Resource and Energy Economics 64 (2021) 101231

Contents lists available at ScienceDirect

Resource and Energy Economics

journal homepage: www.elsevier.com/locate/ree

Energy efficiency and heating technology investments: Manipulating financial information in a discrete choice experiment☆

Ghislaine Lang[a,*], Mehdi Farsi[b], Bruno Lanz[b,c,d], Sylvain Weber[b]

[a] University of Lausanne, Faculty of Business and Economics (HEC Lausanne), Switzerland
[b] University of Neuchâtel, Institute of Economic Research, Switzerland
[c] ETH Zürich, Switzerland
[d] Massachusetts Institute of Technology, USA

ARTICLE INFO

Article history:
Received 16 June 2020
Received in revised form 1 February 2021
Accepted 6 February 2021
Available online 11 February 2021

JEL classification:
D1
D8
H23
Q4
Q5
R31

Keywords:
Energy efficiency
Low-carbon technologies
Informational interventions
Product familiarity
Discrete choice experiments
Mixed logit models
WTP space estimation

ABSTRACT

We elicit homeowners' willingness to pay (WTP) for energy efficiency and low-carbon technologies in the context of heating appliance replacement. We employ a within-between subject design that involves manipulating information in a two-stage discrete choice experiment (DCE) and use WTP space estimation to identify the role of financial information in reducing fossil fuel use. We find that homeowners' average valuation of energy efficiency exceeds associated heating cost savings, suggesting that they also consider non-monetary benefits when evaluating this type of investment, whereas information about private and pro-social benefits of investments only has a limited impact on WTP. Evidence also suggests that homeowners have a strong preference for the existing technology. Consequently, fossil fuel users' WTP for switching to low-carbon technologies does not cover respective investment cost differentials, and we derive evidence on how combined subsidies and information can induce these users to opt out of fossil technologies.

1. Introduction

In the last two decades, low-carbon technologies have been at the center of global policy makers' efforts to meet CO_2 emissions targets. Despite important public resources dedicated to foster private investment, however, adoption of low-

☆ We would like to thank the editor, three anonymous referees, Dorothée Charlier, Meredith Fowlie, Paul Burger, and Philippe Thalmann for useful comments and discussions. We also thank participants of the 2020 EAERE conference, the 2017 SHEDS workshop, and 2017 SAEE meeting for questions and comments. This research is part of the activities of SCCER CREST (Swiss Competence Center for Energy Research), which is financially supported by Innosuisse. Any remaining errors are ours.

* Corresponding author.
E-mail address: ghislaine.lang@unil.ch (G. Lang).

https://doi.org/10.1016/j.reseneeco.2021.101231
0928-7655/

carbon technologies is slow, and explanations generally point to market failures, behavioral biases, and modeling errors (see, e.g., Allcott and Knittel, 2019; Gillingham and Palmer, 2014; Gerarden et al., 2017). In the residential context, imperfect information (Newell and Siikamäki, 2014; Allcott and Wozny, 2014; Jacobsen, 2015) and inertia (or status quo effects, see, e.g., Hartman et al., 1991; Banfi et al., 2008; Kwak et al., 2010) have been suggested to act as barriers to the uptake of novel technologies. While every building element requires renovation at some point (so that inertia eventually expires), a growing body of evidence shows that even during replacement decisions, homeowners prefer to adopt a familiar technology (Sopha et al., 2010; Michelsen and Madlener, 2012, 2016). Because a large share of residential heating systems are based on fossil fuels,[1] heating replacement decisions are critical, and empirical evidence is required to inform policies that incentivize low-carbon choices among fossil fuel users.

In this paper, we provide experimentally controlled evidence on how homeowners' willingness to pay (WTP) for alternative heating systems are affected by information. In particular, we design a discrete choice experiment (DCE, Louviere et al., 2000; Train, 2009) simulating a hypothetical scenario in which the respondent's heating appliance needs replacement, and they can select between multiple alternatives described by varying degrees of energy efficiency (B, A, or A^+, see Council of European Union, 2013), different types of technology (heating oil, natural gas, wood pellets, or heat pump), and several levels of investment cost.[2] Participants reside in Switzerland and own the single family home in which they live, allowing us to focus on the relevant subset of the population which will face a replacement decision in the future. By contrast, apartment buildings are excluded from the experiment due to the high prevalence of centralized heating systems, which would necessitate a different approach to preference elicitation.

The objective of our experimental design is to isolate homeowners' preferences for the attributes of interest, and we do so by considering a constrained replacement decision (no opt out) and experimentally fixing the level of comfort across alternatives. In this context, the main contribution of this paper is to employ a two-by-two experimental design that combines *within*- and *between*-subject variation in exposure to information (Charness et al., 2012). First, within-subject variation is achieved by presenting participants two sets of DCE choice tasks with an information script in-between, an approach inspired by the work of Allcott and Wozny (2014), Allcott and Taubinsky (2015). More specifically, after pre-treatment choice tasks, subjects are randomly assigned to a treatment intervention informing them about financial implications related to their decisions. We focus on two aspects of the decisions: (i) private returns to investments (savings on heating costs), and (ii) pro-social implications of choices (lower CO_2 tax payments). Subjects then complete a second set of choice tasks, which allows us to identify the impact of information on WTP estimates. Our approach is also closely related to the work of Caputo et al. (2017), who manipulate the presentation of DCE attributes in the middle of the choice task sequence.

The second source of experimental variation is *between* subjects and involves a control group and four treatment conditions. Specifically, two of our experimental conditions focus on heating cost savings. We inform homeowners that choosing energy label A^+ instead of B (about 25% more energy efficient, see Council of European Union, 2013), reduces energy bills by CHF 390 per year (exchange rate 2017 CHF 1 ≈ USD 1). Within these treatment conditions, we vary the degree of salience of the information, which has been shown to be important in related contexts (Newell and Siikamäki, 2014; Sallee, 2014). The other two conditions test homeowners' reactions to tax-inclusive prices (as opposed to pure financial savings) by providing information about CO_2 tax payments *included* in heating costs (the existing CO_2 tax levied on fossil heating fuels in Switzerland amounted to CHF 84 per ton of CO_2 in 2017, see Federal Council, 2012). Varying the salience of CO_2 tax payments allows us to contribute to a behavioral literature on salience in the context of externality-correcting taxes (see, e.g., Li et al., 2014; Houde and Aldy, 2017; Lanz et al., 2018).

Our second contribution is to provide evidence on homeowners' preferences for the pre-existing technology, the one that is already installed at the time of the survey. A growing body of research finds that one of the key determinants of homeowners' choice is the familiarity with the technology (e.g., Sopha et al., 2010; Michelsen and Madlener, 2012, 2016). Common behavioral explanations include expectations about transition costs (switching technology is associated with an extra cost, Energieheld Schweiz, 2020), comfort (installing novel equipment takes time and requires changing one's habits of use, Michelsen and Madlener, 2012, 2016), and uncertainty with respect to future costs (see, e.g., Alberini and Bigano, 2015). The design of our experiment allows us to document the importance of familiarity when these three aspects are fixed experimentally. More specifically, in our experiment up-front investment costs include possible extra transition costs (financial concerns), homeowners are asked to consider a *replacement* decision and that the new equipment meets their general requirement in any case (comfort considerations), and we experimentally vary whether and how homeowners are informed about financial implications of their choices (informational biases).

[1] In the U.S., 57.7% of all homes use natural gas as their main heating fuel (EIA, 2015). In the E.U., 43.1% of residential buildings are heated with natural gas, and 14.0% with heating oil (based on Eurostat, 2017). In Switzerland, 39.4% of residential buildings are heated with heating oil, and 20.7% with natural gas (FSO, 2017). Lang and Lanz (2020) show that compared to a number of other building retrofits, switching heating fuel is an effective CO_2 abatement strategy.

[2] Stated preference studies allow independent variation of attribute levels and elicitation of WTP for non-financial attributes, while at the same time controlling information about available choice sets. However, they can also induce hypothetical and strategic biases. A randomized control trial would avoid these issues by eliciting revealed preferences, although in our setting it would be difficult to implement because of the substantial investment cost and the low replacement rate underlying the appliances we consider. With this in mind, our experimental script employs a number of measures to encourage participating homeowners to disclose their true preferences (such as reminding them about budget constraints and consequentiality of choices, as we discuss later), and mainly focus on comparisons between and within subjects.

The third contribution of our work is to provide novel evidence that specifically focuses on how fossil fuel users can be incentivized to select low-carbon technologies despite the aforementioned familiarity effects. This is important because heating oil and natural gas are responsible for roughly a third of residential energy end-uses (IPCC, 2014), and homeowners using these energy sources are expected to deliver large CO_2 emissions reductions in the coming decades. Moreover, since most homeowners wait until a particular building component reaches the end of its useful life to replace it (Achtnicht and Madlener, 2014), the comparatively long life span of heating appliances implies that homeowners are temporarily *locked in* a particular technology (see, e.g., Rapson, 2014; Volland et al., 2020). In line with this, we employ the results from our DCE to quantify how information affects WTP for these homeowners, and estimate the size of a subsidy which would make oil and natural gas owners switch to either a wood-based heating appliance or a heat pump.

The experiment is administered to an online panel of 511 respondents each completing six pre-treatment and six post-treatment DCE choices. We find that homeowners' pre-treatment WTP for energy label A^+ relative to label B amounts to over CHF 13,000, which is more than twice the expected gains from energy savings (about CHF 5850 for 15-year undiscounted, 2017 energy prices). Our results further show that respondents' valuations remain roughly unchanged even after they are provided with information about financial implications of their choices on heating costs. This suggests that a significant proportion of respondents consider more than mere financial benefits when making efficiency choices, and imperfect information about benefits of energy efficiency investments is not affecting choices in our sample. Importantly, this conclusion also holds for fossil fuel users, as average WTP for this subgroup is also barely affected by information on heating costs.

By contrast, the results indicate that a significant share of homeowners is not willing to pay the investment cost differentials associated with low-carbon technologies. In particular, only about 40% (20%) of respondents are willing to pay an investment cost premium of CHF 15,000 in exchange for a heat pump appliance (wood pellet-based boiler) instead of a boiler operating on heating oil. We show that this can be explained in part with a distinct preference for the pre-existing technology, which affects specifically the 75% of our sample that use fossil fuels (heating oil or natural gas). Lastly, DCE results derived from the subsample of fossil-fuel users reveal that incentivizing fossil fuel users to switch to low-carbon alternatives would require a technology-specific subsidy of about CHF 6–10,000 for wood pellets, CHF 0–3000 for air source heat pumps, and CHF 24–28,000 for ground source heat pumps. While preferences for the pre-existing fossil-based technology prevail even after respondents are exposed to information about CO_2 tax payments levied on fossil fuels, this type of intervention can reduce the size of the subsidy necessary to opt out of fossil technologies. In particular, it has the potential to eliminate the need for additional financial incentives increasing the attractiveness of wood pellets relative to heating oil.

