, Farsi (2010) shows that disregard for the possible effects of risk adverse behavior might cause the WTP figures in Banfi et al. (2008) to be underestimated. Taken together, these results call into question the intended purpose of a subsidy program that gives further financial incentives.

A common theme emerging from the above studies is that disregard of free-riding will likely yield an overestimation of the true program success, thereby encouraging the government to pursue potentially unfavorable programs and complicating the task of optimally allocating scarce public resources. The present paper takes up this theme in the context of home renovations by building on the analysis of Grösche and Vance (2009), who develop a discrete choice random-parameter model to investigate the problem of free-ridership using revealed preference data. Derived from the cost- and energy-saving coefficient estimates of the model, Grösche and Vance (2009) designate potential free-riders as those whose estimated marginal WTP for a particular retrofit option is higher than the observed investment cost, and find a free-rider share approaching 50 %.

Drawing on the same data set as Grösche and Vance (2009), the present paper takes a different and considerably more revealing route for identifying potential free riders. First, the model specification employed is improved by allowing for differential effects of household-level socioeconomic variables across each retrofit option. More importantly, rather than relying on the coefficient estimates to derive WTP, we now use the model estimates to generate predicted choice probabilities for each option. This has the advantage of enabling us to study the effects of a grants program on retrofit choice under different assumptions about the size of the subsidy provided by the program. While the approach of Grösche and Vance (2009) estimates the free-rider share only for individual retrofit options, the methodology employed here incorporates the entire set of options, thereby allowing us to explore substitution effects across cheap and expensive retrofits as the amount of the grant changes. We find that as the size of the subsidy increases, households switch to more expensive retrofit options, with the consequence that the share of program funds allocated to free-riders decreases even as the overall cost of the program increases. With a subsidy covering 10 % of the retrofit costs, some 90 % of program expenses are awarded to free-riders; increasing the subsidy to 50 % reduces the free-rider share to 65 %.

The remainder of the paper is outlined as follows. The following Section 2 analyzes the determinants that trigger home-owners retrofit behavior by means of a discrete-choice model. Using the empirical results, Section 3 describes the procedure to gauge the share of free-riders. Section 4 derives the policy implications and concludes.

2 How energy saving prospects and investment cost affect retrofit choice

In order to gain insights into the underlying determinants of retrofit behavior, we draw data 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, 1329 out of 2128 households – 62 % of the sample – retrofitted their homes between 1995 and 2004.

Table 1 further gives an overview of the average investment costs, the energy savings and the ratio of both as a measure of profitability corresponding to each option. While columns 1 to 3 refer to the unconditional means of the whole sample, the last four columns are conditional on those households that actually chose the respective option. Note that cost and energy savings were not surveyed but are exogenously determined technical estimates, which are calculated based on the individual characteristics of the homeowner's dwelling. This information was derived for each candidate retrofit measure. Costs are expressed in 1000 € while energy savings are expressed in megawatt-hours, and are computed as the reduction of the building's primary energy demand following a renovation. The appendix details the data assembly; the calculation comprises information on

Table 1 Description of the choice set

	Means for the entire sample			Means for retrofitting households			
	Cost	ΔQ	$\frac{\Delta Q}{\text{Cost}}$	Households	Cost	ΔQ	$\frac{\Delta Q}{\text{Cost}}$
No renovation	–	–	–	799	–	–	–
Roof	12.45	6.68	0.55	75	11.02	5.11	0.47
Window	6.59	2.86	0.43	87	7.03	3.64	0.52
Façade	10.90	7.28	0.67	20	11.73	9.28	0.80
Heating	2.40	3.28	1.30	300	2.39	4.00	1.69
Roof, Window	19.04	9.53	0.51	84	17.54	13.70	0.78
Roof, Façade	21.03	13.95	0.67	13	19.42	15.61	0.79
Roof, Heating	14.85	9.26	0.61	81	15.84	11.97	0.78
Window, Façade	17.49	10.13	0.58	24	18.09	13.87	0.77
Window, Heating	8.99	5.86	0.64	202	9.32	7.59	0.82
Façade, Heating	13.31	9.81	0.72	20	14.87	13.24	0.88
Roof, Window, Façade	27.62	16.81	0.61	37	28.42	23.59	0.83
Roof, Window, Heating	21.44	11.83	0.55	168	21.80	17.78	0.81
Roof, Façade, Heating	23.43	15.79	0.67	20	24.76	23.34	0.90
Window, Façade, Heating	19.89	12.39	0.61	50	18.81	15.90	0.84
Roof, Window, Façade, Heating	30.02	18.36	0.61	148	32.90	27.31	0.84

In total 2128 households from western Germany. Investment cost expressed in 1000 €, measured in prices of the year 2000. Energy savings (ΔQ) expressed in 1000 kWh (MWh). The ratio $\frac{\Delta Q}{\text{Cost}}$ measures the energy saving in kWh per invested €.

