The Alignment Effect of Auditing and its Welfare Implications

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Abstract

Governments use information interventions to help consumers avoid mistakes, typically judging the success of interventions by their effectiveness in changing behavior. We evaluate both the effectiveness and the welfare implications of information provision in the context of a widely used policy tool: energy efficiency audits. In our framed field experiment, participants in the treatment group receive personalized information about the potential cost savings from retrofitting their heating system, while those in the control group do not. Our findings show that average effectiveness is a poor proxy for welfare impacts. Although providing audit information does not increase the average willingness to pay for a retrofit, it improves welfare by aligning households' decisions more closely with their cost savings.

Keywords: Information provision, nudge, welfare, heterogeneity, framed field experiment, energy efficiency.

JEL-code: C93, D83, Q41, Q48

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1 Introduction

Imperfect information and inattention lead to welfare losses in a variety of contexts. A well-known example is the so-called Energy Efficiency Gap (Stavins and Jaffe, 1994; Gerarden et al., 2017), i.e., the observation that households and firms appear to underinvest in energy efficiency. This gap is particularly evident in the residential building sector, where many households choose not to carry out energy efficiency retrofits, even when the resulting private energy cost savings would more than justify the investment. One commonly suggested explanation for this seemingly inefficient behavior is a lack of information about the economic benefits of energy efficiency improvements (Gillingham and Palmer 2014; Allcott and Greenstone 2012).

To address persistently low energy efficiency retrofit rates, governments worldwide have focused on making information more easily accessible to households by, e.g., subsidizing energy efficiency audits. Until recently, policymakers and researchers primarily focused on the impact of these audits on the average increase in energy efficiency retrofits following an audit. However, new insights from economic theory suggest that measuring the average effectiveness of information interventions in changing behavior is an inadequate metric to assess their welfare effects (Allcott et al., 2025). Instead, welfare gains depend crucially on the ability of an intervention to correct distortions in consumer decision-making. Even if an information intervention does not substantially increase overall retrofit rates, it can still improve welfare by encouraging households with high benefits to retrofit more frequently while discouraging those with lower benefits.

In this paper, we explore the impact of information from energy efficiency audits on both the willingness-to-pay (WTP) for energy efficiency and on welfare. We implement a framed field experiment with German household heads, i.e. those family members that make financial decisions at the household-level. We randomly assign participants either to a treatment group that receives personalized information on potential energy savings from a retrofit or to a control group that does not. Households in both the treatment and the control group obtain information about the technical energy efficiency improvements associated with the retrofit. This design feature allows us to isolate households' general bias in the economic assessment of energy efficiency improvements, regardless of possible context-specific misperceptions of specific retrofit options. Beyond identifying the average treatment effect on WTP for the retrofit, our within-subject experimental design serves to estimate the effect of the information intervention on heterogeneous consumer biases and environmental damages from carbon emissions. We then apply a model framework recently developed by Allcott et al. (2025) to quantify the welfare effects of our intervention.

In our experiment, participants express their relative WTP for one of two retrofit options using a multiple price list elicitation format. The first option consists of a simple modernization of the heating system by insulating the water pipes according to current standards. The second option additionally includes an optimization of the hydraulic balancing of the heating systems, which German public agencies endorse as one of the most cost-effective retrofit options. Households obtain a budget of 1500€, which they can spend on either retrofit option. Our elicitation of WTP is incentive-compatible as we randomly draw one of the participants and implement his or her choice after the experiment.

We find that personalized energy efficiency information does not change the average WTP for an energy efficiency retrofit, but improves the alignment between participants' WTP and the economic value of retrofitting. Whereas households that indicated a WTP below the monetary value of the retrofit increase their WTP, we observe a decrease for households that indicated a WTP above it. This alignment effect translates into positive welfare effects of the audit of around 43€ per household. Our findings offer a compelling example for the core insight from Allcott et al. (2025) that the welfare effects of information interventions cannot be inferred solely from their average effectiveness in changing behavior. Instead, they hinge crucially on the heterogeneity in biases and treatment effects.

Our paper is related to several strands of literature. First, we contribute to the literature on the Energy Efficiency Gap, which has emphasized the role of information frictions in discouraging investment (for reviews, see, e.g. Gillingham et al. 2009; Allcott and Greenstone 2012; Gillingham and Palmer 2014; Gerarden et al. 2017). In the context of home energy efficiency, several papers study energy efficiency audits as a means to collect and provide information to housing market participants. While these papers have extensively studied whether energy audits can reduce asymmetric information between the buyers and sellers of homes (Palmer and Walls 2017; Walls et al. 2017; Frondel et al. 2020; Myers et al. 2022; Brolinson et al. 2023), experimental evidence on how audits affect retrofit decisions of homeowners is sparse. One exception is Allcott and Greenstone (2017) who conduct a field experiment in which they subsidize home energy audits to study their effect on the adoption of energy efficiency retrofits. We contribute to this literature by directly randomizing access to personalized information about cost savings to study its effect on the adoption of retrofits and welfare.

Second, our article contributes to the growing literature that evaluates the effectiveness of information interventions. Information interventions have been used to study a vast array of topics in economics (for a recent review, see Haaland et al., 2023). Several studies evaluate information provision as a means to induce the adoption of energy-efficient durable goods (Newell and Siikamäki 2014; Allcott and Taubinsky 2015; Allcott and Sweeney 2017; Allcott and Knittel 2019; Andor et al. 2020; Boogen et al. 2022), providing mixed results regarding the effectiveness of such non-price interventions. Some studies focused on the welfare effect of improving the quality of information (Allcott and Taubinsky, 2015; Davis and Metcalf, 2016; Houde, 2018). We contribute to this literature by exploring the welfare effects of information provision in a high-stakes environment. We show that the provision of information in this setting leads to a rotation of the demand curve for the energy efficiency investment. We also quantify the welfare implications of such an alignment effect and show that welfare gains are sufficiently high to warrant an information intervention, despite the absence of an average treatment effect on the WTP for a retrofit.

Third, our paper contributes to an emerging literature that evaluates the welfare effect of non-price interventions (Allcott and Kessler, 2019; Taubinsky and Rees-Jones, 2017; Allcott et al., 2025). We apply the model framework by Allcott et al. (2025) in the context of home energy efficiency retrofits. Our contribution to this literature is to provide empirical evidence that bias heterogeneity is crucial for judging welfare effects of information in a policy-relevant setting, energy efficiency audits. By controlling for context-specific misperceptions in our experiment, the alignment effect we document is likely to generalize to other settings where interventions aim to inform consumers about the link between product characteristics and outcomes - for example, to improve health, encourage savings, or enhance education.

2 Experimental Design and Data

Our experiment was pre-registered at the AEA RCT registry (AEARCTR-0008150). We give an overview of deviations from the pre-analysis plan in Appendix Table D.1. The data used in this study is publicly available (Frondel et al., 2023a,b).

2.1 Implementation

The experiment is included in a household survey on energy efficiency in residential buildings in Germany in 2021. The household survey is drawn from the forsa.omninet panel and is representative of the German population. Survey questions are answered by household heads, i.e., persons in charge of the financial decisions of the household. The survey consisted of two parts. Participants first answered a pre-survey, which elicited household demographics and detailed characteristics of the home inhabited by the household. The main survey was conducted several weeks later and included the information experiment analyzed in this paper.[1]

In this experiment, participants in the treatment group were provided with information about potential energy cost savings from optimizing their homes heating system. This information was calculated based on the building characteristics elicited in the pre-survey. These calculations are based on a simplified version of the engineering model underlying the German energy performance certificates.[2] The engineering model was used to calculate energy cost savings between either a) isolating all heat distribution pipes in the home according to the current legal standard in Germany (henceforth called basic heating system optimization) or b) conducting the retrofit in a) and additionally a so-called "hydraulic balancing" of the heating system (henceforth called comprehensive heating system optimization). It consists of optimizing the settings of a centralized heating system to fit the calculated heat demand of the building. Since central heating is widespread in Germany, it is endorsed by German consumer protection agencies as one of the most cost-effective retrofit options.[3]

Before the start of the experiment, we explained both the basic and the comprehensive heating system optimization to the participants. We also informed participants about the decision problem they would be confronted with in the experiment. In particular, we informed them that they would be provided with a budget of 1,500 €, which they would be asked to spent either on a) a basic heating system optimization or b) a more comprehensive heating system optimization. They were informed that they would receive the remainder of the budget as an

[1] Details on the information experiment are provided in Appendix C. For the full survey, see BMBF Kopernikus-Projekt ARIADNE (2021), in German.

[2] For details on the engineering model, see Appendix A and Loga et al. (2005). The simplified model was developed as a statistically validated tool to calculate building energy demands based on building characteristics that could be elicited without detailed energy audits of the building, e.g., from survey data.

[3] E.g., see Germany's largest consumer protection agency (Verbraucherzentrale NRW e.V., 2022).

unconditional transfer. All participants were provided with an example for a short multiple price list, which was used to illustrate the financial consequences for the participant in case one of his choices would be drawn in the lottery. Finally, we introduced household heads to the incentivization scheme by informing them that for *one* participant, *one* decision would be drawn. After the experiment, the participant would have the option to implement that decision and conduct the selected retrofit at the price indicated in the survey and receive the remainder of the budget as an unconditional transfer.

The experiment was administered to a subset of all homeowners in the sample (N = 2,023). We only considered home owners with a central heating system, which is the predominant way of heating in Germany. We excluded household heads who were not in charge of decisions about retrofits to the building's heating system. We also excluded participants who lived in houses constructed after 2002, who had undertaken a comprehensive heating system optimization since 2002, and who could not provide core information about the features of their house and heating system needed to calculate energy cost savings. Household heads had the opportunity to opt out of the experiment after receiving this information if they were under no circumstances willing to optimize their heating system. We also excluded 212 household heads who did not report a WTP for the comprehensive retrofit (either after or, in cases where the WTP was elicited twice, before the experimental treatment), which leaves us with 1,811 participants.