Our findings complement a burgeoning literature that studies different dimensions of low-carbon technology adoption, namely the role of costs (up-front and operative costs as well as various types of public funding, see, e.g., Alberini and Bigano, 2015; Alberini et al., 2013), comfort (e.g., Bakaloglou and Charlier, 2019; Schleich et al., 2020), and ex-ante information (see Allcott and Greenstone, 2012; Lang and Lanz, 2021). We also contribute to studies that challenge the importance of imperfect information and inattention for energy efficiency purchase decisions (Allcott and Wozny, 2014; Jacobsen, 2015; Allcott and Taubinsky, 2015), and that emphasize the current type of equipment as a major determinant of future heating technology choices (see, e.g., Sopha et al., 2010; Michelsen and Madlener, 2012, 2016). Relative to existing studies, we find that the preference for the familiar technology goes beyond comfort considerations and expectations about financial implications of choices. To our knowledge, this study is the first to shed light on the relationship between rigid preferences for the existing technology and the relative ineffectiveness of information programs in promoting economically sustainable valuations of low-carbon technologies.

The paper proceeds as follows. Section 2 describes our experimental design, including the details of alternative informational interventions. In Section 3, we lay out how we estimate homeowners' WTP and the impact of information. Section 4 presents our results. A brief discussion and concluding comments are provided in Section 5.

2. Experimental design

The objective of the experimental design is to quantify the impact of information treatments on homeowners' preferences for low-carbon technology and energy efficiency. The experiment includes three parts: (i) six pre-treatment DCE choice tasks, (ii) random assignment to one of four information treatments or the control group, and (iii) six post-treatment DCE choice tasks. In the following, we first provide details of the DCE tasks. Second, we discuss the design of our information treatments. Finally, we overview how we administer the experiment. A full set of screenshots of the material is provided in Appendix A.[3]

2.1. Discrete choice experiment

Before starting the choice sequence, we ask participants to imagine that the primary heating appliance of their dwelling requires replacement, and to consider which option would be preferred for their household. We emphasize that, apart from what is mentioned explicitly, appliances perform equally well, meet general requirements, and are expected to have

[3] The survey is available in German, French and English, and most respondents select one of the first two languages. All original versions are available on request.

Fig. 1. Pre-treatment choice task.

the same operating life of 15 years. In addition, we explain to homeowners that the installation of the new system would necessarily take place in the year of the survey (to avoid problems with discounting), and that none of the other components of the heating system (e.g., radiators) would be affected.[4] This allows us to mitigate heterogeneous expectations related to comfort, so that we can provide a clean estimate of homeowners' incremental WTP for various technologies and energy efficiency levels.

In order to reduce the potential for hypothetical and strategic biases encountered in the context of stated preferences, we foster perceived consequentiality of choices with the use of scripts in line with the literature on truthful preference revelation (e.g., Vossler et al., 2012; Newell and Siikamäki, 2014). To do so, we explain to participants that it is in their best interest to answer the questions truthfully as their answers will be used by academic research. Taking into account insights from the stated preference literature (see Johnston et al., 2017), we also make use of budget constraint reminders.[5] Finally, we start each choice sequence with an example to ensure that participants understand the choice tasks. The full text explaining the choice tasks to respondents is reported in Appendix A, Figs. A1 to A4 .

Subsequently, we ask subjects to consider a multi-dimensional choice between different heating appliances (see Fig. 1). In particular, we ask them to choose from three unlabeled alternatives (Offers I, II, and III), each described by means of three attributes: (i) a standard energy efficiency label as mandated by the European Union, which at the time of the survey ranges from A^{++} (most efficient) to G (least efficient)[6] ; (ii) the heating technology; and (iii) up-front investment cost.

Table 1 provides an exhaustive overview of attributes and levels applied in the experiment. In addition to being motivated by previous literature, which shows that the chosen attributes matter in similar contexts (see Jaccard and Dennis, 2006; Scarpa and Willis, 2010; Rouvinen and Matero, 2013; Stolyarova et al., 2015; Franceschinis et al., 2016; Ruokamo, 2016, for heating technologies, and Newell and Siikamäki, 2014; Lang and Lanz, 2021, for energy labels), we select the range of efficiency grades, technologies, and investment cost levels, to be in line with the options available on the local market at the time of the survey. In particular, our pre-treatment scenario reflects the fact that homeowners typically have to infer private returns (i.e., financial savings on energy bills) and pro-social implications of their choices (e.g., CO_2 emissions) by relying on the energy efficiency label and chosen technology (i.e., the energy source). Based on these attribute levels, we derived a first experimental design for the DCE experiment using D-efficiency criteria (Kuhfeld et al., 1994) and piloted the survey to

[4] The exact wording is: "Aside from the specific characteristics of the appliances, please assume that they meet your general requirements, perform equally well, and are expected to have the same operating life of 15 years," and "When making your choices, please assume that the change of appliance will necessarily take place in 2017. The selected heating appliance would fully replace your current heating appliance, but the rest of your heating system, such as the radiators, would not need to be changed."

[5] We include two separate budget reminders: "Some of the following questions will involve costs to your own household; please give careful consideration to how these costs would affect your financial budget," and "In making your choices, please remember that any money spent on your heating will not be available for other expenses by your household. The only right answer is what you would really choose."

[6] As of 2019, the energy efficiency classes for heating systems range from A^{+++} to D. Classes E and G no longer apply, as such inefficient technology is no longer allowed to be sold (see Council of European Union, 2013).

Table 1
Discrete choice experiment attributes and levels.

Attribute	Level 1	Level 2	Level 3	Level 4	Level 5
Energy label	B	A	A$^+$	–	–
Heating technology	Boiler with heating oil	Boiler with natural gas	Boiler with wood pellets	Heat pump using electricity	–
Investment cost	CHF 10,160	CHF 13,010	CHF 17,030	CHF 23,090	CHF 30,140

Notes: Attribute levels for the labels, technologies, and prices are in line with options available on the market at the time of the experiment. Energy label A represents an approximate 10% improvement in energy efficiency relative to label B, and label A$^+$ an approximate 25% improvement (see Council of European Union, 2013). We use a fractional factorial design based on D-efficiency for the pilot and a Bayesian criteria in the main survey. 2017 exchange rate CHF 1 ≈ USD 1.

Table 2
Overview of informational treatment and control interventions.

Indicator	Treatment name	Information screen	post-treatment choice task
C	Control	Neutral	Pre-treatment design
T_A	Heating cost	Heating cost	Pre-treatment design
T_B	Heating cost salient	Heating cost	Pre-treatment + annual heating cost
T_C	CO_2 tax	CO_2 tax	Pre-treatment design
T_D	CO_2 tax salient	CO_2 tax	Pre-treatment + annual heating cost incl. CO_2 tax

Notes: In each treatment group, subjects go through six pre-treatment DCE tasks before being exposed to one of five information treatments. After the information screen (and related quiz question), they either go through another sequence of six "pre-treatment" DCE tasks (conditions C, T_A, and T_C) or some variation of it (conditions T_B and T_D).

ensure that they yield meaningful options for respondents. After the pilot, we revised the DCE experimental design for the main survey using Bayesian D-efficiency criteria.

Importantly, our experimental design focuses on energy labels A$^+$, B, and A (see Table 1), which are arguably the most common classes relevant for our survey. By contrast, label A^{++} was excluded because it was not issued for oil boilers without added solar panels, whereas A^{+++} did not exist for either of the technologies considered in our experiment at the time of the survey. Note that switching from energy label B to label A corresponds to an approximate 10% improvement in energy efficiency and from B to A$^+$ reflects an approximate 25% improvement (see Council of European Union, 2013).

Our experiment includes four different heating technologies available on the market at the time of the experiment (see Table 1), two of which are typical fossil fuel-based technologies (boiler with heating oil and boiler with natural gas). The other two can be considered as renewable energy sources in Switzerland (boiler with wood pellets and heat pump using electricity).[7] In order to generate heat, a boiler warms up cold water by combusting the respective fuel, while a heat pump pulls heat from the surrounding environment (i.e., air, water, or ground). At the time of the survey, these four technologies make up about 88% of Swiss households' primary heating appliances (FSO, 2019a).

Up-front investment cost levels included in the final experiment range from CHF 10,160 to CHF 30,140 (see Table 1), which mirrors actual prices in the local market at the time of the survey (2017 exchange rate CHF 1 ≈ USD 1). Specifically, the price for a new boiler operating on heating oil ranges from CHF 18,500 to CHF 30,000 in Switzerland. The cost for a new gas boiler ranges from CHF 14,000 to CHF 27,500, for a new wood pellet boiler from CHF 30,000 to CHF 42,000. Lastly, a new air source heat pump ranges from CHF 29,000 to CHF 42,000, and a new ground source heat pump from CHF 43,000 to CHF 65,000 (Energieheld Schweiz, 2020; EnergieSchweiz, 2020).[8]

2.2. Informational interventions

Table 2 summarizes the five treatment conditions to which respondents are randomly allocated after completing the six pre-treatment choice tasks. Each condition consists of an information screen plus the six subsequent post-treatment choice tasks. All information screens closely mirror each other in design, structure, complexity, and length, so that only the actual informational content should affect homeowners' decisions (see Figs. A9 to A11).

In order to foster effective transmission of information to respondents, we take two specific steps inspired by Allcott and Wozny (2014) and Allcott and Taubinsky (2015). On the one hand, interventions include both verbal and visual (i.e., a figure) information. On the other hand, we trigger homeowners' attention by announcing upfront that each information screen will be followed by a short quiz question testing comprehension of the core information of the information screen. Participants need to answer the quiz question before being able to continue the experiment (when homeowners answer incorrectly, the right answer is displayed). 83% of homeowners in our sample answered the quiz question correctly.