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.

the respective living space, the building's age and the original insulation standard, and draws on regional information concerning material cost and craftsman wages.

Comparing the ratio averages $\frac{\Delta Q}{\text{Cost}}$ for the complete sample and the averages pertaining to the retrofit measures actually chosen shows that the subgroup of retrofitting households consistently exhibit a higher return for every option, with the exception of the roof option. This suggests that households take the profitability aspects into account when deciding on a retrofit measure.

2.1 Model specification

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 an error component. In the general case, the utility U_{ij} of household i for alternative j is defined as:

$$U_{ij} = V_{ij} + \psi\mu_j + \epsilon_{ij} = \alpha'_j z_i + \beta_1 C_{ij} + \beta_2 \Delta Q_{ij} + \psi\mu_j + \epsilon_{ij}. \quad (1)$$

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 z_i . The elements of this vector include the household's annual income (measured in 1000 €), its annual energy consumption (in MWh), 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.⁴ As each of these variables is measured at the household level, the identification of this effect necessitates interaction with an alternative-specific variable. For this purpose, we create for each of the 16 retrofit candidates interactions with an indicator vector α'_j including an alternative-specific constant term.

It bears recognizing that decisions pertaining to a retrofit are at least in part determined by unobserved influences such as improving living comfort, preparing the house for a sale, and signaling to the neighborhood. To the extent that these factors are correlated with the explanatory variables, bias may result. Nevertheless, while it is rarely feasible to completely rule out the possibility of omitted variable bias, we believe that the included explanatory variables afford reasonably broad coverage of the determinants of retrofitting. The alternative specific constants and associated interaction terms, in particular, should capture many of the influences impacting on individual retrofit options that are otherwise difficult to observe directly.

The error structure of the model is comprised of two components. The first is the usual random-utility error term that augments the deterministic utility associated with each alternative. The other component pertains only to a subset of the alternatives, thereby imposing a particular correlation structure across the utility of different choice alternatives (Brownstone/Train 1999). A dummy variable, μ_j , captures unobserved variance specific to the set of alternatives. The error component $\psi \sim N(0, \sigma_\psi^2)$ is specified as normally

⁴ 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.

distributed random parameter with zero mean, and groups 13 of the retrofit combinations involving the roof and façade, as these tend to produce annoying levels of dirt and disarray. In specifying this correlation structure, the aim was to capture latent effects whose influence could otherwise violate the assumption of independence of irrelevant alternatives implied by the standard conditional logit model.

Assuming the remaining error terms ϵ_{ij} in Equation (1) to be identically and independently distributed as Gumbel (or Type I extreme value), and conditioning on a particular value of ψ , the conditional choice probabilities of the error-component logit model are equal to (Brownstone/Train 1999):

$$L_i(j) = \frac{e^{V_{ij} + \psi \mu_j}}{\sum_k e^{V_{ik} + \psi \mu_k}}. \quad (2)$$

Because ψ is typically unknown, the (unconditional) choice probability is given as integral over all possible values of ψ , weighted with its density:

$$P_i(j) = \int L_i(j) f(\psi|\Omega) d\psi, \quad (3)$$

where Ω takes the parameters of the mixing normal distribution. If the latent effect turns out to be irrelevant, meaning that $\sigma_\psi^2 = 0$, then Equation (3) collapses to the conditional logit choice probabilities.

2.2 Coefficient estimates and model fit

Table 2 presents the results of the conditional and the error-component logit model. For brevity, the estimated interaction terms are presented in the appendix (Table A2), 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-component 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 the error component improves model performance. The likelihood-ratio-chi-square statistic is 32.8 with one degree of freedom, implying a statistically significant improvement in fit. The 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 the effect of higher access to information is to raise the likelihood of a retrofit action, while the coefficient estimates for energy consumption typically lack statistical significance. Likewise, household income does not appear to be an important correlate of the decision.⁵

⁵ The insignificance of income could be possibly explained by its high correlation with the household's living space. As the appendix reveals, we used living space together with the number of existing floors in order to calculate the outer surface (façade and roof) of the dwelling. The calculation of the investment cost and the energy savings in turn rest on the building's envelope. Thus, it is possible that the insignificance of income is due to the link of investment cost and energy savings.