2.2 Treatments

Participants were randomly assigned to a treatment group (T) or a control group (C). After explaining both options for heating system optimization, we provided participants in the treatment and control group with an estimate for the total energy savings in kWh per square meter and year for both retrofit options. This information serves to ensure that participants do not misjudge the technical characteristics of both retrofit options.[4] In doing so, we isolate the role of biases in decision-making that stem from consumers imperfect processing of technical information into long-run monetary consequences. This design feature guarantees that our measure of bias is not confounded by context-specific misperceptions - such as limited understanding of the technical details of hydraulic balancing - that would fail to generalize to other settings.

[4] Our design is equivalent to, e.g., Allcott and Taubinsky 2015 who inform participants about the technical characteristics of lightbulbs prior to their information provision experiment.

Participants in the treatment group additionally received a personalized estimate for the annual monetary savings implied by both retrofits (see Appendix C for the full survey text, including the information screens). This estimate translates the energy efficiency improvements into annual energy cost savings. Participants obtained information about the difference in savings between both options over a 10 year period under different energy price scenarios (increasing by 2% per year / constant / decreasing by 2% per year).[5] For participants in the control group, we did not translate the energy efficiency improvement into monetary savings. Instead, they received a placebo text informing them about the constant bi-quarterly number of heating system optimizations in Germany in 2017 - 2019.

For both the treatment and control group, we implement two sub-treatment arms. We randomly allocate participants to either a subgroup (50%) where we elicit their relative WTP for the comprehensive retrofit only after the treatment (denoted by $C1$ and $T1$, respectively) or to another subgroup (50%), in which we elicit their WTP both before and after treatment (denoted by $C2$ and $T2$, respectively). The sub-treatment arms with only one WTP elicitation enable us to test for experimenter demand effects, which may arise when eliciting outcome variables both before and after an intervention.

2.3 Balance and Descriptives

Table 1 displays descriptive statistics for our sample across the four treatment arms of the experiment. We find no evidence that our randomization failed to achieve covariate balance between treatment arms in our experiment.[6]

Our study population consists of homeowners who are in charge of maintaining their home's heating system and live in a home that was built before 2002. These homes are likely to benefit from investments in energy efficiency and form the likely target population of governmental information interventions. Among these homes, 48% were constructed before the implementation of the first federal rules in Germany for building energy efficiency in 1978 (WärmeschutzV, 1977). About 60% of households in our sample heat with gas and about 30% heat with oil. Only 18% had their heating system retrofitted since 2000. Furthermore, only about 15% of households hold an energy performance certificate (EPC) and only 19% of households intend

[5]We refrained from calculating a net present value because participants' discount rates are unobserved and difficult to measure.

[6]Differences in group averages along any covariate of interest are not jointly significant at the 5 %-level (F-test, $df_1 = 3$, $df_2 \in [858, 1807]$).

Table 1: Descriptive statistics and balance between treatment arms

	Sample Characteristics					Germany
	C1	C2	T1	T2	P-value	
Panel A: Household Characteristics						
No. household members	2.4	2.5	2.5	2.4	0.83	2.0
Household net income	4,016.11	3,951.98	4,046.33	4,108.88	0.38	3,490.58
Panel B: Participant Characteristics						
Share females, in %	39	36	39	36	0.60	50
Household head age	59.8	59.6	59.5	60.0	0.93	44.7
Highschool/professional degree, in %	89	88	90	90	0.66	51
Tertiary degree, in %	60	66	67	65	0.13	28
Employed, in %	53	55	57	53	0.71	56
Retired, in %	41	39	38	43	0.31	25
Panel C: Home Characteristics						
Share single-family home, in %	96	95	97	95	0.19	45
Share multi-family home, in %	3	4	2	3	0.22	52
Share holding EPC, in %	14	15	15	13	0.90	.
Space heated, in m^2	149	148	153	152	0.13	94
Share gas boiler, in %	60	56	61	61	0.44	57
Share heat pump or biomass, in %	6	5	7	5	0.51	8
Share district heating, in %	6	5	4	5	0.19	2
Share oil boiler, in %	28	33	28	29	0.65	22
Share build before 1978, in %	48	50	47	48	0.89	60
Stated heating expenditures, in Euro p.a.	1,127.62	1,077.83	1,072.43	1,091.01	0.17	.
Model-based heating expenditures, in Euro p.a.	1,671.19	1,575.23	1,668.95	1,675.00	0.22	.
Panel D: Comprehensive vs. Simple Heating System Optimization						
Savings over 10 years, in Euro	473.15	454.13	479.61	483.66	0.39	.
WTP for retrofit (prior to treatment), in Euro	.	655.17	.	708.77	0.39	.
Emission abatement over 10 years, in kg CO2	2,092	2,062	2,079	2,142	0.78	.
Emission abatement benefits, Euro	475.79	469.01	472.87	487.21	0.78	.
Share heating system optimized since 2000, in%	17	22	19	16	0.08	.
thereof hydraulic balancing, in %	0.00	0.00	0.00	0.00	.	.
thereof pipe insulation, in %	3.13	4.04	4.32	3.73	0.81	.
Share intending to optimize before 2030, in %	19	20	18	19	0.94	.
Number of households	447	445	463	456	.	.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: The p-values are obained from F-tests for the equivalence of the treatment group averages for the corresponding variable. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. *German household and participant characteristics are obtained from the German Federal Statistical Office (2021),"Statistischer Bericht: Mikrozensus - Haushalte und Familien" and "Statistischer Bericht: Gemeinschaftsstatistik zu Einkommen und Lebensbedingungen". German home characteristics are obtained from DENA (2023), "Gebäudereport 2023" and DENA (2024), "Gebäudereport 2024".*

to retrofit their heating system before 2030.

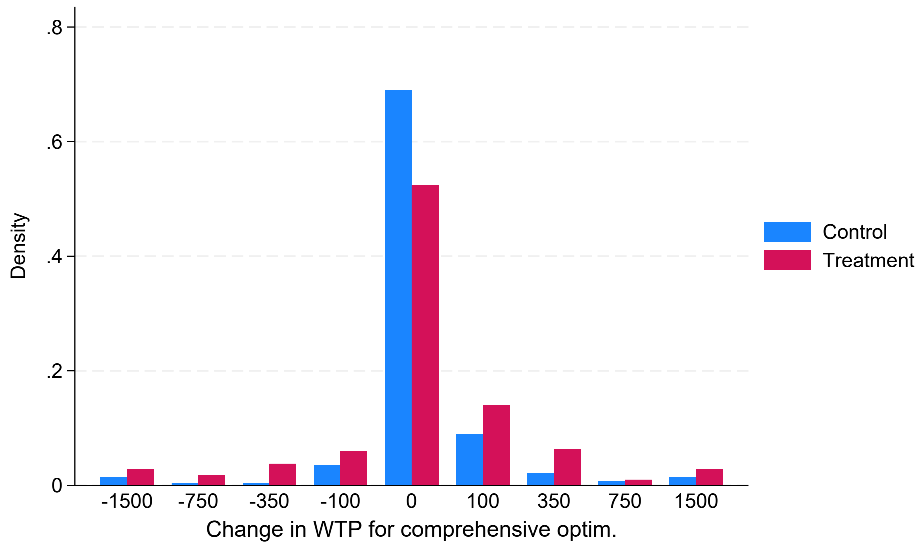
We measure heating cost in two ways. First, based on the detailed elicitation of house characteristics in our survey, we employ an engineering model developed for the German housing stock (Loga et al., 2005). In our experiment, we base our predictions of cost savings from a retrofit on these engineering estimates. Second, for a subgroup of participants, we elicited stated annual heating expenditures in coarse expenditure bins. In line with evidence from weatherization programs in the US (e.g., Fowlie et al. 2018), we find that the engineering estimates of annual heating expenditures exceed stated expenditures on average (1,092 EUR vs. 1,648 EUR per year). To ensure that such differences do not distort the average level of our bias measure, we conduct robustness checks that correct for the difference between both metrics (see section 3.3 for details). For identifying bias heterogeneity, it is particularly relevant that the predicted cost savings uncover relevant features of retrofits that households misperceive. Here, we find that the engineering estimates indeed capture important non-salient drivers of household energy costs that are not incorporated in households' willingness-to-pay for a retrofit.[7]

As shown in Panel D of Table 1, a comprehensive heating system optimization on average leads to predicted energy cost savings of €472 over a period of 10 years, relative to the simple optimization. This value amounts to 4% of the average stated heating expenditures, which is in line with savings typically reported by consumer protection agencies (see e.g. Verbraucherzentrale NRW e.V. 2022). In addition, the comprehensive heating system optimization implies a CO_2 emission abatement of roughly two tonnes compared to the simple heating system optimization. Using a social cost of carbon of $185 US dollars per ton (Rennert et al., 2022), this corresponds to a positive environmental externality of roughly €470. Details about the measurement of externalities and biases are provided in Appendix B.

Reflecting that our study population consists of home owners responsible for heating system decisions, our sample is comprised predominantly of single-family home owners. The corresponding households are larger and wealthier than the average German household and

[7] Appendix Table D.3 shows that engineering predictions of cost savings correlate positively with stated energy costs, whereas participants' baseline WTP for a comprehensive retrofit does not. Hence, the engineering predictions capture some drivers of stated energy costs that are not taken into account by household heads when assessing the benefit of a retrofit option. To identify these drivers, we regress the baseline WTP, the engineering estimate of the cost savings and stated energy costs on a set of household and home characteristics in Appendix Table D.4. We find that easily observable home characteristics, such as the size of the home, or the primary heating fuel, are correlated to all three variables. Characteristics that have a more subtle effect on building energy demand, such as the age of the home and prior wall insulation, are predictors for stated energy expenditures and the engineering estimate, but not for households' WTP for the retrofit.