After completion of the quiz question, homeowners receive instructions for the set of post-treatment choice tasks. In some treatment conditions we modify the choice task design in order to reinforce salience of the information provided. As a

[7] Electricity generation in Switzerland mainly derives from hydro (56%) and nuclear (35%) power (SFOE, 2019).
[8] Note that we chose to randomly increase each of the selected investment cost levels by <2% in order to avoid round numbers and make prices look more realistic (e.g., CHF 10,160 instead of CHF 10,000).

result, participants either face the same choice tasks as they did before treatment, or a marginally modified version of them (see Table 2). In the following subsections, we detail our various control and treatment conditions.

2.2.1. Control group (C)

Our within-subject treatment design gives rise to a number of potential time-variant factors commonly associated with repeated choices (such as learning and fatigue, see e.g., Day et al., 2012; Campbell et al., 2015). These factors are unrelated to the specific information content of our treatments, and should be disentangled from treatment effects. The neutral control information allows us to control for a general time trend.

The control group receives neutral information that is designed not to affect homeowners' choices, while not appearing as completely out of context. Specifically, respondents are provided with information detailing the age of the Swiss building stock (information screen *Neutral*, Fig. A9). After completing the one-question quiz, participants face a new series of six choice tasks designed similarly as the ones in the pre-treatment sequence (see Fig. 1).

2.2.2. Information about energy efficiency and heating costs (T_A and T_B)

Treatment groups T_A and T_B are shown an information screen about expected annual heating costs associated with appliances of different energy efficiency grades (information screen *Heating cost*, shown in Fig. A10). This allows testing the importance of specific financial information for investors' choices. The information screen conveys an average expenditure of CHF 1710 per year for a standard appliance with efficiency label B and CHF 1320 per year for the more energy efficient alternative with efficiency label A^+, which roughly translates to the 25% improvement in energy efficiency that can be expected when switching from label B to A^+ (see Council of European Union, 2013).[9]

Treatment conditions T_A and T_B provide the same information screen (and quiz question), but they differ in the design of the post-treatment choice tasks. Homeowners in treatment group T_A face the same choice set design as before treatment, so that post-treatment WTP from this group allows measuring the effect of the information screen about heating costs on homeowners' valuations of different energy efficiency grades. Conditional on respondents not already being fully aware of financial savings associated with energy efficiency prior to the intervention (both financial and energy literacy have been declared barriers to energy efficiency investments, see Blasch et al., 2019; Brent and Ward, 2018), we expect treatment T_A to increase respective WTP as compared to before the treatment. This treatment is labeled *Heating cost*.

Homeowners in treatment group T_B, labeled *Heating cost salient*, complete a post-treatment choice task which explicitly displays an estimate of heating costs associated with each alternative (see Fig. 2). The displayed heating costs do not constitute an additional attribute as such, but rather an extension of the energy efficiency grade (irrespective of other attributes). This format is conceptually similar to U.S. energy efficiency labels for water heating systems studied by Newell and Siikamäki (2014). Concretely, alternatives containing efficiency grades B, A, and A^+, are associated with annual heating costs of CHF 1710, CHF 1530, and CHF 1320, respectively, which is consistent with the preceding information screen. Reminding subjects about implications of energy efficiency for future heating costs *during* choices increases salience of the informational content, and can thus be expected to reinforce the informational intervention. If salience matters in this context, we would expect post-treatment WTP for energy efficiency to be higher in treatment group T_B than in treatment group T_A, i.e., $WTP^{label}(T_A) < WTP^{label}(T_B)$.

2.2.3. Information about technology choice and carbon tax payments (T_C and T_D)

Information treatment groups T_C and T_D aim at conveying *public good* considerations in the form of environmental implications of technology choices. This is achieved with an information screen about the carbon tax levied on heating fuels in Switzerland and its implications on heating costs (information screen *CO_2 tax* is shown in Fig. A11). At the time of the experiment, the tax amounts to CHF 84 per ton of CO_2 (Federal Council, 2016), and is imposed on all fossil heating and process fuels (mainly oil and natural gas, see Federal Council, 2012). Payments are claimed on fuel invoices (in addition to the VAT), and the tax increases over time, so that the cost associated with fossil-based heating increases as well (Federal Council, 2016). Importantly, respondents are informed that low-carbon technologies (wood pellets and heat pumps in our setting) are not taxed, signaling that they are less harmful to the climate.

Treatments T_C and T_D again differ in terms of whether or not the CO_2 tax information is displayed in the post-treatment choice task. In treatment T_C, participants face the pre-treatment choice task design reported in Fig. 1, and post-treatment WTP of this group allows us to measure the effect of the information screen about CO_2 tax payments on homeowners' valuation of different heating technologies. Conditional on respondents not having been fully aware of tax implications associated with different technology choices (a substantial portion of Swiss residents have a poor understanding of the CO_2 tax, see Burger et al., 2018), we expect treatment T_C to increase WTP of low-carbon technology choices as compared to before the treatment. This treatment is labeled *CO_2 tax*.

In treatment T_D, the post-treatment choice tasks integrate financial information about both energy expenditures and inclusive CO_2 tax payments. We label this treatment *CO_2 tax salient*, and an example of the subsequent decision task is

[9] Heating costs can be expected to fluctuate across dwellings and over time, and previous literature shows that raising subjects' awareness to uncertainty of future energy savings dampens their valuation of these savings (Alberini and Bigano, 2015; Lang and Lanz, 2020b). The specific numbers used in our experimental interventions merely support our objective of quantifying how information on financial savings affects homeowners' WTP.

Fig. 2. Post-treatment choice task with heating costs (T_B).

shown in Fig. 3. The tax level does not provide separate information as it is a function of both the respective heating technology and the energy label. In particular, for energy efficiency grade B, the annual heating costs (CHF 1710 as per above) include CHF 550 in CO_2 tax payments for heating oil and CHF 320 for natural gas. For efficiency grade A, the heating costs (CHF 1530) include CHF 490 in taxes for heating oil and CHF 290 for natural gas. Finally, for efficiency label A^+, the heating costs (CHF 1320) include CHF 420 in taxes for heating oil and CHF 250 for natural gas. Boilers operated with wood pellets and heat pumps using electricity are not taxed. If salience matters for the formation of homeowners' preferences regarding CO_2 tax payments, then post-treatment WTP for both energy efficiency and low-carbon technologies of treatment group T_D should be higher than corresponding post-treatment WTP in treatment group T_C, i.e., $WTP^{label}(T_C) < WTP^{label}(T_D)$ and $WTP^{tech}(T_C) < WTP^{tech}(T_D)$.

Note that we measure subjects' reactions to tax-inclusive prices, so that comparing treatment conditions T_B and T_D provides clean evidence about whether the information about CO_2 taxes affects WTP. If environmental motives play a role in the formation of homeowners' preferences, we would expect respondents' post-treatment WTP for more efficient (fossil fuel-based) technologies to be higher in treatment group T_D compared to that in treatment group T_B, i.e., $WTP^{label}(T_B) < WTP^{label}(T_D)$.

2.3. Implementation

We script our DCE with *Qualtrics* and field it in April–May 2017 as part of a wider online survey on energy consumption by households in Switzerland (Weber et al., 2017). Respondents are drawn from an online pool of subjects managed by a private survey company (*Intervista*), which holds over 90,000 subscribers at the time of the survey. Subjects are contacted by email and participation is encouraged with vouchers (equivalent to CHF 6 for completion of the full survey).[10] Out of 5015 subjects that participate in the wider study, a total of 511 homeowners are randomly assigned to our experiment.

Restricting the sample to homeowners implies that we survey a relatively old and wealthy minority of Swiss households. However, it also allows us to focus on respondents with the authority to make heating replacement decisions independently. Based on this, the experiment covers owners of detached (60%), semi-detached (22%), and terraced houses (18%), and we

[10] The neutral e-mail invitation states: "Dear Sir or Madam, we have the pleasure to invite you to participate in a new Intervista survey. With a click to the link below you can access the survey directly. If you are part of the target group and complete the survey integrally, you will receive 60 bonus points. Answering the survey will take about 30 min of your time. We wish you a lot of fun answering this survey! Kind regards, your Intervista team." The response rate is approximately one third.

Fig. 3. Post-treatment choice task with heating costs and CO_2 tax (T_D).

exclude apartment owners from the experiment because of the high prevalence of centralized heating systems across multi-unit apartment buildings in Switzerland. In such a setting, heating replacement decisions generally result from a vote, which would make our elicitation approach highly hypothetical. While homeowners represent a small share of Swiss households (23% live in single family homes, see FSO, 2020), we note that single family homes make up 57% of the residential building stock (FSO, 2020). Importantly, and in part due to the larger share of exterior walls, single family homes emit about 40% more kg CO_2/m^2 compared to apartment buildings (Wüest Partner, 2020).

The fact that our respondents are drawn from a panel of subscribers means that our sample is not completely random, but the survey company handles representativeness. In terms of average observable characteristics (see Table B1, Appendix B), our sample is in line with figures from the Federal Statistical Office (FSO) on the Swiss population of *homeowners* (FSO, 2019b,c) for age (56 years in our sample compared to 57 years in Switzerland), high-education groups (44% of our sample completed tertiary education against 37% in Switzerland), and income (CHF 6000–8999 compared to CHF 8029 in Switzerland). The fact that our sample includes larger dwellings (172 m^2 compared to 138 m^2 in Switzerland) with higher annual heating costs (CHF 1920 against CHF 1042 in Switzerland) is likely due to the fact that official statistics for Switzerland include apartment owners. As compared to the general population of Swiss residents (FSO, 2019a), respondents in our sample more frequently heat with heating oil (47% compared to 39% in Switzerland) and natural gas (29% compared to 21% in Switzerland).[11]

In Table B2 of B, we summarize treatment randomization across conditions. The average number of respondents per condition is 102, and the minor differences across groups are due to a small number of subjects that did not complete all of the experiment.

3. Econometric framework

Our econometric framework is based on standard Random Utility Theory (McFadden, 1974, 1984), which assumes that utility for a particular product is derived from its characteristics (*attributes*). In turn, observed choices reveal which set of attribute levels provides them with the highest utility (among a set of *alternatives*). Formally, individual n's utility for alternative j in choice situation t, called U_{njt}, is separated into a deterministic component V_{njt} and an unobserved stochastic

[11] Our sample also covers households heating with heat pump (11%), electricity (9%), and wood (5%). Census data on the distribution of Swiss *homeowners'* heating energy sources is lacking to date.

component ε_{njt} so that $U_{njt} = V_{njt} + \varepsilon_{njt}$. As is customary in the literature, we assume that ε_{njt} is independently and identically distributed according to a Gumbel distribution (McFadden, 1974).