Table 2 Estimation Results of Logit Models

	Conditional Logit		Conditional Logit with Error Component	
	$\hat{\beta}$	s. e.	$\hat{\beta}$	s. e.
(C_{ij})	-0.104**	0.012	-0.150**	0.015
Energy Savings (ΔQ_{ij})	0.196**	0.010	0.287**	0.017
Standard deviation for error component				
Annoying renovation	—	—	2.158**	0.348
Log-Likelihood	-4159.9		-4143.5	

** Significant at the 1 % level. Investment cost C_{ij} are measured in €, energy savings ΔQ_{ij} are measured in kWh. Detailed results for the alternative specific constants and the interaction effects with the households specific vector z_i are presented in Table A2 in the appendix.

In the subsequent scenario analysis, our results will illustrate the effect of subsidized cost on predicted probabilities.

3 How financial incentives alter the retrofit choice

The German government provides soft-loans and grant programs in order to encourage home retrofits, extending more than € 5.3 billion to home owners in 2009. Clausnitzer et al.'s (2010) calculated annual energy-savings of some 2.6 billion kWh imply a cost of about € 1.96 per saved kWh. Because the incidence of free-riding is neglected, however, the calculated energy-savings should be regarded as gross savings. The net-savings – the savings that are causally linked to the provided programs – are likely to be below the reported numbers, implying that the „price“ per net-saved kWh will be higher. The question emerges as to *how much* an energy-efficiency program induces renovation activities beyond those that would have otherwise occurred in their absence. To clarify this issue, we calculate in the following the effect of introducing a grant that is provided as share of the respective investment cost and effectively reduces the cost of the considered retrofit options. With θ we denote the portion of investment cost C_{ij} received as grant, and a specific household that receives a grant of θC_{ij} has to bear a cost of $(1 - \theta)C_{ij}$ on its own.

3.1 Scenario setup

We assume rational behavior by the households, meaning households who undertake a retrofit without subsidies would still do the same retrofit measure, or a more expensive one, if they received a cash payment. If the household decides to undertake exactly the same retrofit, we would observe no additional energy savings from this household despite taking the grant. If the household instead decides to advance his renovation activities, the grant causes additional energy savings.

The critical point of our analysis is that we never know for sure as to whether a specific household would free-ride on the grant. In order to gauge the associated effect on its retrofit decision, we use the estimated choice probabilities from the error-component logit model. We modify the respective investment cost to $(1 - \theta)C_{ij}$ and compute revised probabilities $P_i(j|\theta)$ for each element j in the retrofit choice set. This provides insights into how a particular household changes its renovation behavior due the introduction of a grant.

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 predicted number of sampled households $N_{j|\theta}$ that would choose the respective option j is computed as:

$$N_{j|\theta} = \sum_{i=1}^I P_i(j|\theta), \quad (4)$$

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 program expenses for a particular scenario:

$$Exps(\theta) = \sum_j \sum_i P_i(j|\theta) \theta C_{ij}. \quad (5)$$

The energy savings $Sav(\theta)$, which are 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:⁶

$$Sav(\theta) = \sum_j \sum_i P_i(j|\theta) \Delta Q_{ij}. \quad (6)$$

$Sav(\theta)$ represents gross energy savings in the specific scenario. Autonomous energy savings that occur even in the absence of grants can thus be calculated as $Sav(\theta = 0)$. By 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.

3.2 Scenario results

Table 3 gives a detailed summary of the scenario results for the error-component logit model. The upper panel shows the calculated share $1/I \cdot N_{j|\theta}$ for each retrofit option. As we empirically observe the revealed choices of the sampled households in the scenario with zero grants, we also provide the observed shares in the first column of Table 3. A closer inspection of the first two columns reveals that we slightly overestimate the share of households that abstain from renovation, with the consequence that our subsequent analysis overestimate the effectiveness of the subsidy program.⁷

It can be seen that the fraction of households declining a retrofit decreases with the introduction of grants: With zero grants, about 40 % of the households abstain from renovation; this share decreases to 37 % when a grant of 10 % of investment cost is

⁶ We assume the absence of any rebound effect, meaning that the calculated energy savings ΔQ_{ij} , derived from technical estimates, are fully realized and a retrofit does not change the energy consumption behavior of the households.