Figure 1: Change in the relative WTP for a comprehensive optimization



Notes: relative willingness to pay is the difference between the willingness to pay for a basic optimization vs. a more comprehensive optimization of the heating system. Treatment: treatment group T2 (N = 456). Control: control group C2 (N = 445). For these treatment arms, the willingness to pay was elicited both before and after the information treatment.

led by heads that are older and better educated than the population averages in Germany (for a comparison, see last row of Table 1). Hence, the behavioral biases we document for our sample are likely a lower bound for the biases in the German population.

3 Results

In this section, we present reduced-form evidence on the treatment effects, quantify welfare effects, and discuss the identifying assumptions involved in the welfare analysis. Our main analyses are based on the treatment arms $T2$ and $C2$. We use the treatment arms $T1$ and $C1$ for robustness tests to demonstrate that our pre-intervention elicitation of WTP did not affect our estimates (see Appendix Table D.2 for details).[8]

3.1 Reduced-Form Treatment Effects

In Figure 1, we provide first evidence that our treatment influenced participants' WTP. In the control group, 22% of participants adjust their WTP across choices. Since these participants did not receive any material information, changes in WTP represent elicitation noise – that is,

[8]To do so, we adapt the replication codes from Allcott et al. (2022) to our experimental setting.

idiosyncratic changes in WTP across different elicitations. For the treatment group, the share of participants adjusting their WTP is substantially higher (42%).

To identify the average treatment effect (ATE) of the information treatment on the relative WTP for a comprehensive retrofit of the heating system, we estimate the following Difference-in-Differences regression:

$$\Delta Y_i = \beta_0 + \tau T_i + \Delta \epsilon_i, \tag{1}$$

where i denotes a participant, T_i is the treatment indicator, ΔY_i is the difference in WTP between the baseline and endline elicitation, β_0 is a constant, and $\Delta \epsilon_i$ is an error term that captures idiosyncratic variation in participants' responses.

We find that the effect of the information treatment on the WTP for the comprehensive retrofit is not statistically significant at any conventional significance level (column 1 of Table 2). The lack of statistical significance does not reflect low precision in estimating the average treatment effect, but a small effect size. The 95% confidence interval in our main specification in column (1) spans from $+39.7$ to -44.9€, which corresponds to only 0.07 standard deviations of the control group pre-treatment WTP. Appendix Table D.2 shows that our result is robust to alternative specifications including individual-specific covariates as controls instead of a specification in first-differences (columns 2-3), or extending the analysis on the full sample (column 4) that includes participants with only an endline elicitation of WTP.

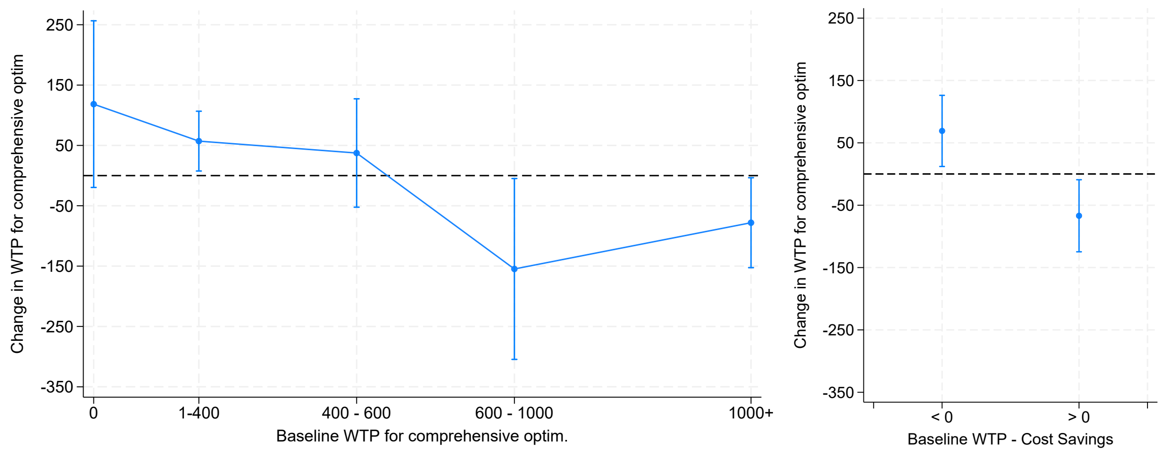
Column (2) of Table 2 presents the results from estimating an augmented version of Equation (1), where we additionally include an interaction effect between the (demeaned) baseline WTP and the treatment variable. We find that the interaction effect is negative and statistically significant at the 1% level. Hence, the information treatment induces a rotation in the demand curve. It reduces the average WTP for participants with an above average baseline WTP and increases the WTP for participants with a below-average baseline WTP (see Appendix Figure D.2 for a depiction of the demand curve).

To explore treatment effect heterogeneity further, we estimate conditional average treatment effects (CATE) for subgroups with different baseline WTP. As shown in panel A of Figure 2, we find a null-effect for the group of households with a WTP between 400 and 600€, which roughly corresponds to the average cost savings over 10 years of around 470€ (Table 1). The conditional average treatment effects for subgroups with a lower WTP are positive, whereas the conditional effects for subgroups with a higher WTP are negative. In Panel B of Figure

Figure 2: Subgroup treatment effects

(a) By baseline WTP

(b) By baseline WTP − cost savings



Notes: Treatment effect estimates on the difference-in-differences between the willingness to pay for the comprehensive and the basic heating system optimization. Panel A: Treatment effects were estimated separately on the subgroups with a baseline relative willingness to pay for the comprehensive retrofit of i) 0 €, ii) between 1 and 400, iii) between 400 and 600, iv) between 600 and 1000, v) more than 1000 €. Panel B: Treatment effects were estimated separately on the subgroups with a positive or a negative bias. Bias is measured as the difference between the relative baseline WTP and the communicated cost savings. 95 % confidence intervals are indicated (using heteroskedasticity-robust standard errors).

2, we estimate the CATE among participants who indicated a higher vs. a lower WTP than the estimated 10-year cost savings from conducting the retrofit. Again, we find that the information treatment increased WTP for those households whose baseline WTP was below the 10 year cost savings and decreased WTP for households with a baseline WTP above that value. Both findings support the conjecture that our intervention corrected a misalignment between participants' WTP for a retrofit and its cost savings.

3.2 Welfare Effects

In this section, we estimate the welfare effects of the energy audits provided in the experiment, following the framework by Allcott et al. (2025). To obtain the parameters needed for the welfare calculations, we estimate the following regression equations:

$$\Delta Y_i = \tau T_i + \beta_1 \hat{\gamma}_i + \beta_2 \hat{\phi}_i + \beta_0 + \Delta\epsilon_i \quad (2)$$

$$\Delta Y_i = \tau T_i + \alpha_1 \hat{\gamma}_i T_i + \alpha_2 \hat{\phi}_i T_i + \beta_1 \hat{\gamma}_i + \beta_2 \hat{\phi}_i + \beta_0 + \Delta\nu_i, \quad (3)$$

Table 2: ATE on the participants willingness to pay for energy efficiency

	(1) OLS (1)	(2) OLS (1)	(3) OLS (2)	(4) OLS (3)	(5) Mixed effects (2)	(6) Mixed effects (3)
Treated	-2.62	3.22	1.86	21.60	1.40	21.60
	(21.57)	(20.60)	(20.76)	(45.02)	(20.73)	(44.89)
Baseline × Treated		-0.22***				
		(0.03)				
Bias × Treated				-0.12***		-0.12***
				(0.04)		(0.03)
Externality × Treated				-0.01		-0.01
				(0.07)		(0.07)
Adjusted R^2	-0.001	0.087	0.087	0.099		
Observations	901	901	901	901	901	901
Bias			✓	✓	✓	✓
Externality			✓	✓	✓	✓

Notes: * p<0.10, ** p<0.05, *** p<0.010. Bias - the difference between baseline willingness to pay and the estimated energy cost savings was included as a control. Externality - the estimated reduction in CO2 emissions from adopting the comprehensive heating system optimization was included as a control. Baseline - the demeaned baseline willingness to pay. Only households in control group 2 and treatment group 2 were included. Standard errors clustered by treatment group in parentheses.

where ΔY_i, T, and $\Delta\epsilon_i$ are defined as in Equation (1) and $\hat{\phi}_i$ reflects environmental externalities in the form of additional CO_2 emissions from choosing the simple instead of the comprehensive retrofit measure. Our measure for consumer bias, $\hat{\gamma}_i$, is given by the difference between their baseline WTP for the retrofit and the (undiscounted) energy cost savings calculated by the engineering model accumulated over a 10 year period under current energy prices.[9] In the framework we use, biases may be measured with error, as long as the measurement error is mean-zero and independent of the actual bias, the externality and the treatment effect (Allcott et al., 2025). We estimate both equations using an ordinary least squares estimator, as well as a linear mixed-effects estimator that treats the treatment effect τ as a random coefficient.[10]

As shown in column (3) of Table 2, we find that the average treatment effect on the willingness to pay for the comprehensive retrofit is not significantly different from zero. The treatment effect is smaller for participants with a higher measure of bias (Column 4 of Table 2). Our esti-

[9] For details on the computation of consumer biases and environmental externalities, see Appendix B.

[10] We identify the mixed-effects versions of (2) and (3) based on one choice per participant. In contrast to Allcott et al. (2025), we thus cannot identify a random intercept $\beta_{0,i}$. However, identification of the random coefficient τ_i is possible, which is essential for capturing treatment effect heterogeneity. It involves the additional assumption that τ_i is independent from elicitation noise, i.e., from changes in the WTP between pre- and post-treatment elicitation in the absence of treatment (captured by $\Delta\epsilon_i$ and $\Delta\nu_i$). In our context, this assumption is mild since the effect of information about future benefits of an intervention is plausibly uncorrelated to random changes in WTP between two subsequent elicitations.

mate of the interaction effect implies that a one Euro increase in the bias decreases the treatment effect on WTP by 12 cents. By contrast, we do not find that the magnitude of the treatment effect differs for homes with different environmental externalities. In column (5) and (6), we display the regression results for the mean effects in the mixed-effects models. The mean effects are almost identical to the effects displayed in column (3) and (4), which suggests that the assumptions on the distribution of treatment effects and the error term implied by the mixed-effects model do not cause systematic bias.