In choice situation t, respondent n selects alternative j which is assumed to reveal a utility-maximizing option: $U_{njt} > U_{nit}$ $(\forall j \neq i)$. In our setting, individual n is asked to choose 12 times ($t \in 1, 2, \ldots, 12$) from a set of three alternatives ($j \in 1, 2, 3$), here replacement heating appliances, each described by three attributes of varying levels (see Table 1). Importantly, $t \in [1, 6]$ indicates observations before treatment, and $t \in [7, 12]$ indicates observations after treatment. Then, the deterministic portion of utility before treatment V_{njt}^{pre} can be expressed as follows:

$$V_{njt}^{pre} = \beta_n^A label_{njt}^A + \beta_n^{A^+} label_{njt}^{A^+} + \beta_n^{gas} gas_{njt} + \beta_n^{wood} wood_{njt} + \beta_n^{pump} pump_{njt} + \delta_n cost_{njt} \tag{1}$$

where $label_{njt}^A$ and $label_{njt}^{A^+}$ are *energy label* indicators, gas_{njt}, $wood_{njt}$, and $pump_{njt}$ are *heating technology* indicators, and $cost_{njt}$ is a continuous variable capturing *investment cost*. The set of coefficients in β_n (β_n^A, $\beta_n^{A^+}$, β_n^{gas}, β_n^{wood}, β_n^{pump}) and δ_n are the marginal utility parameters of interest measured for choices before treatment. More specifically, the coefficients β_n^A and $\beta_n^{A^+}$ are measured relative to the reference category *label B*, while the coefficients β_n^{gas}, β_n^{wood}, and β_n^{pump} are measured relative to the reference category *heating oil*. Note the absence of an alternative specific constant for opt-outs as we consider a replacement decision and respondents are not allowed to stay without a heating appliance.

In order to identify the effect of our informational interventions on post-treatment choices, while at the same time controlling for the effect of the placebo intervention, we interact each attribute with a post-treatment indicator denoted P_t equal to one if $t \in [7, 12]$, zero otherwise, as well as a set of treatment-specific indicator variables T_{kn} equal to one if individual n is assigned to treatment group k ($k \in \{A, B, C, D\}$), zero otherwise. Formally, post-treatment utility is given by:

$$\begin{aligned} V_{njt}^{post} &= V_{njt}^{pre} + P_t \cdot (\eta_n^A label_{njt}^A + \eta_n^{A^+} label_{njt}^{A^+} + \eta_n^{gas} gas_{njt} + \eta_n^{wood} wood_{njt} + \eta_n^{pump} pump_{njt}) \\ &\quad + P_t \cdot \sum_k T_{kn} \cdot (\lambda_{nk}^A label_{njt}^A + \lambda_{nk}^{A^+} label_{njt}^{A^+} + \lambda_{nk}^{gas} gas_{njt} + \lambda_{nk}^{wood} wood_{njt} + \lambda_{nk}^{pump} pump_{njt}), \end{aligned} \tag{2}$$

where the set of η_n parameters accounts for potential changes in the control group (C) during the post-treatment period, and the vector of coefficients in λ_{nk} represents average treatment effects on utility. More precisely, λ_{nk} evaluates the incremental effect of each treatment condition (i.e., T_A, T_B, T_C, and T_D) relative to the control intervention C.

We further model choices directly in WTP space, which allows making assumptions regarding the distribution of WTP directly (Train and Weeks, 2005).[12] To do so, the utility function is scaled with the cost coefficient δ_n. Specifically, we estimate:

$$V_{njt}^{WTP} = \delta_n [V_{njt}^{pre} + V_{njt}^{post}] \tag{3}$$

where the notation follows from above, and all pre- and post-treatment choices are jointly considered in the estimation. The (negative of the) marginal utility of income δ_n multiplies all the coefficients of interest (β_n, η_n and λ_{nk}), so that the resulting estimates can directly be interpreted in WTP-space. This particular set of coefficients is labeled θ_n^{WTP}.

Next, we make a number of assumptions about the mixing distribution of tastes and WTP in our sample, denoted $f(\theta^{WTP} \mid \Omega)$, where Ω refers to the parameters of the distribution to be estimated from the data. First, we pragmatically follow the majority of the literature in assuming that β_n are normally distributed, whereas δ_n is log-normal.[13] Second, we assume that taste heterogeneity is not affected by the treatment interventions, and that these only shift the mean of the distribution. Concretely, we only estimate the average for η_n and λ_{nk}, and do not estimate the standard deviation separately.[14]

Individual choice probabilities are based on a mixed logit (MXL) model (Revelt and Train, 1998; McFadden and Train, 2000).[15] Specifically, the MXL probability that individual n selects alternative i in choice situation t is given by:

$$P_{nit} = \int \prod_{t=1}^{T} \left(\frac{\exp(V_{nit}^{WTP})}{\sum_{j=1}^{J} \exp(V_{njt}^{WTP})} \right) f(\theta^{WTP} \mid \Omega) \mathrm{d}\theta^{WTP}$$

---

12 Alternatively, modeling in preference space requires assuming a distribution for the separate coefficients and deriving WTP for changes in a particular attribute as the ratio of the attribute coefficient and an estimate of the marginal utility of money. This can lead to WTP distributions that are heavily skewed and that potentially do not have well-defined moments (Train and Weeks, 2005; Hole and Kolstad, 2012).

13 Semi-parametric approaches can be used to identify more flexible distributions of tastes (i.e., multimodal and asymmetric distributions, see Train, 2016; Bansal et al., 2018a,b; Bazzani et al., 2018; Caputo et al., 2018; Scarpa et al., 2020). Sample size limitations and difficulties with numerical convergence prevent us from implementing these approaches. For the same reason, taste parameters are assumed to be uncorrelated.

14 Our empirical investigations with the data confirmed that the standard deviation estimates do not differ significantly across pre- and post-treatment choices. We therefore prefer a more parsimonious specification where treatment indicators are allowed to shift the empirical distribution of WTP.

15 The alternative multinomial logit (MNL) model cannot accommodate random preference heterogeneity and imposes heavy structure on the data due to the property of 'irrelevance of independent alternatives'. In our data, using a MXL model considerably increases the explanatory power of our model.

Given that the MXL choice probabilities have no closed-form expression, the parameters are estimated via simulated maximum likelihood (Train, 2009). In particular, we approximate the choice probabilities based on $R = 2000$ Halton draws, and maximize the following simulated log-likelihood function:

$$SLL(\Omega) = \sum_{n=1}^{N} \ln \left\{ \frac{1}{R} \sum_{r=1}^{R} \prod_{t=1}^{T} \left(\frac{\exp(V_{nit}^{WTP}(\theta_n^{WTP[r]}))}{\sum_{j=1}^{J} \exp(V_{njt}^{WTP}(\theta_n^{WTP[r]}))} \right) \right\}$$

where $\theta_n^{WTP[r]}$ refers to the r-th draw for individual n from the distribution of θ^{WTP}.

Based on the estimated distribution of WTP in our sample, we then use the method of Revelt and Train (2000) to simulate *individual-level* WTP parameters $\hat{\theta}_n^{WTP}$. More precisely, we calculate individual-specific WTP parameters by conditioning on homeowners' observed choices and on the estimated sample distributions of tastes from Eq. (3):

$$\hat{\theta}_n^{WTP} = \frac{\frac{1}{R}\sum_{r=1}^{R} \theta_n^{WTP[r]} \prod_{t=1}^{T} \left(\frac{\exp(V_{nit}^{WTP}(\theta_n^{WTP[r]}))}{\sum_{j=1}^{J} \exp(V_{njt}^{WTP}(\theta_n^{WTP[r]}))} \right)}{\frac{1}{R}\sum_{r=1}^{R} \prod_{t=1}^{T} \left(\frac{\exp(V_{nit}^{WTP}(\theta_n^{WTP[r]}))}{\sum_{j=1}^{J} \exp(V_{njt}^{WTP}(\theta_n^{WTP[r]}))} \right)}$$

where $\theta_n^{WTP[r]}$ refers to the rth draw for individual n from the estimated distribution of θ^{WTP}, and we again set $R = 2000$ Halton draws.

Finally, as mentioned previously, we apply the above framework both to our full sample of homeowners and to the subsample of homeowners who use fossil fuels. In particular, we estimate Eq. (3) separately for households that heat their own house with either heating oil or natural gas. Based on MXL model results, we then predict choice probability in order to quantify the monetary amount that would make these users switch to one of the renewable technologies (wood or heat pump).

4. Experimental results

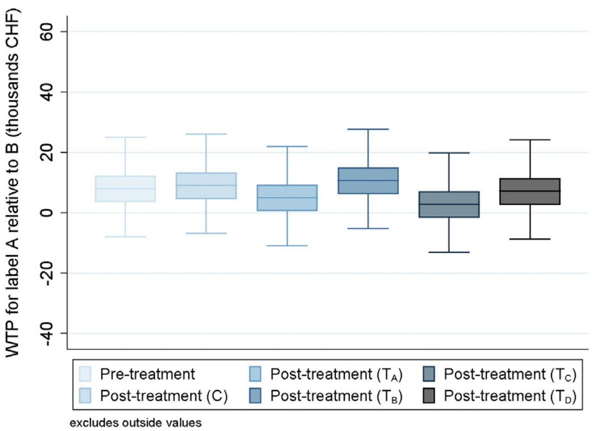
This section reports the main results of our analysis. We first provide evidence on homeowners' WTP for energy efficiency and heating technologies, and exploit within- and between-subject variations in information disclosure to identify the impact of information on subjects' WTP. We then provide evidence about preference heterogeneity for homeowners with different pre-existing technologies. Finally, we focus on the subsample of fossil fuel users and derive implications about how these homeowners select renewable technologies, either through information or through financial incentives.