⁷ For instance, the actual percentage of households foregoing any renovation is 38 % instead of 40 % that are computed by the error-component logit model. As a consequence, the error-component logit model predicts autonomous energy savings that underestimate the autonomous savings calculated from the actual observed shares. For the sake of completeness, we report the simulation results of the conditional logit model in Table A3 in the appendix.

Table 3 Results for the Error-Component Logit Model

	observed	0 %	5 %	10 %	15 %	20 %	25 %	30 %	35 %	40 %	45 %	50 %
Predicted share of households $1/(1 + N_{ij})^\theta$ in %, given a grant of $\theta =$												
No renovation	38 %	40 %	39 %	37 %	36 %	34 %	33 %	32 %	31 %	29 %	28 %	27 %
Roof	4 %	3 %	3 %	3 %	3 %	3 %	3 %	3 %	3 %	3 %	3 %	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 %	13 %	12 %	12 %	11 %	11 %	10 %	10 %
Roof, Window	4 %	3 %	4 %	4 %	4 %	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 %	3 %	3 %	3 %	3 %	3 %	3 %
Roof, Window, Heating	8 %	7 %	8 %	8 %	8 %	9 %	9 %	9 %	10 %	10 %	10 %	11 %
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 %	3 %	3 %	3 %	3 %
Roof, Window, Façade, Heating	7 %	7 %	8 %	9 %	10 %	11 %	12 %	13 %	14 %	15 %	16 %	17 %
Gross Energy Savings $Sav(i)$, MWh	11497	10872	11456	12034	12598	13196	13779	14368	14954	15512	16098	16640
Net Energy Savings, MWh			584	1162	1726	2324	2907	3495	4082	4640	5226	5768
Program Expenses $Exps(i)$, 1000 €			922	1944	3063	4289	5611	7036	8560	10165	11884	13670

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

awarded. A more generous grant of as much as 50 % of the investment cost causes the share of refraining households to decline to 27 %. Turning to the retrofit decisions, we observe an apparent shift to more expensive choices with increasing grants. In the absence of financial support, 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 17 %.

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 852 households (40 % of the sample) abstain from renovation, while the remaining 1276 (=2128-852) households retrofit their homes in some way, yielding autonomous energy savings of 10,872 MWh. Raising the grant to 10 % of investment cost, 792 households (37.2 %) still do not undertake maintenance, while the remaining 1336 households choose one of the 15 retrofit options. The gross energy-savings amount in this scenario to 12,034 MWh. Deducting the autonomous savings yields net energy-savings of 1,162 MWh. These net-savings originate from the two observed substitution patterns between options: some households who initially do not renovate now exhibit some conservation activity, and the program also induces some households to switch to a retrofit with higher energy-savings, for instance if an insulation of the exterior walls is amended by a roof insulation. Last but not least, the last row of Table 3 shows that in the scenario with a grant of 10 %, nearly two million euros are paid as a subsidy to the retrofitting households, assuming that each implemented retrofit is financially supported.

3.3 The effects of free-riding on fund-allocation

The implications of the grants program on expenses and energy savings are summarized in Figure 1. The grant increases along the horizontal axis from 0 % to 50 %, and the vertical axis measures the gross energy-savings $Sav(\theta)$ and the program expenses $Exps(\theta)$. The solid line denotes $Sav(\theta)$ for the scenarios, and the circle depicts the gross energy-savings of a grant of 10 %. The dashed horizontal line renders the autonomous energy savings of 10,872 MWh. The net energy-savings in each scenario is the space between the solid and the dashed horizontal line.

A line starting from the origin of Figure 1 depicts the program expenses $Exps(\theta)$ that trigger 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.⁸

As the figure 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 that the program authority cannot identify such households, there is an incentive to free ride on the grant. While we

⁸ As can be 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 reports that on average $3.28\text{MWh}/2,400 = 1.44 \text{ kWh}$ energy savings arise for this option per invested €. On the other hand, retrofitting the complete building shell and the heating equipment yields $18.36\text{MWh}/30,020 = 0.61 \text{ kWh}$ energy savings per invested €.