In a next step, we calculate the welfare effect of our information interventions. To do so, we slightly modify the framework by Allcott et al. (2025) to calculate the welfare effect of a nudge in the presence of an arbitrary uniform tax or subsidy (see Appendix E for a derivation). This modification allows us to calculate the welfare effect of the intervention under the current German subsidy scheme for heating optimizations that covers 15% of the cost and amounts to €400 on average (Verbraucherzentrale NRW e.V., 2022). This welfare effect is given by

$$\Delta W(t=t') \approx {}^{1}\!/_{2} \left\{ \underbrace{(\mathbf{E}[\delta] - t' + \mathbf{E}[\tau])^2 - (\mathbf{E}[\delta] - t')^2}_{\text{average distortion effect}} + \underbrace{2Cov[\delta,\tau] + Var[\tau]}_{\text{distortion variance effect}} \right\} D_p, \quad (4)$$

where $\delta = \gamma + \phi$ is the full distortion described by consumer misperceptions and the environmental externality and D_p is the slope of the demand curve.[11] Since the latter is negative, a welfare gain materializes if the sum of average distortion effect and distortion variance effect is negative. The average distortion effect is negative, i.e., welfare-increasing, if the average treatment effect ($\mathbf{E}[\tau]$) and the average uninternalized bias ($\mathbf{E}[\delta] - t'$) have opposing signs. It increases welfare most when the average treatment effect exactly matches the average uninternalized bias. The distortion variance effect is negative if the covariance between the treatment effect and the distortion is sufficiently negative. When the covariance is negative, the intervention counteracts distortions. By contrast, a high variance in treatment effects that is unrelated to biases adds noise to consumer choices and thus reduces welfare.

To calculate the welfare effect based on this formula, we proceed as follows. First, we estimate the average treatment effect using equation (2) and obtain an estimate for the treatment effect variance from the respective mixed-effects specification. We obtain estimates for

[11] To reflect strong competition in the heating optimization market, we assume full pass-through and zero mark-up.

Table 3: Welfare effects

Panel A: Parameter Estimates		
D'_p	Demand slope (share of purchases/(€ /unit)	-0.00208
$\mathbf{E}[\gamma]$	Average bias (€ /unit)	213
		(21.95)
$\mathbf{E}[\phi]$	Average externality (€ /unit)	-478
		(9.13)
$\mathbf{E}[\tau]$	Average treatment effect (€ /unit)	1.86
		(20.76)
$Var[\tau]$	Treatment effect variance ((€ /unit)^2)	71,910
		(23,718)
$Cov[\gamma, \tau]$	Bias and treatment effect covariance ((€ /unit)^2)	-51,059
		(14,602)
$Cov[\phi, \tau]$	Externality and treatment effect covariance ((€ /unit)^2)	-5,260
		(5,286)
Panel B: Total Surplus Effects Under Different Assumptions		
$\Delta W(t = 0)$	Total surplus effect with no tax (€ /unit)	43.29
	special case 1: $\mathbf{E}[\tau] = 0$	42.26
	special case 2: $Cov[\delta, \tau] = Var[\tau] = 0$ (homogeneous)	1.02
	special case 3: $\mathbf{E}[\tau] = Cov[\delta, \tau] = 0$ (pure noise)	-74.62
	special case 4: $Cov[\gamma, \tau] = \mathbf{E}[\gamma] = 0$ (ignore bias)	-61.86
	special case 5: $Cov[\phi, \tau] = \mathbf{E}[\phi] = 0$ (ignore externality)	30.52
$\Delta W(t = t^*)$	Total surplus effect with optimal tax (€ /unit)	42.26
$\Delta W(t =$€ $60)$	Total surplus effect with arbitrary tax (€ /unit)	43.52

Notes: Panel A displays estimates for the parameters going into the welfare estimation. Details on the estimation are outlined in Section 3.2. Panel B displays welfare estimates. $\Delta W(t = 0)$ is calculated using Equation (4), setting the tax $t' = 0$. The following scenarios depart from the same equation, setting additional parameters to zero (as indicated). $\Delta W(t =$€ $60)$ is calculated using Equation (4), setting the tax $t' = 60$. $\Delta W(t = t^*)$ is calculated using Equation (E.4). Standard errors in parentheses.

the covariances between consumer biases or environmental externalities and the treatment effect from coefficients α_1 and α_2 in equation (3). To conduct the welfare calculations, we need additional information on the slope of the demand curve D_p, which we estimate by approximating the slope of the baseline WTP curve between €0 and €100. In our context, we assume the pass-through rate of the tax to be 100% and that markups for firms providing the energy efficiency retrofits are zero, which is consistent with a competitive market for small-scale energy efficiency retrofits.

We summarize the parameters and results of the welfare calculations in Table 3. In the case without corrective taxation (compare equation (E.3) in Appendix E), we find that the information intervention increases welfare per household by €43.3. To disentangle the mechanisms that lead to this welfare effect, we conduct five counterfactual special cases. When we, first, set the ATE to zero, we find that the welfare effect is virtually unchanged, which reflects that our ATE estimate is small. Second, assuming a homogeneous treatment effect across all consumers, the welfare effect of the information intervention reduces to (almost) zero. This case demonstrates that the welfare effects in our case arise exclusively from a reduction in bias heterogeneity. Third, we set both the covariance between distortions and treatment effects and the average treatment effect to zero, which leads to a reduction of welfare by around €75. This finding illustrates that an information treatment that changes consumer decision-making randomly reduces welfare. Fourth, we assume that biases do not exist, but leave externalities in place, which leads to welfare reductions of around €61. By contrast, when we ignore the externality in special case 5, we obtain a positive welfare effect of €31. These findings highlight that the welfare effects in our study are almost exclusively driven by an alignment effect between biases and willingness-to-pay, which is reflected in a high negative correlation between consumer biases and treatment effects.

We next determine the welfare effects when a tax or subsidy exists. If the tax is set optimally (compare equation (E.4) in Appendix E), the welfare effect of the information intervention remains virtually unchanged compared to the case without taxation. This is because even an optimal tax can only counteract the average distortion, which is not the main driver behind the positive welfare effects we estimate. On a related note, when we calculate the welfare effects of our intervention taking current subsidy levels in Germany into account (compare equation (4)), we again estimate almost identical welfare effects.

From a policy perspective, our results demonstrate that even seemingly ineffective interventions may yield sizable welfare improvements when they reduce bias heterogeneity. To put our estimates into perspective, a welfare gain of roughly €43 corresponds to 16% of the average distortion ($\mathbf{E}[\gamma] + \mathbf{E}[\phi]$ in Table 3). Interventions that provide easily scalable audit information are likely cost-effective, given that information on energy cost savings can be provided based on a 15-minute survey and tools that are available online (KfW Bankengruppe, 2025). As a simple back-of-the-envelope calculation, a welfare gain by €43 exceeds the time-cost in terms of forgone wages for the average employee in Germany (earning an hourly wage after taxes of €20.75 (Statistisches Bundesamt, 2025)) by a factor of more than eight.

3.3 Discussion of identifying assumptions and robustness checks

A challenge to the assumption that biases are measured with mean-zero error is that engineering models tend to overestimate the savings of energy efficiency investments (e.g., Fowlie et al. 2018; Christensen et al. 2023). In our setting, the model-based annual heating expenditures exceed the annual heating expenditures stated by the participants by 51% (1,648€ vs. 1,092€ , see Table 1). Such overestimation could imply that the specific savings from heating optimization are overestimated, too.

We find no evidence that this is the case. The average estimated savings from heating optimization correspond closely to numbers communicated by consumer protection agencies. Furthermore, adjusting cost estimates to account for aggregate overestimation does not change our results. We estimate virtually the same welfare effects after rescaling energy uses such that projected and stated energy cost are equal on average (see Appendix Table D.5).[12] This is because measurement error influencing the *average* bias does not meaningfully affect welfare gains from improved *alignment* between WTP and savings.

4 Conclusion

This paper analyzes the effect of information from energy efficiency audits on retrofit rates and on welfare. We do so by exploring data from a framed field experiment with German house-

[12] We refrain from using stated heating expenditures at the individual level in our welfare analyses for two reasons: First, we observe this variable for only half of our respondents and many respondents are only poorly informed about their heating cost. Second, stated expenditures are elicited in bins, which introduces additional measurement error when using this variable at the individual level.

holds concerning retrofits of heating systems. In line with recent advances in economic theory (Allcott et al., 2025), our evidence provides a striking example for the insight that an average treatment effect of an information intervention is a poor metric for its welfare implications. In our setting, translating technical energy efficiency information into the likely monetary gains does not change the average WTP for energy efficiency. However, it aligns participants' WTP to the economic value of the retrofit. This alignment effect translates into positive welfare effects of the audit of around 43€ per household.

Our results provide evidence that information interventions, which assist consumers in translating technical information into monetary metrics relevant to decisions, are important to improve decision quality. Neglecting their alignment effect implies that even highly cost-effective policy interventions will not be considered to improve welfare and will therefore not be implemented. From a methodological perspective, our study demonstrates that evaluations of information interventions require quantifying bias and treatment effect heterogeneity to produce reliable welfare estimates. Our findings suggest that carefully quantifying these metrics may similarly change the welfare assessment of consumer protection interventions in various settings, including nutrition, education, and durable good investment.