4.1. Mixed logit model of homeowners' WTP

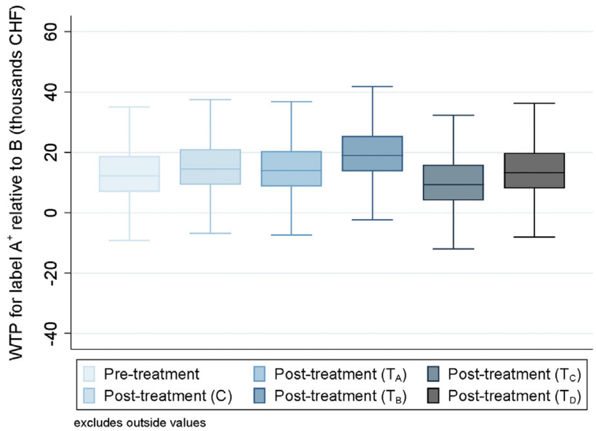
Table 3 reports our main MXL model results in WTP space. Columns (1) and (2) provide respectively mean and standard deviation estimates of the WTP distribution (in thousands CHF) for *energy label* (A and A^{+} indicators relative to B) and *heating technology* (natural gas, wood pellet, and heat pump indicators relative to heating oil), as well as the underlying estimates for the *investment cost* variable. Column (3) reports the average effect of the control intervention on individuals' WTP. Columns (4–7) show the effect of each informational intervention on respondents' average WTP net of the impact of the control condition (see Eq. (2)). We report standard errors clustered at the respondent-level in parentheses.

Estimates from columns (1) and (2) show that pre-treatment average WTP for energy label A and A+ are positive and highly statistically significant, with point estimates equal to CHF 7970 and CHF 13,250 respectively (2017 exchange rate CHF 1 ≈ USD 1). WTP estimates for technologies indicate small and statistically insignificant mean estimates for boilers operating on natural gas or wood pellets relative to heating oil, whereas mean WTP for a heating appliance powered by a heat pump using electricity is around CHF 10,350. The investment cost variable is negative and highly statistically significant, indicating that respondents traded-off attributes and the cost as expected.

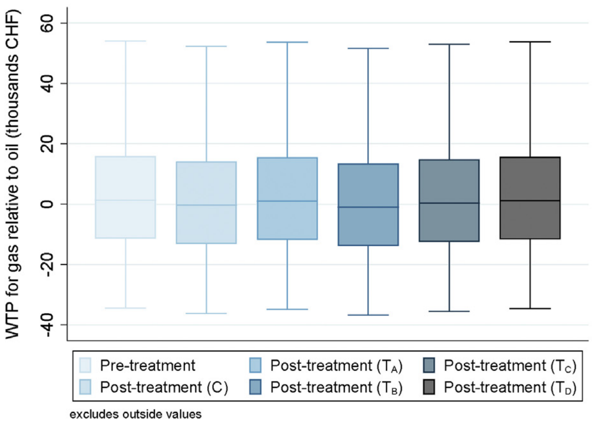
Our results also show that all standard deviation estimates are highly statistically significant and relatively large in magnitude. This indicates substantial heterogeneity in WTP across respondents. We note that heterogeneity is particularly pronounced for alternative technologies, where the standard deviations exceed the mean estimates by a large margin, and suggest that a fraction of respondents hold negative WTP for some of the technologies. This is illustrated in Fig. 4, which displays boxplots of simulated individual-specific WTP for all attributes both before treatment and, separately for each treatment condition, after treatment. Specifically, panel (c) shows that before treatment about 50% of homeowners in our sample are unwilling to pay a premium in exchange for a boiler operating on natural gas relative to heating oil. Moreover, only about 40% (20%) of respondents are willing to pay an investment cost premium of about CHF 15,000 in exchange for



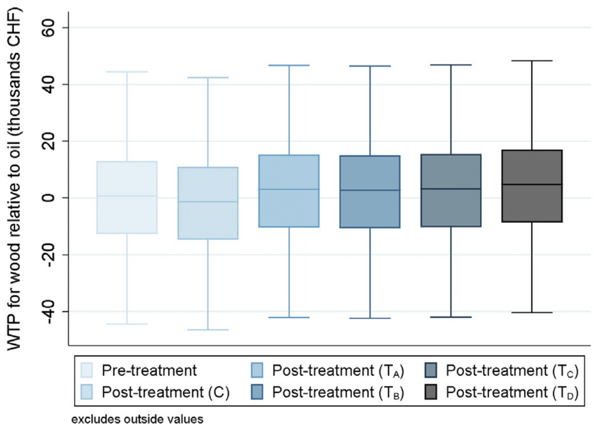
(a) Energy label A



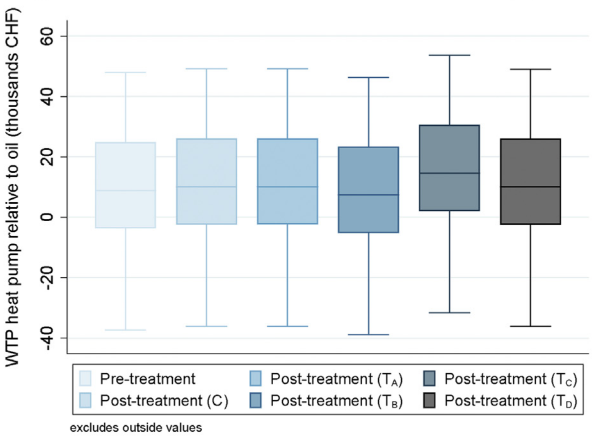
(b) Energy label A^+



(c) Natural gas



(d) Wood pellets



(e) Heat pump

Fig. 4. Distributions of simulated individual-specific WTP by treatment status. *Notes:* The boxplots summarize the distribution of simulated individual-specific WTP before and after treatment, where the latter are conditioned on treatment conditions. The lines in the box represent the 25th, 50th and 75th percentile, while the whiskers extend to include lower and upper adjacent values to the respective quartiles. 2017 exchange rate approx. CHF 1 = USD 1.

Table 3
Mixed logit model estimates in WTP space (thousands CHF).

	Main effects (pre-treatment estimates)		Interaction effects (post-treatment estimates)				
	Mean	Std. dev.	Post $\times P_t$	Heating cost $\times P_t \cdot T_A$	Heating cost salient $\times P_t \cdot T_B$	CO_2 tax $\times P_t \cdot T_C$	CO_2 tax salient $\times P_t \cdot T_D$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Energy label A	7.97***	9.10***	1.03	−4.00*	1.64	−6.21**	−1.89
	(0.92)	(0.76)	(1.40)	(2.06)	(2.02)	(2.73)	(2.13)
Energy label A+	13.25***	10.28***	2.33	−0.59	4.40**	−5.16***	−1.24
	(1.15)	(1.06)	(1.54)	(2.69)	(2.06)	(1.92)	(2.38)
Natural gas	2.98	21.73***	−1.74	1.38	−0.64	0.70	1.54
	(3.52)	(2.03)	(2.68)	(2.96)	(2.74)	(4.08)	(3.38)
Wood pellets	0.01	20.56***	−1.99	4.32	3.99	4.41	5.99
	(3.06)	(1.86)	(2.14)	(3.64)	(2.55)	(2.98)	(3.93)
Heat pump	10.35***	21.39***	1.21	0.02	−2.76	4.48	−0.04
	(1.64)	(1.57)	(1.82)	(2.63)	(2.78)	(3.32)	(2.68)
Investment cost	−1.55***	0.56***	–	–	–	–	–
	(0.13)	(0.15)	–	–	–	–	–
Observations	18,204						
Subjects (clusters)	511						
Log-pseudolikelihood	−4065						
AIC	8205						
BIC	8453						
Pseudo R^2	0.39						

Notes: MXL estimation for the full sample of homeowners reported. Column (1) reports pre-treatment mean WTP estimates (in thousands CHF), and column (2) displays corresponding standard deviation estimates. Reference categories for the energy labels (A, A+) and the technology variables (natural gas, wood pellets, heat pump) are energy label B and heating oil, respectively. Column (3) reports (mean) interaction effects of each attribute with a post-treatment indicator variable. Column (4) reports interaction effects of each attribute with a post-treatment indicator specific for treatment condition T_A (=1 if the choice is made after being subject to treatment condition T_A). Columns (5–7) report interaction effects for treatment conditions T_B, T_C, and T_D, respectively. 2017 exchange rate CHF 1 ≈ USD 1. Standard errors are clustered at the respondent-level and reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

an air source heat pump (wood pellet-based boiler), and less than 10% consent to invest an extra CHF 40,000 in a ground source heat pump (see panels d and e).[16]

Turning to post-treatment results, column (3) shows that on average the placebo intervention (C) had no statistically significant impact on respondents' WTP. This suggests that the within-subject design generates WTP evidence that remains stable despite time-varying factors such as learning and fatigue. However, this is also true for most treatment interventions, as apparent in Fig. 4. More specifically, column (4) shows that the impact of treatment condition T_A is marginally significantly negative on the WTP for energy label A, and near zero for label A+. When financial implications are made salient during the choice tasks (condition T_B, column 5), WTP for energy label A increase by CHF 1640 on average (p-value > 0.1), and by CHF 4400 for label A+ (p-value < 0.05)

Importantly, both pre-treatment and post-treatment WTP of conditions T_A and T_B bunch around CHF 15,000 for energy label A+ relative to B (see Fig. 4). As a result, WTP is more than twice the expected financial gains that were communicated in the informational intervention (CHF 390 energy savings per year, or CHF 5850 for 15-year undiscounted, 2017 energy prices). This suggests that homeowners also consider non-monetary benefits when evaluating energy efficiency investments. As expected, we observe no impacts on WTP for alternative technologies.

Lastly, columns (6) and (7) show that informing homeowners about carbon tax payments associated with fossil fuel-based technologies (treatment conditions T_C and T_D) has no statistically significant effect on average WTP for lower-carbon technologies. This result is also illustrated in Fig. 4, panels (c–e). It shows that even after being informed about environmental benefits of low-carbon technologies, homeowners are on average unwilling to pay associated cost premiums (CHF 15,000 for wood pellets and air source heat pumps relative to oil, and CHF 40,000 for ground source heat pumps, see EnergieSchweiz, 2020). Unexpectedly, treatment condition T_C decreases respondents' WTP for energy labels A and A+ (column 6), although this effect vanishes once carbon tax payments are made salient (condition T_D, column 7).

[16] In Appendix C, Fig. C1, we explore potential drivers of the observed heterogeneity. In particular, we display boxplots for simulated individual-specific WTP before treatment, separated by alternative sets of household characteristics (i.e., by age, education, income, dwelling size, individual metering, and heating costs). Differences in simulated WTP across subsamples are minor. Heterogeneity based on the pre-existing heating technology is explored in the next section.