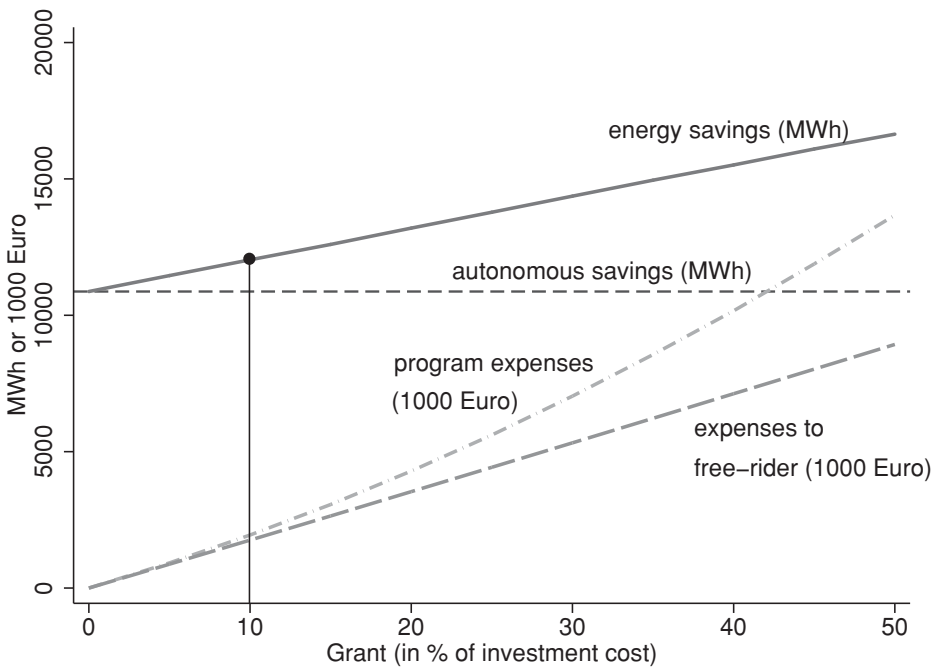


Figure 1 Effects of a Grant Introduction

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 extent to which the grants program may suffer from misspent funds is captured by an accordingly labeled line in Figure 1. It illustrates the amount of program expenses (in 1000 €) assigned to free-riders.⁹ With a grant of 10 %, it almost coincides with the dashed line of program expenses $Exps(\theta)$. In this scenario, some 90 % of the expenses will be awarded to free-riders. This finding should be of little surprise, since a small grant hardly encourages households to implement a costly retrofit, but the grant is attractive for those households who would have undertaken a retrofit anyway. Expanding the program causes the free-rider-quota to drop, as the program gradually induces net benefits, but even when covering 50 % of the investment cost, about 65 % of the public disbursements do not induce net energy savings.

One observation in the scenario analysis is the shift to more expensive options as the financial support rises. Moreover, Table 4 shows that the subsidy per gross-saved kWh rises from € 0.08 to € 0.82 when moving from a 5 % grant onward to 50 %. Households therefore tend to implement retrofits with diminishing energy-savings per invested €, meaning from a social point of view that households realize energy-efficiency investments with descending profitability. This message proceeds if one limits the attention to

⁹ The amount is calculated using the autonomous energy savings (10,872 MWh, Table 3) times the subsidy per gross-saved kWh provided in Table 4. Since the subsidy per kWh increases with rising grant level, the amount of program expenses assigned to free-riders rise, as well.

Table 4 Public expenses per saved kWh

	5 %	10 %	15 %	20 %	25 %	30 %	35 %	40 %	45 %	50 %
€/kWh, gross	0.08	0.16	0.24	0.33	0.41	0.49	0.57	0.66	0.74	0.82
€/kWh, net	1.58	1.67	1.77	1.85	1.93	2.01	2.10	2.19	2.27	2.37

The cell entries are calculated using the scenario results from the last three rows of Table 3.

the energy net-savings but shifts the cost scale upwards: with a 5 % grant the subsidy calculated from net-savings amounts to € 1.58/kWh_{net} and rises to € 2.37/kWh_{net}. In any case, the subsidy per net-saved kWh exceed the respective value for gross-saving by multiple times.