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Online Appendix

A Engineering Model

We calculate participants' final energy demand on the basis of an engineering model calibrated for Germany, the "Kurzverfahren Energieprofil" (Loga et al., 2005). The final energy demand indicates how much energy is required to heat, supply hot water, ventilate and cool the building. It is an important parameter for the energy efficiency of a residential building and is also used in the EU Energy Performance Certificate, for instance.

The final energy demand is calculated on the basis of a multitude of building characteristics (e.g. wall structure, window glazing, insulation), the installed system technology (e.g., the heating technology), and climate parameters. The calculation procedure consists of the three parts: First, estimating the volume of the house based on its shape and floor space, second, the calculation of heat transfer coefficients (U-values), and, third, the calculation of the flat-rate values of the system technology. Core parameters for these calculations are based on the Energy Saving Ordinance (EnEV) from 2002. The outcomes of the calculation are the final energy demand in kWh/m^{2}a, the predicted energy costs in €/a and the energy standard of the building in W/(m^{2}K).

B Consumer Bias and Environmental Externalities

Based on the engineering model outlined in Appendix Section A, we calculate the energy demand of a building after a simple heating system optimization ($W_i = S$) or a comprehensive heating system optimization ($W_i = K$). Since we know the fuel types used by household i for heating, we also calculate the associated CO_2 emissions $E_i(W_i)$ and energy cost in Euro $C_i(W_i)$ per year, given assumptions about the unit price and CO_2 emissions per unit of energy used.[13]

Based on additional parameter assumptions summarized in Table B.1, we can use these inputs to measure consumer biases in the decision to adopt the comprehensive heating system optimization $\hat{\gamma}_i$, as well as the associated environmental externalities $\hat{\phi}_i$. The energy cost savings communicated in the experiment were accumulated over a period of 10 years. For consistency with the information treatment provided in the experiment, we calculate both consumer

[13] A full list of parameters for the engineering model can be found in (Loga et al., 2005).

biases and the environmental externality, taking into account energy savings over a period of 10 years. We assume a typical life span of 10 years since a heating system optimization is beneficial only until other major retrofits are undertaken, which again require a re-optimization of the heating system.

Table B.1: CO_2 Emission Factors and Energy Prices

Variable	Value	Source
Social Cost of Carbon	\$185 US dollars	following Rennert et al. (2022)
Life span of heating system optimization	10 years	By assumption
Discount rate	0%	By assumption
Energy price changes	constant over 10 years	By assumption
Exchange rate	1.2296 Euro/Dollar	European Central Bank (2021), January 4, 2021 reference rate

Consumer biases are calculated as the difference between the implied energy cost savings over a ten-year period and the participant's relative WTP for the comprehensive heating system optimization:

$$\hat{\gamma}_i = Y_i^{pre} - (\omega\,(C_i(S) - C_i(K))) \tag{B.1}$$

where Y_i^{pre} is household i's relative WTP for the comprehensive retrofit prior to treatment, $\omega = 10$ is the factor to accumulate the annual energy cost savings, assuming that energy prices remain constant (in real terms) over a period of 10 years.[14]

The environmental externality is calculated as the CO_2 emissions abated over a ten-year period, valued at a social cost of carbon of $SCC = \$185$ US-dollars per ton of CO_2 emitted, following Rennert et al. (2022), converted to Euros using an exchange rate of 1.2296 Euros per Dollar (observed on January 4, 2021 European Central Bank, 2021). This implies that the environmental externality, i.e., the environmental benefit from choosing the comprehensive energy efficiency retrofit is calculated as follows:

$$\hat{\phi}_i = 10\,(E_i(S) - E_i(K)) \times \text{SCC} \times 1.2296 \tag{B.2}$$

[14]Since individual discount rates are difficult to measure, we refrain from discounting future energy costs.

C Survey Questions

The experiment studied in this paper is part of the first wave of the Heating and Housing Panel of the BMBF Kopernikus Project ARIADNE (Wärme- und Wohnen-Panel, BMBF Kopernikus-Projekt ARIADNE), which is a household survey on energy efficiency in residential buildings in Germany in 2021. In this section, we provide the catalog of survey questions used in the experiment. The experiment was contained in the third module of the questionnaire. To calculate the CO_2 emission reductions and energy cost savings associated with the energy efficiency retrofit studied in the experiment, inputs from the first module of the questionnaire are needed. This module contained questions about household demographics and building characteristics. It follows closely the simplified engineering model described in Appendix A. For the sake of brevity, we thus do not include these survey questions in the appendix of this paper. The interested reader can find the full questionnaire in BMBF Kopernikus-Projekt ARIADNE (2021).

ExpSan_1 Introduction to Heating System Optimization

This part of the survey is about your interest in optimizing your heating system. During a heating system optimization, a professional insulates the heating pipes in your home, calculates the heating energy demand for each of your rooms, and adjusts the radiators accordingly. The optimization has no effect on the lifespan of your radiators or heating system. It does not require major renovations and can usually be completed in one working day.

ExpSan_2 Introduction to the Procedure I

You now have the opportunity to choose between two types of heating system optimization:

- **Simple heating system optimization:** A professional company insulates your heating pipes according to current insulation standards. This heating system optimization takes about 12 hours.
- **Comprehensive heating system optimization:** A professional company insulates your heating pipes according to current insulation standards. In addition, the company calculates the heating demand of your rooms and optimally adjusts your radiators. This heating system optimization takes about 78 hours.

ExpSan_3 Introduction to the Procedure II

You receive a budget of €1500 to commission either a simple or a comprehensive heating system optimization. **Your decision can have real consequences.** One randomly selected participant will actually receive the budget and be able to use it to commission a heating system optimization. For this participant, the chosen heating system optimization will be implemented by a specialized company. In addition, the participant will receive that part of the budget as a payout that exceeds the price of the chosen heating system optimization .

The lottery draw will take place in the coming weeks. You will be notified if you have been selected at random. **The specialist company will be selected in consultation with you.** Please consider your decisions on the following pages carefully, as it may have real consequences for you.

ebewertung_1 If you are not considering optimizing your heating system under any circumstances, please click on the following box. You will then not take part in the draw. This will not affect the duration of the survey. To take part in the draw, please simply click continue.

[Checkbox] Under no circumstances will I consider optimizing my heating system and forgo the opportunity to receive a budget of EUR 1500, which I can use for a heating system optimization, among other things.

ExpSan_4 Presentation of the Energy Savings Potential

We will now inform you about the improvement in your energy requirements that can be achieved through a simple or comprehensive heating system optimization in your home. The calculations take into account the information you have provided on the properties of your house. They are based on a method that is prescribed, among other things, for the issue of energy performance certificates. *[Info button: As a simplified method is used, the values may differ slightly from the values stated on energy performance certificates].*

The calculated savings also take into account what type of heating system optimization you may have already carried out. The savings are given in kilowatt hours of heating energy per heated living space per year (kWh/m2 *a).

[Option A and Option B are determined randomly. This means that some participants are randomly shown the simple optimization as option A, while others are shown the comprehensive optimization as option A. Option B is then accordingly the comprehensive optimization in the first case and the simple optimization in the second case. The information on which option is displayed as option A should be saved]

	Option A: Simple Heating System Optimization	Option B: Comprehensive Heating System Optimization
Annual energy demand	*[energy demand status quo]* kWh/m2*a	*[energy demand status quo]* kWh/m2*a
Annual energy demand after optimization	*[energy demand after simple optimization]* kWh/m2*a	*[energy demand after comprehensive optimization]* kWh/m2*a
Energy saved:	*[energy demand status quo after simple optimization]* kWh/m2*a	*[energy demand status quo after comprehensive optimization]* kWh/m2*a

ExpSan_5 Explanatory note

We present you with 15 choices between these two heating system optimizations, where only the price of the comprehensive heating system optimization differs. Please select in each of the 15 lines which heating system optimization you prefer for at the given prices. The decisions are about the influence of the prices you have to pay on your choice between the two heating system optimizations. The fact that the price for a comprehensive heating system optimization differs may be due, for example, to different subsidies or taxes. However, you can be sure that the quality of the heating system optimization does not differ and that it is always carried out by a specialist company. If you are drawn by lot, you will receive the heating system optimization you have selected in a line at the specified price. Which line this is will be determined at random. You will also receive your remaining budget (1500 euros minus the respective price of the heating system optimization) by bank transfer. As each line can be selected, you should carefully consider your decision in each line.

For a better understanding, we will now show you an example.

A section of the table in which you will enter your decisions will look like the following depiction.

You only make your decisions on the next page. You cannot select any options in this table. *[Display the options as option A or B as described above]*

Option A: Simple heating system optimization (savings = *[final energy demand now - final energy demand after simple optimization kWh/m2*a]*)

Option B: Comprehensive heating system optimization (savings = *[final energy demand now - final energy demand after comprehensive optimization kWh/m2*a]*)

Decision	Option A: Simple (€ 300)	Option B: Comprehensive (varies)
7	€ 300	€ 500
8	€ 300	€ 550
9	€ 300	€ 600

Each row in the table contains a decision to be made. **For each decision**, select either option A or option B.

Now assume, for example, that you have been drawn by lottery and line 8 has been randomly determined.

- If you have chosen option B in line 8, you will receive the comprehensive heating system optimization at a price of 550 euros. We will also transfer your remaining budget of EUR 1500-550 = EUR 950.
- If you have selected option A in line 8, you will receive the simple heating system optimization at a price of EUR 300. In addition, we will transfer your remaining budget of 1500-300 = 1200 EUR.

ExpSan_6_C2_T2 Decisions Round I

[Display only for groups C2 and T2]

We now show you 15 decisions between a simple and a comprehensive heating system optimization. The choices differ only in the price you have to pay for comprehensive heating system optimization. For all 15 lines, please select the heating system optimization that you prefer for the corresponding prices:
[Info button: Reminder: You will receive a budget of 1,500 euros for your decision. In the case of simple heating system optimization, the optimization of your heating system will be carried out at a price of 300 euros and your remaining budget of 1,200 euros will be transferred to you. In the case of a comprehensive heating system optimization, the optimization of your heating system will be carried out at the price indicated in the respective line and your remaining budget will be transferred to you. One participant drawn at random will actually receive this budget. However, your decision has no influence on the draw.]