4.2. Pre-treatment preferences and the role of familiarity

In Fig. 5, we report kernel densities for simulated individual-specific WTP before treatment, with median WTP indicated as a vertical bar. For each attribute, we condition on the pre-existing heating technology of participants (oil, natural gas, or others).[17] Panels (a) and (b) show pre-treatment WTP for energy efficiency grades A and A$^+$ (relative to B), respectively. Panel (c) displays pre-treatment WTP for natural gas (relative to heating oil), whereas panels (d) and (e) focus respectively on wood pellets and heat pumps.

Panels (a) and (b) of Fig. 5 show that heating oil and natural gas users' preferences for energy efficiency are close to those of the remainder of the sample. By contrast, panels (c) to (e) with simulated WTP for heating technologies show significant variations across pre-existing technologies. Specifically, median WTP estimates suggest that users value pre-existing technologies significantly more than alternatives, with a substantial portion of gas, wood, and heat pump users favoring the more familiar technology. This is consistent with the previously cited status quo or familiarity effect inherent in homeowners' heating technology choices. Quantitatively, about 80% of both natural gas users and heat pump users are willing to pay the expected market premium for the familiar technology relative to oil (no premium for gas and CHF 15,000 for air source heat pumps), whereas the same is true for about 40% of wood users (CHF 15,000 differential) and 20% of heat pump users with respect to ground source heat pumps (CHF 40,000 differential, see EnergieSchweiz, 2020).

One important finding is that oil users' median WTP to switch to other, lower-carbon technologies is either negative or close to zero in all cases. Moreover, the simulated distribution for these owners is slightly more dispersed toward lower valuations than that of non-oil users. Importantly, only about 30% of oil users are willing to pay more for a boiler operating on natural gas compared to the familiar technology. About 20% are willing to cover the expected investment cost premium for an air source heat pump and about 10% for a wood pellet-based boiler (CHF 15,000 differential each, see EnergieSchweiz, 2020). Finally, less than 5% of oil users consent to cover the extra investment associated with a ground source heat pump (CHF 40,000). This confirms a certain unwillingness to switch technology among a large proportion of oil users as well.[18]

4.3. WTP results for fossil fuel users and technology subsidy

We now focus on preferences and informational treatment effects pertaining to respondents whose pre-existing technology uses fossil fuels. MXL regression results reported in Table 4, based on equation (3), only consider the DCE response data of homeowners who currently heat their dwelling with heating oil or natural gas ($N = 386$). The structure of the table follows the logic of Table 3.

Fossil fuels users' WTP for energy efficiency labels reported in column (1) are comparable with those derived from the main sample: CHF 8410 for energy label A relative to B, and CHF 11,780 for label A$^+$. The same is true for natural gas (CHF 3300 relative to heating oil). By contrast, fossil fuel users display a lower average WTP for wood pellet-based heating systems (CHF −2630 compared to CHF 10 in Table 3), and a lower average WTP for heat pumps (CHF 4430 compared to CHF 10,350 in Table 3). These results are consistent with the discussion in the previous section. The coefficient for investment cost and the standard deviation estimates reported in column (2) are also very similar to those for the main sample.

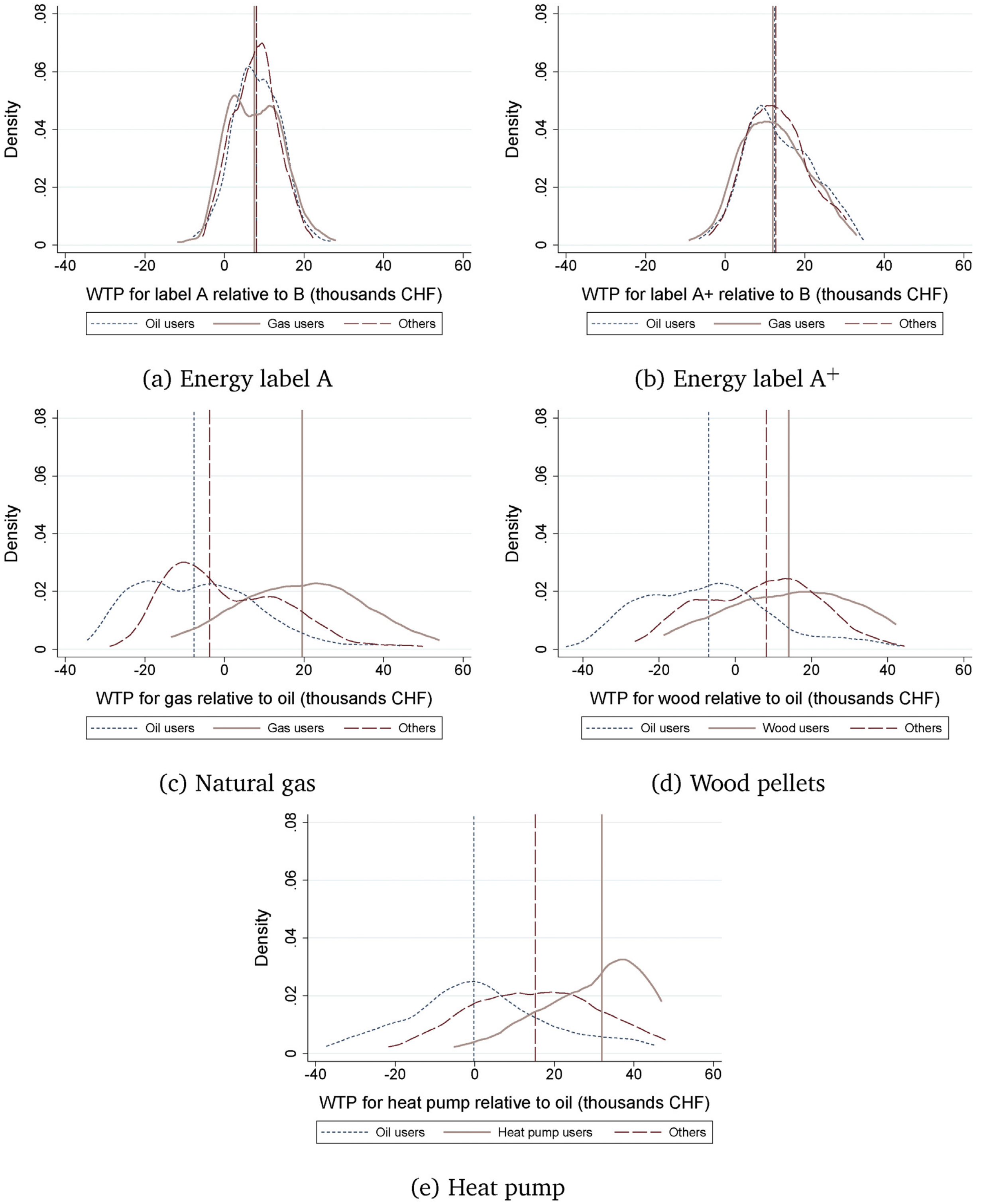
Turning to the effect of the informational interventions, column (3) shows that fossil fuel users are barely affected by the control intervention (C), and information about heating cost savings (treatment conditions T_A and T_B) has no significant impact on WTP for energy efficiency (columns 4 and 5). Similar to the main sample, WTP for energy label A$^+$ (relative to B) amounts to over CHF 13,000 after being exposed to conditions T_A and T_B, which is more than double the communicated heating cost savings (CHF 390 energy savings per year, or CHF 5850 for 15-year undiscounted, 2017 energy prices). Instead, heating cost treatments increase average WTP for wood pellet-based boilers (relative to heating oil) by CHF 5400 (column 4, p-value < 0.05) and CHF 4060 (column 5, p-value < 0.1). The increase is, however, relatively small as compared to the standard deviation of the WTP distribution (see Appendix C, Fig. C2).

Information about carbon tax payments levied on fossil fuels (treatment conditions T_C and T_D) tend to increase WTP for low-carbon solutions. Specifically, average WTP for wood pellet-based solutions (relative to heating oil) increases by CHF 5060 (column 6) and CHF 7010 (column 7) depending on salience. The average treatment effect on WTP for heat pumps (relative to oil) is CHF 4050 (p-value < 0.1). However, Appendix C, Fig. C2, again illustrates that overall the differences in magnitudes between pre-treatment and post-treatment WTP are small.

Next, we use the coefficient estimates reported in Table 4 to predict choice probabilities for alternative heating replacement scenarios. These are summarized in Table 5. In scenario 1, we predict fossil fuel users' probability of choosing a highly efficient (energy label A$^+$) wood pellet-based heating system over a cheap (CHF 20,000 investment cost), standard (energy label B) oil-based alternative, at various levels of investment cost associated with the wood pellet boiler. In a second step,

[17] The subcategory "Others" is composed of different user categories, namely wood pellets, heat pump, and electricity for panels (a–c), natural gas, heat pump, and electricity for panel (d), and natural gas, wood pellets, and electricity for panel (e).

[18] Given that average age in our sample is relatively high in comparison to the general population, reflecting the fact that we focus on homeowners, one hypothesis we have tested is whether preferences for the pre-existing technology are different for younger and older respondents. However, we did not find significant differences in the distribution of WTP in that dimension.



(a) Energy label A

(b) Energy label A$^+$

(c) Natural gas

(d) Wood pellets

(e) Heat pump

Fig. 5. Pre-treatment distributions of simulated individual-specific WTP by pre-existing heating technology. *Notes:* Each kernel density estimate uses Epanechnikov kernel function with an optimal bandwidth. The vertical lines represent the corresponding estimates for the median. 2017 exchange rate CHF 1 ≈ USD 1.

Table 4
Mixed logit model estimates in WTP space for fossil fuel users (thousands CHF).