4 Policy implications

Residential energy efficiency is an ongoing issue on the political agenda, not only to contribute to climate protection but also in order to mitigate import dependency from fossil fuels and to countervail the budgetary implications of rising energy prices. As to whether an investment in energy-efficiency is profitable depends on the investment cost relative to the saved energy cost in the future. While the investment cost is an irreversible expenditure, the future energy cost is uncertain, making the investment a risky choice. To the extent that households are risk averse, they might even abstain from a renovation with a positive return. A policy supporting residential energy conservation activities, for instance by providing investment grants, might encourage households – at least at the margin – to take up retrofitting measures.

Of outstanding importance for such a subsidy is that households might behave strategically, and self-select themselves into the subsidy program. Quantification of such free-riding behavior, 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. Against this backdrop, this paper empirically assesses the extent of free-riding in a subsidy program, one very akin to a contemporary grants program in Germany.

Our empirical results suggest, however, that only moderate energy savings occur beyond what would have come along in the program's absence. Because the program essentially subsidizes each implemented retrofit, in the worst case, under which every eligible household behaves rationally and hence applies for the grant, a remarkable share of 90 % of the program expenses will be awarded to free-riders when the grant covers 10 % of retrofit expenses. As the predictions from the econometric model illustrates, this enormous share might be lowered with increasing the grant and thereby inducing more and more households to renovate. However, a sizeable grant is not a sensible option, since such an expansion would mean that the public pays a rising price for privately conserved energy. Our empirical disclosure is in line with Wirl's (1997, 2000) analytical conclusion that households behave strategically with respect to subsidies, and seriously raises doubts about whether programs that subsidize conservation activities are the appropriate instruments to increase the energy efficiency of the building stock on a significant scale.

What are the policy implications of these findings? Among the first candidates that select themselves into the program are typically those households that are most sensitive to the cost of energy consumption. Households for whom the cost of energy is unimportant are

among the last entrants of the program. Unfortunately, the price-insensitive households are precisely those at which the subsidy is targeted. A possible avenue out of this policy dilemma would be to raise the energy price, for example by increasing the energy tax without subsidizing the renovation cost. While a tax essentially conscripts all homeowners into internalizing some of the external cost of fossil fuel consumption, it would mainly affect those households who are least willing to change their energy consumption behavior. As a byproduct, the government would obtain an additional source of tax revenues.

Appendix

Data assembly

Our data is drawn from a sample of 2128 single-family home owners, surveyed in 2005 as part of the German Residential Energy Consumption Survey. The data contain a location identifier for each household, which is measured at the municipal level. The data additionally contain socioeconomic and dwelling characteristics, including whether the household received an energy audit and which retrofit measure was implemented within the last 10 years, if any. Four different retrofit measures (and their combinations) are surveyed: roof insulation, façade insulation, windows replacement, and heating-equipment replacement.

Energy savings

The computation of energy savings are based on engineering relationships and are measured as the decline of the building's annual primary energy demand following a retrofit. We first reconstruct the size of the building shell using computer aided design. This reconstruction, which combines information on the area of living space, the number of stories, and simplifying assumptions concerning the building form, allows us to derive the extent of the heat-transmitting surface and the required heating power. Following the relationships provided by the respective technical standards set by the German Institute for Standardization, the demand for primary energy can be expressed as:

$$Q = (Q_H(H_T) + Q_W) * e_p, \quad (7)$$

where Q is the building's primary energy demand, Q_H is the demand for space heating, and Q_W is the energy demand for hot water, all under standardized conditions. The term $e_p \geq 1$ is the efficiency factor of the heating equipment and converts final energy demand (such as energy for space heating) into primary energy demand. Q_H is determined by dwelling size and the insulation quality of the building's envelope. The better the insulation, the less heat is lost due to transmission through the building's envelope. The total heat loss H_T of a building, measured in Watts per year, is computed as:

$$H_T = \sum_r (U_r + 0.05) * A_r, \quad (8)$$

with A_r describing the surface in m^2 of a certain component r of the building's envelope. The so-called „U-Value“ expresses the heat loss of the component in watts per m^2 , given a difference of 1 Kelvin between indoor and outdoor temperature.¹⁰ The smaller the

¹⁰ Thermal bridges in the component are incorporated by adding 0.05 W per m^2 .