[Presentation of the options as option A or B as described above.]

Option A: Simple heating system optimization (savings = *[final energy demand now - final energy demand after simple optimization kWh/m2*a]*)

Option B: Comprehensive heating system optimization (savings = *[final energy demand now - final energy demand after comprehensive optimization kWh/m2*a]*)

[Answer options: For each decision situation there are two possible answers (boxes): one for Choose A and another for Choose B]

Decision	Option A: Simple (€ 300)	Option B: Comprehensive (varies)
1	€ 300	€ 300
2	€ 300	€ 350
3	€ 300	€ 400
4	€ 300	€ 450
5	€ 300	€ 500
6	€ 300	€ 550
7	€ 300	€ 600
8	€ 300	€ 650
9	€ 300	€ 700
10	€ 300	€ 750
11	€ 300	€ 800
12	€ 300	€ 900
13	€ 300	€ 1000
14	€ 300	€ 1200
15	€ 300	€ 1500

ExpSan_7_T1_T2 Additional Information for the Treatment Group

[Display only for groups T1 and T2]

We would like to provide you with additional information about cost savings:

	Option A: Simple Heating System Optimization	Option B: Comprehensive Heating System Optimization
Annual energy savings for your flat:	*[Display result: floor area Œ (energy demand before - after simple optimization)]* kWh	*[Display result: floor area x (energy demand before after simple optimization)]* kWh
Annual energy cost savings:	*[Display result: heating cost before after simple optimization]* EUR	*[Display result: heating cost before after simple optimization]* EUR

The comprehensive heating system optimization therefore results in annual cost savings that are *[costs now - costs after comprehensive refurbishment) - (costs now - costs after simple refurbishment) = cost difference in EUR]* higher for you than under the simple heating system optimization.

Over the course of 10 years, the cost advantage of comprehensive heating system optimization compared to simple heating system optimization

- adds up to *[Cost savings*10]* EUR with constant energy prices
- adds up to *[Cost savings*1.02*((1-1.02**10) / (1-1.02))]* EUR with energy prices increasing by 2% annually
- adds up to *[Cost savings*0.98*((1-0.98**10) / (1-0.98))]* EUR with energy prices falling by 2% annually

ExpSan_7_C1_C2 Screen for control group

[For group C1a and C2 (group C1b sees neither screen for control group nor for treatment group)]

We would now like to provide you with further information on the frequency with which heating system optimizations are carried out over time. In Germany, the implementation of heating system optimizations has been at a constant level for years.

- In the 1st half of 2017, 69,720 optimizations were carried out.
- In the 2nd half of 2017, 79,789 optimizations took place.
- In the 1st half of 2018, 71,248 optimizations took place.
- 77,987 optimizations took place in the 2nd half of 2018.
- In the 1st half of 2019, 67,744 optimizations took place.

[Info: Source: Wuppertal Institut für Klima, Umwelt, Energie gGmbH/ Arepo Gmbh (2017).]

ExpSan_8_C2_T2 Decisions Round II

[For group C2 and T2]

You now have the opportunity to make your decisions again and adjust them if necessary. We will again show you 15 choices between a simple and a comprehensive heating system optimization. For all 15 lines, please select the heating system optimization that you prefer for the corresponding prices.

[Display the options as option A or B as described above.]

Option A: Simple heating system optimization (savings = *[final energy demand now - final energy demand after simple optimization kWh/m2*a]*)

Option B: Comprehensive heating system optimization (savings = *[final energy demand now - final energy demand after comprehensive optimization kWh/m2*a]*)

[Info button: Reminder: If you are drawn, your budget is 1500 EUR, which you can spend on a of the options. The remaining part of the budget will be paid out to you]

[Possible answers: For each decision situation, there are two possible answers (boxes): one for Choose A and another for Choose B]

- **Choose A for 300** OR **Choose B for 3001500** *[same price sequence as ExpSan_7_C2_T2]*

ExpSan_8_C1_T1 Decisions Round II

[For group C1 and T1]

You now have the opportunity to make your decisions. We will show you decisions between simple and comprehensive heating system optimization, which differ only in price. For each of the 15 lines, please select the heating system optimization that you prefer for the corresponding prices. the corresponding prices.

[Display the options as option A or B as described above.]

Option A: Simple heating system optimization (savings = *[final energy demand now - final energy demand after simple optimization kWh/m2*a]*)

Option B: Comprehensive heating system optimization (savings = *[final energy demand now - final energy demand after comprehensive optimization kWh/m2*a]*)

[Info button: Reminder: If you are drawn, your budget is 1500 EUR, which you can spend on a of the options. The remaining part of the budget will be paid out to you]

[Possible answers: For each decision situation, there are two possible answers (boxes): one for Choose A and another for Choose B]

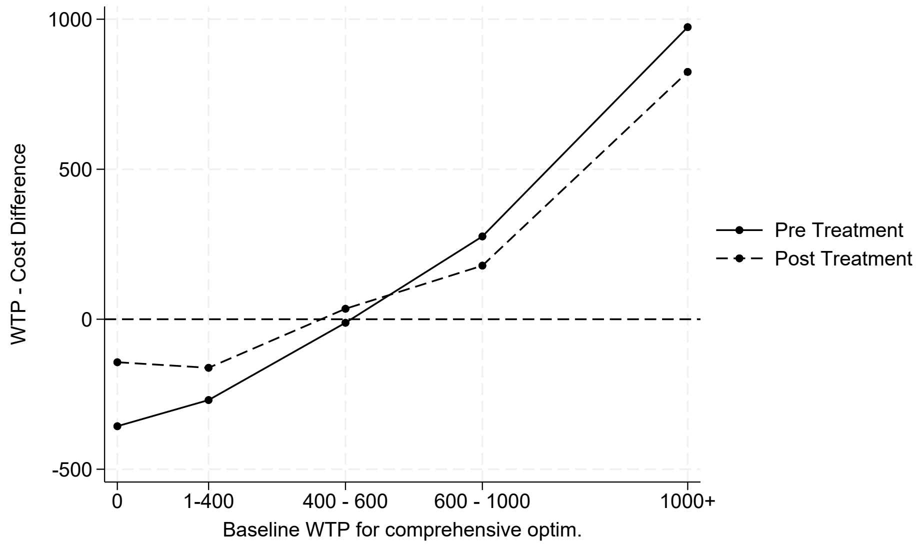
- **Choose A for 300** OR **Choose B for 3001500** *[same price sequence as Exp-San_7_C2_T2]*

D Additional Tables and Graphs

Table D.1: Summary of Deviations from the Pre-Analysis Plan

Category	Original Plan	Actual Implementation	Rationale for Deviation
Intervention	Filter out participants who optimized their heating system since 2000.	This filter did not apply due to an error. Households who did a comprehensive heating system optimization are not included, but households who did other heating system optimizations are included in the experiment.	Error in the implementation. This error changes the definition of our study population slightly.
Sample size	Planned number of clusters (observations): 4000.	Final sample size, number of clusters (observations): 1811.	Since participants' choice was consequential, they could opt out from the survey. Most of the participants' who opted out stated to be not responsible for conducting a retrofit. The lower sample size thus reflects a lower than anticipated percentage of respondents who are actually responsible for making retrofit choices (our target population).
Experimental design	Implement an additional control group without a control group screen. To test whether the control group information had a treatment effect itself.	The additional control group was not implemented.	Not feasible, given the smaller than anticipated sample size.
Outcome variable	Translate relative WTP for the comprehensive retrofit into a WTP per unit of energy efficiency improvement	We decided to leave WTP unchanged.	Ensures consistency with the framework by Allcott et al. (2025).

Figure D.1: Biased beliefs by baseline WTP, treatment group T2



Notes: points indicate the average difference (bias) between the relative willingness to pay for a comprehensive retrofit and the estimated energy cost savings. Pre-treatment indicates the baseline bias, post-treatment indicates the "bias" after the information treatment. Only treatment group T2 is included.

Table D.2: ATE on the participants willingness to pay for energy efficiency

	Δ WTP	WTP (post)		
	(1)	(2)	(3)	(4)
Treatment	-2.622	1.831	46.156	2.111
	(21.570)	(20.644)	(40.365)	(28.668)
Baseline WTP		0.898^{***}		
		(0.022)		
Treatment × Baseline		-0.122^{***}		
		(0.037)		
Constant	15.506	696.303^{***}	692.729^{***}	879.298^{***}
	(11.927)	(55.765)	(141.329)	(106.971)
Adjusted R^2	-0.001	0.741	0.015	0.012
Observations	901	901	901	1811
DiD	✓	✓		
Interaction		✓		
Covariates		✓	✓	✓
With Baseline Elic.	✓	✓	✓	

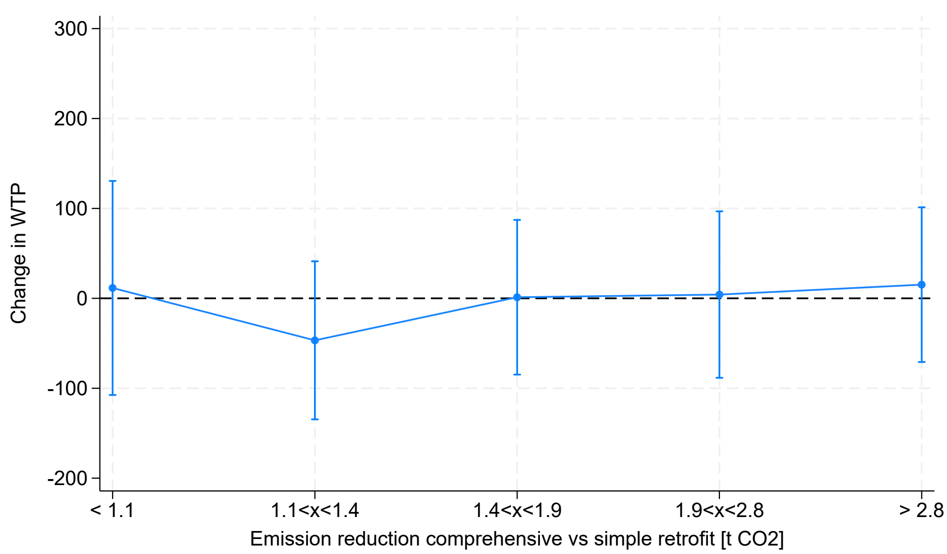
Notes: Significance markers * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Heteroskedasticity-robust standard errors in parentheses. DID - treatment coefficient indicates the difference in first-differences instead of a difference in mean willingness to pay. Interaction - the treatment coefficient was interacted with the demeaned baseline willingness to pay. Covariates - the following covariates were included in the regression: household size, female household head dummy, dummy whether the household plans further retrofits until 2030, the energy demand of the building as estimated by the household head, household head education (high school or professional degree dummy, tertiary education dummy), net household income, household head employment dummy, household head retired dummy. In models 1 - 3, only households in control group 2 and treatment group 2 were included. In model 4, all households who were able to conduct the relevant retrofit were included.