	Main effects (pre-treatment estimates)		Interaction effects (post-treatment estimates)				
	Mean	Std. dev.	Post $\times P_t$	Heating cost $\times P_t \cdot T_A$	Heating cost salient $\times P_t \cdot T_B$	CO_2 tax $\times P_t \cdot T_C$	CO_2 tax salient $\times P_t \cdot T_D$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Energy label A	8.41***	8.04***	0.44	−1.60	2.20	−4.49*	−1.13
	(0.70)	(0.69)	(1.65)	(2.09)	(2.18)	(2.45)	(2.14)
Energy label A+	11.78***	11.45***	2.73*	−0.61	3.70	−5.62***	−1.06
	(0.87)	(0.83)	(1.46)	(1.85)	(3.18)	(1.96)	(2.04)
Natural gas	3.30***	23.74***	−1.41	1.24	−1.28	2.00	0.65
	(0.94)	(2.49)	(2.16)	(2.51)	(2.54)	(2.60)	(3.16)
Wood pellets	−2.63***	20.24***	−2.77	5.40**	4.06*	5.06**	7.01**
	(1.02)	(1.67)	(1.94)	(2.30)	(2.35)	(2.46)	(3.32)
Heat pump	4.43***	17.66***	1.09	1.54	−3.57	4.05*	−1.00
	(0.81)	(1.39)	(1.64)	(2.24)	(3.23)	(2.38)	(2.88)
Investment cost	−1.33***	0.83***	–	–	–	–	–
	(0.16)	(0.19)	–	–	–	–	–
Observations	13,773						
Subjects (clusters)	386						
Log-pseudolikelihood	−3111						
AIC	6296						
BIC	6534						
Pseudo R^2	0.38						

Notes: MXL estimation for the sample of oil and natural gas users. Column (1) reports pre-treatment mean WTP estimates (in thousands CHF), and column (2) displays corresponding standard deviation estimates. Reference categories for the energy labels (A, A+) and the technology variables (natural gas, wood pellets, heat pump) are energy label B and heating oil, respectively. Column (3) reports (mean) interaction effects of each attribute with a post-treatment indicator variable. Column (4) reports interaction effects of each attribute with a post-treatment indicator specific for treatment condition T_A (=1 if the choice is made after being subject to treatment condition T_A). Columns (5–7) report interaction effects for treatment conditions T_B, T_C, and T_D, respectively. 2017 exchange rate CHF 1 ≈ USD 1. Standard errors are clustered at the respondent-level and reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

Table 5
Selected heating replacement scenarios.

	Standard heating system		Low-carbon alternative	
Energy label	B	B	A+	A+
Heating technology	Boiler with heating oil	Boiler with natural gas	Boiler with wood pellets	Heat pump using electricity
Investment cost	CHF 20,000	CHF 20,000	Varying	Varying
Scenario	1 and 2	3 and 4	1 and 3	2 and 4

Notes: 2017 exchange rate CHF 1 ≈ USD 1.

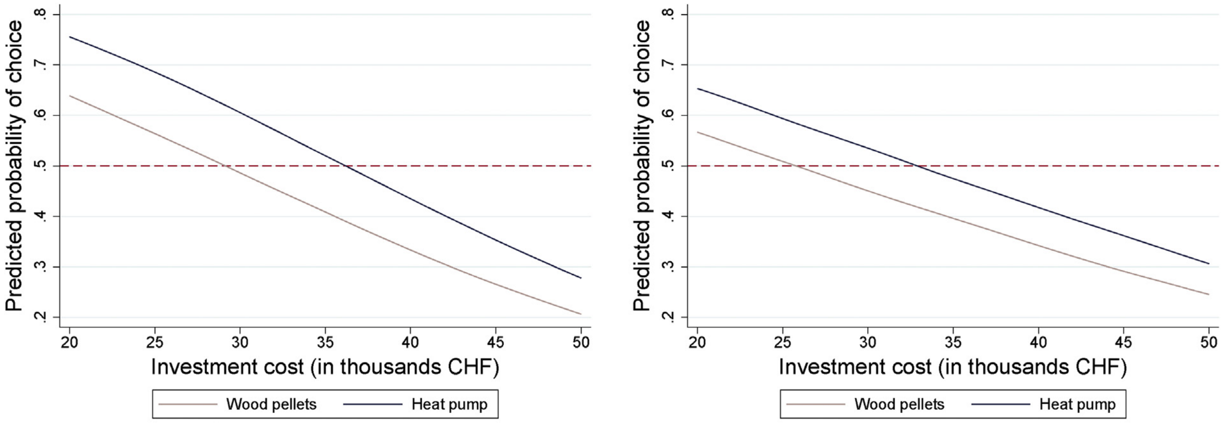
we replace the wood pellet boiler with a heat pump using electricity (scenario 2). In a third step, we replace the oil-based reference scenario with a boiler operating on natural gas (scenarios 3 and 4).

We illustrate the resulting predictions for scenarios 1 and 2 in Fig. 6, panel (a). Specifically, we plot fossil fuel users' predicted probability of choosing a highly efficient (energy label A+) low-carbon heating system over a relatively cheap (CHF 20,000 investment cost), standard (energy label B) oil-based alternative, as a function of the investment cost associated with the low-carbon alternative. This shows that the probability of selecting the low-carbon solution falls below 50% at an investment cost of CHF 29,000 for wood pellets and CHF 36,000 for heat pumps.

Fig. 6, panel (b), displays the same functions for a choice between a standard (energy label B) heating system operating on natural gas at CHF 20,000 investment cost and an efficient option based on either wood pellets or heat pump (scenarios 3 and 4). In this case, the predicted probability of switching to the efficient low-carbon solution falls below 50% at an investment cost of CHF 25,000 for wood pellets and CHF 32,000 for heat pumps.

Comparing these results with current market prices is indicative of the level of subsidy that would incentivize fossil fuel users to invest in low-carbon technologies. In our setting, EnergieSchweiz (2020) reports that oil-based and gas-based heating systems cost approx. CHF 20,000, CHF 35,000 for wood pellet-based heating systems and air source heat pumps, and CHF 60,000 for ground source heat pumps. These data suggest that phasing out heating oil would require subsidies of about CHF 6000 for wood pellets (scenario 1) and CHF 24,000 for ground source heat pumps (scenario 2), whereas air source heat pumps do not require additional incentives (scenario 2). By contrast, moving away from natural gas calls for a public subsidy of about CHF 10,000 for wood pellets (scenario 3), CHF 28,000 for ground source heat pumps (scenario 4), and CHF 3000 for air source heat pumps (scenario 4).

Lastly, we note that our information treatments suggest that informing fossil fuel users about CO_2 tax payments has the potential to reduce the size of the required public subsidy for low-carbon alternatives. While the reduction associated with



(a) Relative to standard oil-based alternative (scenarios 1 and 2)

(b) Relative to standard gas-based alternative (scenarios 3 and 4)

Fig. 6. Fossil fuel users' predicted probability to choose highly efficient low-carbon heating system (before treatment). *Notes:* The graph depicts the predicted probability of choosing a highly efficient low-carbon solution over a cheap (CHF 20,000) standard fossil fuel-based solution as a function of investment cost of the low-carbon solution. See Table 5 for the definition of the scenarios. 2017 exchange rate CHF 1 ≈ USD 1.

the required subsidy for ground source heat pumps is relatively low in magnitude (air source heat pumps do not require additional incentives), our results show that salient information about the carbon tax might eliminate the need for additional financial incentives promoting wood pellets.

5. Discussion and conclusion

In order to meet stringent CO_2 abatement targets, homeowners are expected to invest in energy efficiency and low-carbon energy sources. However, while these types of investments have the potential to substantially reduce CO_2 emissions, the level of realized investment remains low. In this paper, we conducted a DCE on a sample of 511 Swiss homeowners to estimate their valuation of various product attributes related to alternative replacement heating appliances, and study how they respond to informational interventions laying out financial implications of their choices.

In a nutshell, our findings suggest that homeowners are willing to invest on average CHF 7970 (2017 exchange rate CHF 1 ≈ USD 1) for efficiency class A and CHF 13,250 for class A^+ (both relative to B). While homeowners' WTP for label A^+ can be increased slightly with salient information on heating costs (by CHF 4400 on average), WTP of fossil fuel users is not affected by information. This could suggest that a significant share of respondents is already well informed about expected energy savings, which is in line with recent literature challenging the importance of imperfect information and inattention for energy efficiency investment decisions (Allcott and Wozny, 2014; Jacobsen, 2015; Allcott and Taubinsky, 2015). But in our case, we cannot rule that this is a specific feature of the participants in our survey.

We further identify large heterogeneity in preferences for different heating technologies (i.e., heating oil, natural gas, wood pellets, and heat pump), with a significant share of respondents experiencing disutility from switching to a technology that is different from the one currently installed at their home. In particular, our results suggest that fossil fuel users are not willing to pay investment cost differentials associated with low-carbon technologies, as their average WTP to switch to wood pellets or heat pumps (both relative to heating oil) is CHF −2630 and CHF 4430, respectively. Moreover, while fossil fuel users' preferences are only weakly affected by information about CO_2 tax payments, the interventions have the potential to reduce the need for subsidies promoting low-carbon choices (by CHF 5060–7010 for wood pellets and CHF 4050 for heat pumps on average).

In view of reducing CO_2 emissions from residential space heating, our findings provide useful insights for effective policy design. On the one hand, it seems that homeowners value energy efficiency beyond simply financial returns on average, and that there is limited potential to correct imperfect information market failure and attentional biases with information programs targeting private and pro-social consequences of choices (note that this conclusion likely does not extend to tenants, see Myers, 2020; Lang and Lanz, 2021). On the other hand, fossil fuel users might be unwilling to invest in low-carbon technologies simply because they hold strong and persistent preferences towards the familiar technology. As a result, promoting and incentivizing specific low-carbon technologies might be more effective than subsidizing appliances with higher energy efficiency, and policies are likely to benefit from targeting and segmentation (e.g., based on the currently installed heating system).

Conflict of interest

The authors acknowledge financial support from the University of Neuchatel (primary employer) as well as from Innosuisse under Grant No. KTI. 1155000154.

Appendix A. Experimental script

In this section of the survey, we will focus on the use of energy to heat and produce warm water for your dwelling, also called central heating system. We will focus on the dwelling you currently own and live in.

We want to understand your perceptions about alternative central heating choices. The information that we collect will be used to inform Swiss energy policy, and it is therefore important that your answers reflect your specific situation and your personal tastes.

In particular, some of the following questions will involve costs to your own household; please give careful consideration to how these costs would affect your financial budget.

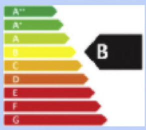
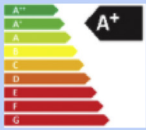
Fig. A1. Introductory screen 1.

For the next set of questions, please imagine that the current appliance supplying heat to your dwelling has to be replaced. We will consider a set of replacement options, and these options are described by:

- The technology and associated fuel:
  - A boiler that burns either heating oil, natural gas, or wood pellets to warm the house
  - A heat pump that pulls heat from outside to warm the house, using electricity
- The one-off investment cost that has to be paid to install the new appliance, in Swiss Francs (Fr.)
- A standard label grading how efficient the appliance is at converting the energy in its fuel to heat. Energy efficiency is graded from G (very low) to A++ (very high), and the label for grade A looks like this:

Fig. A2. Introductory screen 2.