Table A1 U-values and efficiency factors

	Home Constructed Between				Required Standard
	< 1975	1975–1990	1991–2001	2002–2005	
U(Roof)	1.5	0.5	0.4	0.3	0.3
U(Façade)	1.5	1	0.5	0.35	0.35
U(Window)	3.5	3.5	2	1.7	1.3
Efficiency Factor for Heaters	< 1987	1987–2001	2002–2005		Required Standard
e_p (Non-Electric)	1.19	1.11	1.05		1.05
e_p (Electricity)	1.05	1.05	1.05		1.05

Note: U-values are measured in $W/(m^2 \cdot K)$. Source: Ecofys (2004), IWU (1997).

U-Value, the better the insulation, and the smaller the heat loss and the energy demand for space heating.

Roof and façade insulation as well as window replacement alter H_T by lowering the U-Value of a specific component, and hence reduce Q_H and Q . An efficiency improvement of the heating equipment lowers e_p . Thus, energy savings ΔQ are computed as the difference in the building's annual primary energy demand in response to changes in H_T and e_p :

$$\Delta Q = \frac{\partial Q}{\partial Q_H} \frac{\partial Q_H}{\partial H_T} dH_T + \frac{\partial Q}{\partial e_p} de_p. \quad (9)$$

Because we lack data on exact U-values and efficiency factors e_p of the buildings in our sample, we use typically applicable figures by construction year, reported in Table A1.

Cost

Turning to the measurement of costs for each retrofit measure, we use a Geographic Information System (GIS) to calculate a cost-variable that draws on two principle information sources. The first of these is the BKI, or Construction-Cost Information Center of German Architects, which publishes unit-cost figures for various types of retrofit measures based on samples of retrofitted buildings (BKI 2006). Because these figures are national averages that aggregate material and labor costs, we supplement this information with regional wage data for various classes of craftsman obtained from a labor-survey conducted by the FDZ (2006).¹¹

We normalize both average-unit cost and wage data so that they are measured in prices of the year 2000. The final step in calculating investment cost involves constructing the ratio of local wages to the national average, which serves as a regional weighting scheme to be multiplied by the average construction cost from the BKI. This figure is in turn

¹¹ This survey contains average wages for various classes of craftsman, and, as with the household data, is measured at the scale of a municipality, of which there are approximately 13,490 in Germany. For a given craftsman class, there is an average of 200 municipalities from across Germany for which wage data is available. To ensure overlapping coverage with the household data, we use GIS to spatially interpolate wages between the centroids of the represented municipality using an inverse-distance weighted algorithm (Childs 2004). In this way, location-specific wage information from the different craftsman classes can be assigned to each household location in the dataset.

multiplied by an additional weight capturing the share of each craftsman's labor required for a certain retrofit measure. The total cost for one of the 16 retrofit combinations i is given as the sum among the surface A_r of retrofitted components r from household j as follows:

$$C_{ji} = \sum_r \left(\sum_c \zeta_c \frac{\text{local wage}_{jc}}{\text{national aver. wage}_c} \right) * \text{average-unit cost}_r * A_{jr}, \quad (10)$$

with subscript c denoting the category of craftsman and ζ_c representing the share of craftsman c 's labor in the retrofit.¹² While households are denoted by the subscript j , the term „local wage $_{jc}$ “ captures the wage of craftsman c in j 's municipality.

Detailed regression results

Table A2 Detailed Regression Results

		Conditional Logit		Conditional Logit with Error Component	
		$\hat{\beta}$	s. e.	$\hat{\beta}$	s. e.
Cost (C_{ij})		-0.104**	0.012	-0.150**	0.015
Energy Savings (ΔQ_{ij})		0.196**	0.010	0.287**	0.017
Roof ^a	Constant	-2.323**	0.440	-2.660**	0.540
	Income	0.003	0.010	-0.002	0.013
	Information Access	0.027**	0.010	0.036**	0.013
	Energy Consumption	-0.015	0.011	-0.017	0.014
Window	Constant	-2.318**	0.358	-2.224**	0.371
	Income	-0.013	0.009	-0.013	0.010
	Information Access	0.003	0.013	0.002	0.012
	Energy Consumption	0.019**	0.007	0.018**	0.006
Façade ^a	Constant	-4.058**	0.819	-4.412**	1.104
	Income	0.016	0.018	0.010	0.021
	Information Access	-0.018	0.035	-0.011	0.044
	Energy Consumption	-0.007	0.018	-0.014	0.025
Heating	Constant	-1.668**	0.230	-1.753**	0.256
	Income	0.001	0.006	0.000	0.006
	Information Access	-0.003	0.009	-0.002	0.009
	Energy Consumption	0.012*	0.005	0.009	0.006
Roof, Window ^a	Constant	-1.641**	0.416	-1.896**	0.509
	Income	-0.018	0.010	-0.024*	0.012
	Information Access	0.012	0.012	0.021	0.017
	Energy Consumption	-0.008	0.009	-0.012	0.011
Roof, Façade ^a	Constant	-3.907**	1.005	-4.513**	1.408
	Income	0.005	0.023	0.001	0.030
	Information Access	0.020	0.027	0.033	0.056
	Energy Consumption	-0.055*	0.027	-0.067*	0.028
Roof, Heating ^a	Constant	-3.259**	0.407	-3.600**	0.448
	Income	0.008	0.010	0.004	0.011
	Information Access	0.014	0.012	0.024	0.018
	Energy Consumption	0.007	0.008	0.000	0.009