Table D.3: Pairwise Correlations Between Baseline Energy Cost Estimates

	(1)	(2)	(3)
	Baseline WTP	Engineering Estimate	Stated Expenditures
Baseline WTP, in Euro	1.00 p = .		
Engineering Estimate, in Euro	0.06*** p = 0.06	1.00 p = .	
Savings based on stated expenditures, in Euro	–0.01 p = 0.86	0.16*** p = 0.00	1.00 p = .

Notes: Pairwise Pearson correlation coefficients. Baseline WTP is the WTP for the comprehensive retrofit relative to pipe insulation alone. Engineering Estimate is the relative cost savings, according to the engineering model. (Savings based on) stated expenditures is an estimate for the energy cost savings of a househould (4% of stated annual energy expenditures). P-values (using STATA's *pwcorr* command) of a t-test for a significant difference of the correlation coefficient from zero are indicated. A */**/*** next to coefficient indicates significance at the 10/5/1% level.

Figure D.3: Subgroup treatment effects with different projected CO2 emissions savings



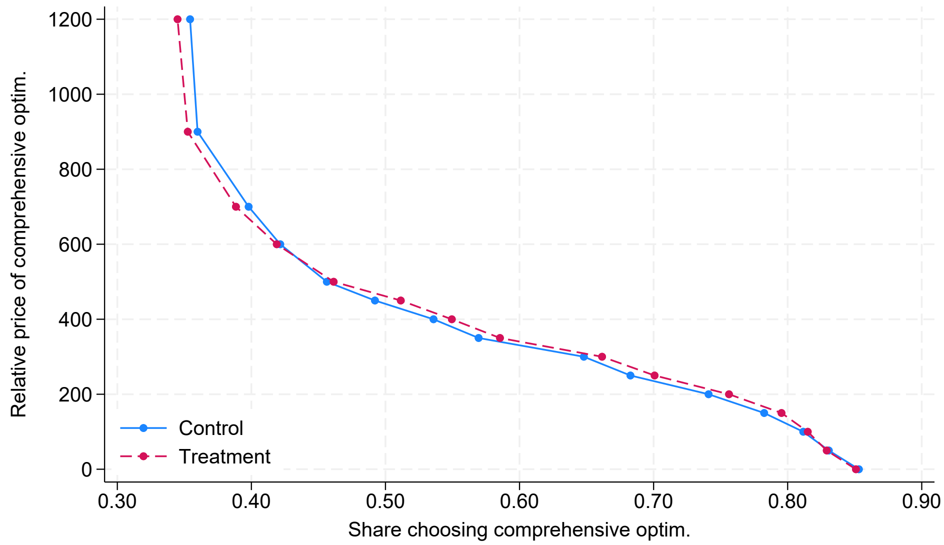
Notes: treatment effect estimates on the difference-in-differences between the willingness to pay for the comprehensive and the basic heating system optimization. Treatment effects were estimated separately on the subgroups for quantiles of the projected CO2 emission savings over a period of 10 years. 95 % confidence intervals are indicated (using heteroskedasticity-robust standard errors).

Table D.4: Correlations of Pre-Determined Covariates With Baseline Cost Estimates

	Baseline WTP (1)	Engineering Estimate (2)	Stated Expenditures (3)
Panel A: Household characteristics			
No. household members	-28.168	-7.401	18.324***
	(23.229)	(7.975)	(6.834)
Household net income	-0.003	-0.006	-0.004
	(0.019)	(0.006)	(0.005)
Female household head	42.840	-19.216	0.242
	(45.218)	(15.492)	(12.031)
Household head age	5.122**	-1.183	1.697**
	(2.287)	(0.824)	(0.728)
Highschool/professional degree	-95.528	-6.779	32.044
	(78.988)	(24.432)	(19.538)
Tertiary degree	32.948	-25.859*	14.639
	(47.914)	(15.241)	(12.112)
Employed	10.021	6.827	4.148
	(57.858)	(19.484)	(16.119)
Panel B: Home characteristics			
Multi-family home	111.878	-26.361	-39.945
	(129.436)	(43.094)	(40.632)
Holding EPC	-75.467	11.606	14.795
	(60.074)	(21.595)	(15.786)
Space heated, in m^2	2.017***	3.004***	0.377**
	(0.579)	(0.217)	(0.151)
Build before 1978	12.419	330.596***	35.572***
	(48.001)	(18.999)	(11.189)
Panel C: Type of heating system			
Heat pump or biomass	269.635**	26.543	-57.850*
	(107.377)	(54.267)	(33.801)
District heating	274.584***	67.364**	-9.826
	(99.542)	(31.086)	(32.586)
Oil boiler	141.301***	-111.971***	23.508**
	(47.739)	(15.622)	(11.764)
Panel C: Retrofits since 2000			
Attic insulation	-19.598	-15.412	-7.540
	(50.613)	(17.191)	(14.858)
Replaced heating system	1.632	-12.229	16.923
	(45.194)	(14.986)	(10.925)
Insulated walls	37.031	-130.915***	-31.385*
	(65.034)	(22.908)	(18.210)
Replaced windows	42.537	-26.310*	0.021
	(49.154)	(15.844)	(12.150)
Optimized heatingsystem	28.135	3.472	11.969
	(56.043)	(20.329)	(12.267)
Adjusted R^2	0.038	0.465	0.078
Observations	803	803	394

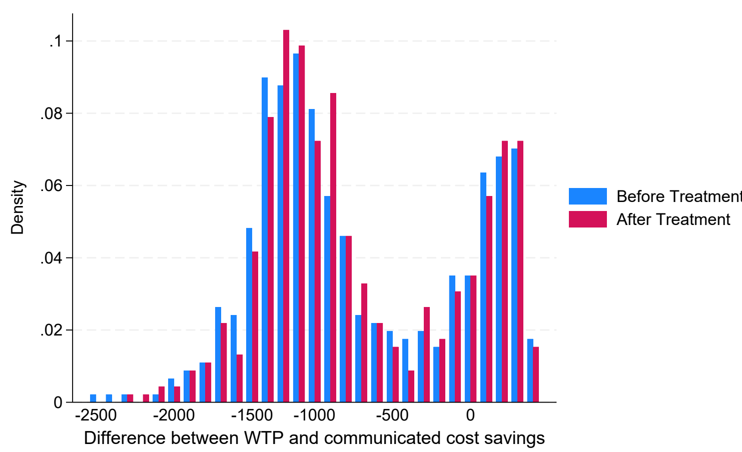
Notes: OLS regressions, controlling for the indicated variables. Each column indicates the result of one regression. Column 1 labeled "Baseline WTP" uses the pre-treatment willingness to pay for the comprehensive retrofit relative to pipe insultaion as the outcome. Engineering estimate (column 2) is the estimate for relative cost savings of the comprehensive retrofit by the engineering model. Stated expenditures (column 3) estimate the relative energy cost savings caused by the comprehensive retrofit as 4% of stated annual household energy expenditures. Household characteristics related to education and employment reflect the outcomes of the household head. Home characteristic "Holding EPC" indicates whether the household reports having an energy performance certificate for their home. The left-out heating system in Panel C is gas boilers. Retrofits since 2000 reflect whether the household indicated to have conducted at least one retrofit within the indicated category. Heteroskedasticity-robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure D.2: Market share of comprehensive retrofit after the experiment



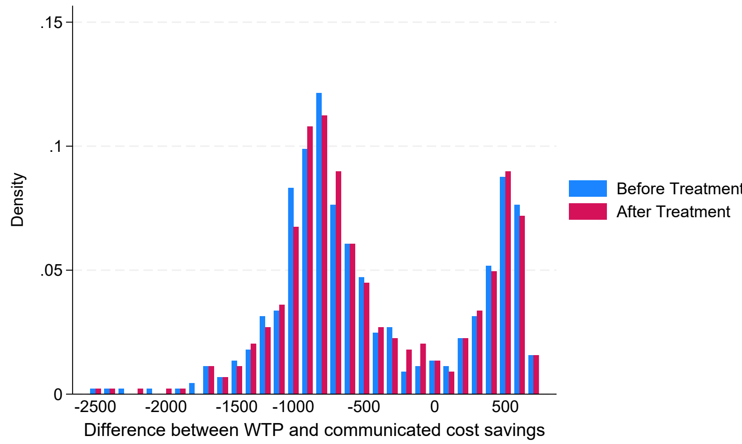
Notes: relative price indicates the difference between the willingness to pay for the comprehensive optimization vs. the basic optimization of the heating system. Treatment indicates the share households receiving an information treatment (N = 919) willing to obtain the comprehensive retrofit for a given relative price. Control indicates the corresponding share for the control group (N = 892).

Figure D.4: Gap between benefit estimate and willingness to pay, treatment group



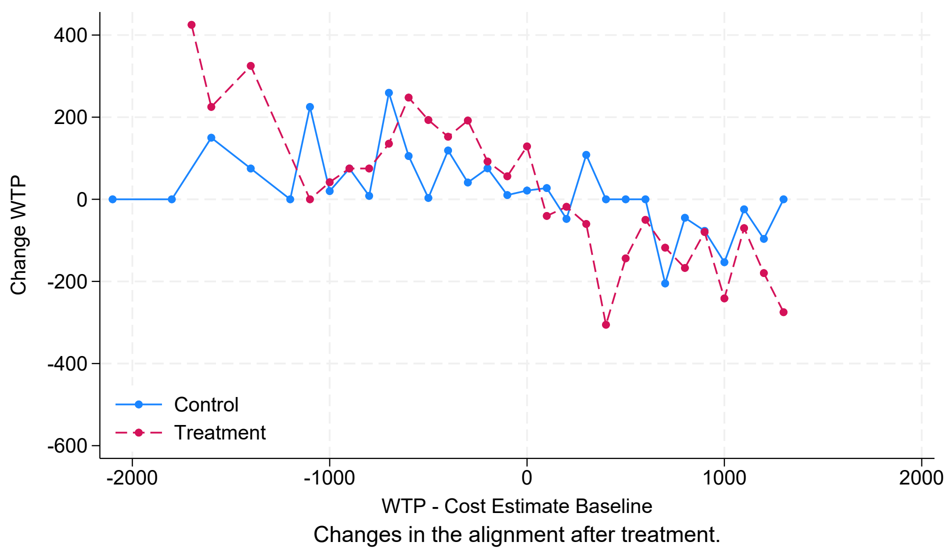
Notes: the difference between the willingness to pay for a comprehensive instead of the basic heating system optimization and the communicated cost savings in the information treatment are plotted. The difference is plotted for the treatment group T2, for which baseline and endline willingness to pay were elicited.

Figure D.5: Gap between benefit estimate and willingness to pay, control group



Notes: the difference between the willingness to pay for a comprehensive instead of the basic heating system optimization and the communicated cost savings in the information treatment are plotted. The difference is plotted for the control group C2, for which baseline and endline willingness to pay were elicited.

Figure D.6: Change in the gap between benefit estimate and willingness to pay



Notes: the change of the gap between the willingness to pay and the energy cost savings over 10 years for the comprehensive heating system optimization relative to the simple optimization is plotted for different pre-treatment levels for the gap.

Table D.5: Sensitivity Analyses: Re-Scaled Engineering Estimates

		Baseline	Adjusted Mean
Panel A: Parameter Estimates			
D'_p	Demand slope (share of purchases/(€ /unit)	-0.00208	-0.00208
$\mathbf{E}[\gamma]$	Average bias (€ /unit)	213	249
		(21.95)	(21.72)
$\mathbf{E}[\phi]$	Average externality (€ /unit)	-478	-478
		(9.13)	(9.13)
$\mathbf{E}[\tau]$	Average treatment effect (€ /unit)	1.86	2.11
		(20.76)	(20.75)
$Var[\tau]$	Treatment effect variance ((€ /unit)^2)	71,910	71,736
		(23,718)	(23,686)
$Cov[\gamma, \tau]$	Bias and treatment effect covariance ((€ /unit)^2)	-51,059	-50,765
		(14,602)	(14,509)
$Cov[\phi, \tau]$	Externality and treatment effect covariance ((€ /unit)^2)	-5,260	-5,363
		(5,286)	(5,279)
Panel B: Total Surplus Effects Under Different Assumptions			
$\Delta W(t = 0)$	Total surplus effect with no tax (€ /unit)	43.29	43.05
	special case 1: $\mathbf{E}[\tau] = 0$	42.26	42.05
	special case 2: $Cov[\delta, \tau] = Var[\tau] = 0$ (homogeneous)	1.02	1.00
	special case 3: $\mathbf{E}[\tau] = Cov[\delta, \tau] = 0$ (pure noise)	-74.62	-74.44
	special case 4: $Cov[\gamma, \tau] = E[\gamma] = 0$ (ignore bias)	-61.86	-61.22
	special case 5: $Cov[\phi, \tau] = E[\phi] = 0$ (ignore externality)	30.52	29.83
$\Delta W(t = t^*)$	Total surplus effect with optimal tax (€ /unit)	42.26	42.05
$\Delta W(t = €\,60)$	Total surplus effect with arbitrary tax (€ /unit)	43.52	43.32
Households		901	901

Notes: Column Baseline presents the welfare calculation in our baseline specification. Column Adjusted Mean uses re-scaled estimate for the energy savings in Equation (B.1), multiplying $(C_i(S) - C_i(K))$ with the ratio between energy cost savings based on stated annual heating expenditures (0.04*10 stated energy costs per annum) and the model-based energy cost savings. Panel A displays estimates for the parameters going into the welfare estimation. Details on the estimation are outlined in Section 3.2. Panel B displays welfare estimates. $\Delta W(t = 0)$ is calculated using Equation (4), setting the tax $t' = 0$. The following scenarios depart from the same equation, setting additional parameters to zero (as indicated). $\Delta W(t = €\,60)$ is calculated using Equation (4), setting the tax $t' = 60$. $\Delta W(t = t^*)$ is calculated using Equation (E.4). Standard errors in parentheses.

E Welfare Effects: Derivations

Using our notation and the definition of variance, we can rewrite equation (3) from Proposition 1 in Allcott et al. (2025) for the case that there is no psychic cost of the information intervention on consumer welfare (in the notation of Allcott et al. (2025), $I = 0$) and where ρ and μ denote pass-through and mark-up, respectively, as

$$\begin{aligned}
\frac{dW}{d\sigma} =& {}^1\!/_2 \frac{\partial}{\partial \sigma} \left\{ \rho E_m \left[(\delta + \sigma\tau - t - \mu) \right]^2 + Var_m \left(\delta + \sigma\tau \right) \right\} D_p \\
=& {}^1\!/_2 \frac{\partial}{\partial \sigma} \left\{ \rho \left(E_m \left[(\delta + \sigma\tau - t - \mu)^2 \right] - Var_m \left(\delta + \sigma\tau - t - \mu \right) \right) + Var_m \left(\delta + \sigma\tau \right) \right\} D_p \\
=& {}^1\!/_2 \frac{\partial}{\partial \sigma} \left\{ \rho \left(E_m \left[(\delta + \sigma\tau - t - \mu)^2 \right] - Var_m \left(\delta + \sigma\tau \right) \right) + Var_m \left(\delta + \sigma\tau \right) \right\} D_p \\
=& {}^1\!/_2 \frac{\partial}{\partial \sigma} \left\{ (1 - \rho)\, Var_m \left(\delta + \sigma\tau \right) + \rho E_m \left[(\delta + \sigma\tau - t - \mu)^2 \right] \right\} D_p, \qquad \text{(E.1)}
\end{aligned}$$

where the subscript m indicates, that the expectation or the variance are evaluated over the set of marginal consumers. Expanding the second moment yields

$$E_m \left[(\delta + \sigma\tau - t - \mu)^2 \right] = \left(E_m [\delta] + \sigma E_m [\tau] - t - \mu \right)^2 + 2\sigma Cov_m [\tau, \delta] + \sigma^2 Var_m [\tau] . \qquad \text{(E.2)}$$

Thus, after simple manipulations and when defining $\Delta X := X(\sigma = 1) - X(\sigma = 0)$, equation (E.1) for comparing the welfare effect of introducing a nudge ($\sigma = 1$) to a situation without the nudge ($\sigma = 0$) yields equation (4) from the main text:

$$\begin{aligned}
\Delta W(t = t') =& {}^1\!/_2 \left\{ (1 - \rho)\, \Delta Var \left(\delta + \sigma\tau \right) + \rho \Delta E \left[\left(\delta + \sigma\tau - t' - \mu \right)^2 \right] \right\} D_p \\
=& {}^1\!/_2 \left\{ (1 - \rho) \left\{ Var (\delta) + Var (\tau) + 2Cov (\delta, \tau) - Var (\delta) \right\} \right\} D_p \\
&+ \left\{ \rho \left[2Cov (\delta, \tau) + Var (\tau) \right] + \rho \left(\left[\left(E [\delta] + E [\tau] - t' - \mu \right)^2 - \left(E [\delta] - t' - \mu \right)^2 \right] \right) \right\} D_p \\
=& {}^1\!/_2 \left\{ Var (\tau) + 2Cov (\delta, \tau) + \rho \left[\left(E [\delta] + E [\tau] - t' - \mu \right)^2 - \left(E [\delta] - t' - \mu \right)^2 \right] \right\} D_p.
\end{aligned}$$

In a scenario without taxation that corrects the average distortion in consumer decision-making (in the form of consumer biases and externalities from CO_2 emissions), the welfare effect of an information intervention is calculated according to:

$$\Delta W(t = 0) \approx {}^1\!/_2 \left\{ (\mathbf{E}[\delta] + \mathbf{E}[\tau] - \mu)^2 - (\mathbf{E}[\delta] - \mu)^2 + 2Cov[\delta, \tau] + Var[\tau] \right\} D_p. \qquad \text{(E.3)}$$

If the policy maker implemented an optimal tax, i.e., $t^* = \mathbf{E}[\delta] - \mu$ if $\sigma = 0$ and $t^* = \mathbf{E}[\delta] + \mathbf{E}[\tau] - \mu$ if $\sigma = 1$, he corrects for the average distortion in consumer decision-making, so that the welfare effect is reflected solely by the distortion variance effect:

$$\Delta W(t = t^*) \approx 1/2 \left\{2Cov[\delta, \tau] + Var[\tau]\right\} D_p. \tag{E.4}$$