¹² We checked our estimates of the average-unit cost against other published estimates (e.g. Jakob (2006) or Finanztest (2007)) and found the figures to be commensurate.

Table A2 (continued) Detailed Regression Results

		Conditional Logit		Conditional Logit with Error Component	
		$\hat{\beta}$	s. e.	$\hat{\beta}$	s. e.
Window, Façade ^a	Constant	-2.632**	0.723	-2.926**	0.800
	Income	-0.028	0.018	-0.035	0.026
	Information Access	-0.024	0.036	-0.018	0.030
	Energy Consumption	-0.006	0.017	-0.013	0.025
Window, Heating	Constant	-2.116**	0.273	-2.142**	0.311
	Income	0.005	0.006	0.005	0.007
	Information Access	0.006	0.009	0.006	0.009
	Energy Consumption	0.013*	0.005	0.010	0.006
Façade, Heating ^a	Constant	-3.871**	0.816	-4.243**	0.857
	Income	0.006	0.018	-0.001	0.018
	Information Access	-0.045	0.046	-0.038	0.041
	Energy Consumption	-0.007	0.018	-0.016	0.019
Roof, Window, Façade ^a	Constant	-2.520**	0.618	-3.127**	0.777
	Income	-0.017	0.015	-0.021	0.017
	Information Access	0.023	0.016	0.036	0.025
	Energy Consumption	-0.047**	0.016	-0.059**	0.019
Roof, Window, Heating ^a	Constant	-1.481**	0.329	-1.791**	0.416
	Income	-0.012	0.007	-0.017	0.010
	Information Access	0.014	0.009	0.024	0.013
	Energy Consumption	-0.005	0.007	-0.011	0.009
Roof, Façade, Heating ^a	Constant	-4.044**	0.798	-4.678**	1.052
	Income	-0.021	0.020	-0.025	0.023
	Information Access	0.038**	0.014	0.052**	0.018
	Energy Consumption	-0.023	0.019	-0.036	0.025
Window, Façade, Heating ^a	Constant	-3.238**	0.522	-3.589**	0.622
	Income	0.000	0.012	-0.007	0.014
	Information Access	0.012	0.016	0.023	0.017
	Energy Consumption	-0.002	0.011	-0.011	0.014
Roof, Window, Façade, Heating ^a	Constant	-2.290**	0.379	-2.917**	0.482
	Income	-0.006	0.008	-0.010	0.010
	Information Access	0.031**	0.009	0.044**	0.012
	Energy Consumption	-0.022**	0.008	-0.034**	0.011
Standard deviation for error component					
<i>Annoying renovation</i>				2.158**	0.348
Log-Likelihood		-4159.9		-4143.5	

** Significant at the 1 % level. ^aAlternative is part of the subset „annoying renovation“ captured by the error component. Base case: no renovation. Number of observations: 2128. Investment cost C_{ij} are measured in €, energy savings ΔQ_{ij} are measured in kWh. The household specific variables annual income and annual energy consumption are measured in 1000 € and MWh, respectively, while information access captures the number of certified home auditors within a 20 kilometer radius from the household's place of residence.

Table A3 Results for the Conditional Logit Model

	actual	0 %	5 %	10 %	15 %	20 %	25 %	30 %	35 %	40 %	45 %	50 %
Predicted share of households $1/I \cdot N_{j \theta}$ in %, given a grant of $\theta =$												
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(θ), 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(θ), 1000 €			998	2088	3273	4554	5930	7403	8972	10638	12402	14263

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

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