Here is an example of the choice we want you to consider. Each offer (I, II and III) describes an alternative central heating appliance that would fully replace your current one. They differ in terms of the heating technology, its investment cost, and its energy efficiency, which is represented by the efficiency label.

	Offer I	Offer II	Offer III
Heating technology	Boiler with natural gas	Boiler with wood pellets	Boiler with heating oil
Investment cost	Fr. 10'160	Fr. 17'030	Fr. 13'010
Energy label			

Which offer do you prefer?	I ○	II ○	III ○

Aside from the specific characteristics of the appliances, please assume that they meet your general requirements, perform equally well, and are expected to have the same operating life of 15 years.

When making your choices, please assume that the change of appliance will necessarily take place in 2017. The selected heating appliance would fully replace your current central heating appliance, but the rest of your heating system, such as the radiators, would not need to be changed.

Fig. A3. Introductory screen 3.

You will now be asked to make 6 decisions. All decisions have the same format.

In making your choices, please remember that any money spent on your heating will not be available for other expenses by your household. The only right answer is what you would choose in reality.

Fig. A4. Introductory screen 4.

	Offer I	Offer II	Offer III
Heating technology	Boiler with heating oil	Boiler with wood pellets	Heat pump using electricity
Investment cost	Fr. 23'090	Fr. 13'010	Fr. 17'030
Energy label			
	I	II	III
Which offer do you prefer?	○	○	○

Fig. A5. Example pre-treatment choice task.

In the next part of the study, you will have the opportunity to learn more about the construction year of residential buildings.

The discussion will be followed by a one-question quiz. Please pay close attention to the discussion so that you can correctly answer the quiz question.

Fig. A6. Instructions for information screens (C).

In the next part of the study, you will have the opportunity to learn more about energy efficiency and heating costs.

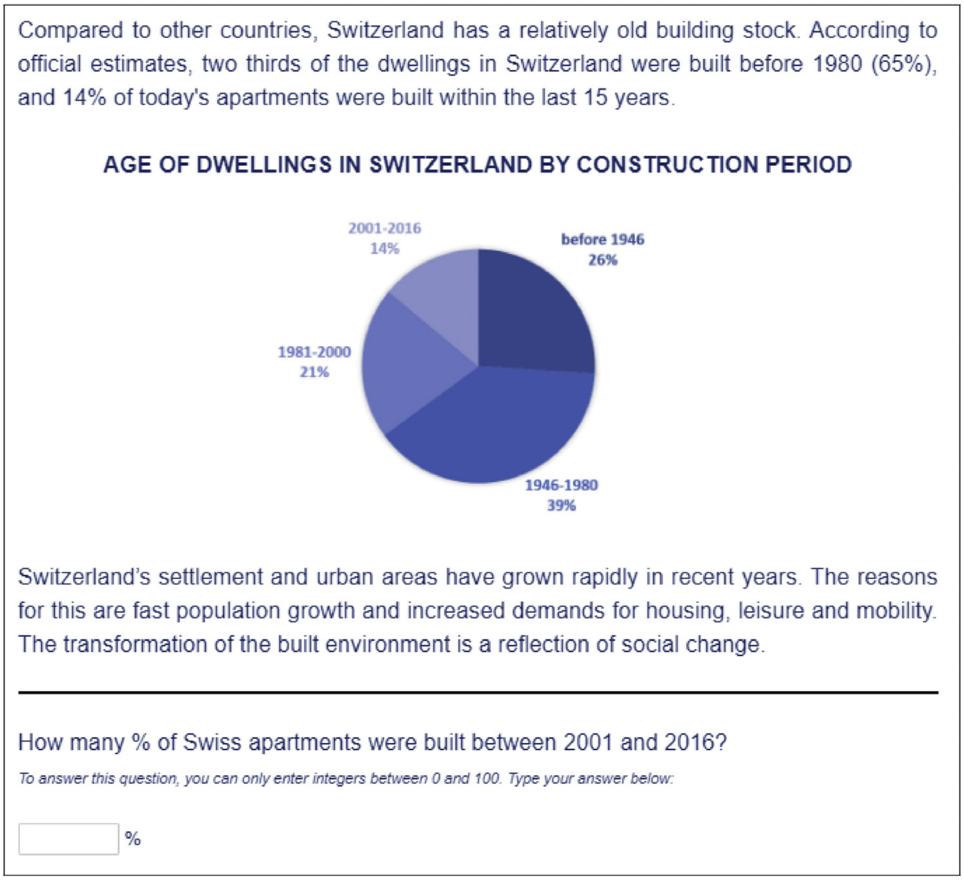
The discussion will be followed by a one-question quiz. Please pay close attention to the discussion so that you can correctly answer the quiz question.

Fig. A7. Instructions for information screens (T_A and T_B).

In the next part of the study, you will have the opportunity to learn more about the CO_2 tax on heating oil and natural gas.

The discussion will be followed by a one-question quiz. Please pay close attention to the discussion so that you can correctly answer the quiz question.

Fig. A8. Instructions for information screens (T_C and T_D).



Compared to other countries, Switzerland has a relatively old building stock. According to official estimates, two thirds of the dwellings in Switzerland were built before 1980 (65%), and 14% of today's apartments were built within the last 15 years.

AGE OF DWELLINGS IN SWITZERLAND BY CONSTRUCTION PERIOD

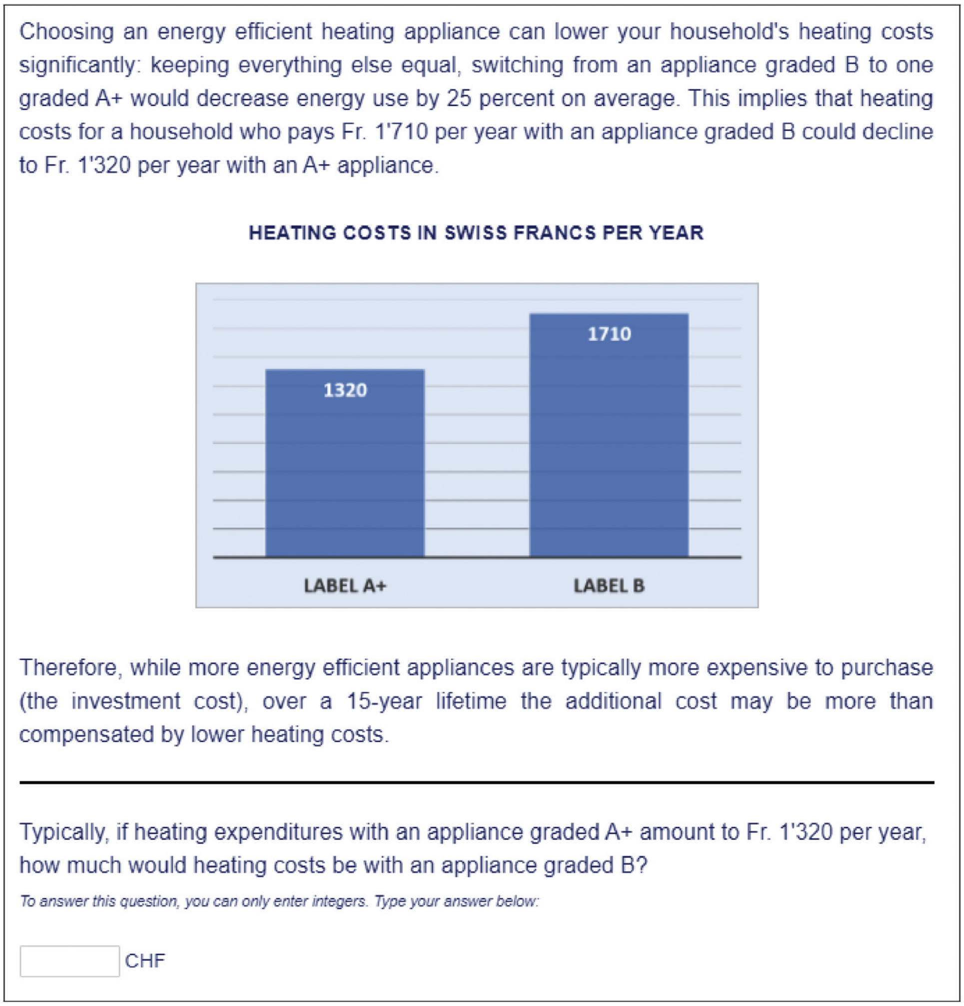
Switzerland's settlement and urban areas have grown rapidly in recent years. The reasons for this are fast population growth and increased demands for housing, leisure and mobility. The transformation of the built environment is a reflection of social change.

How many % of Swiss apartments were built between 2001 and 2016?

To answer this question, you can only enter integers between 0 and 100. Type your answer below:

%

Fig. A9. Information screen – Neutral (C).



Choosing an energy efficient heating appliance can lower your household's heating costs significantly: keeping everything else equal, switching from an appliance graded B to one graded A+ would decrease energy use by 25 percent on average. This implies that heating costs for a household who pays Fr. 1'710 per year with an appliance graded B could decline to Fr. 1'320 per year with an A+ appliance.

Therefore, while more energy efficient appliances are typically more expensive to purchase (the investment cost), over a 15-year lifetime the additional cost may be more than compensated by lower heating costs.

Typically, if heating expenditures with an appliance graded A+ amount to Fr. 1'320 per year, how much would heating costs be with an appliance graded B?

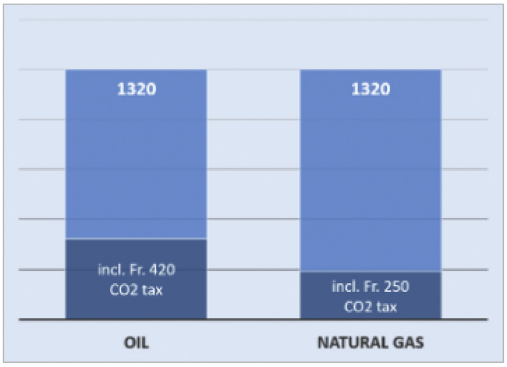
To answer this question, you can only enter integers. Type your answer below:

CHF

Fig. A10. Information screen - Heating costs (T_A and T_B).

Switzerland participates in international efforts to reduce the risk of climate change, and the government has passed laws that require a reduction in CO_2 emissions of 20 percent from 1990 to 2020. Fossil fuels are important contributors to CO_2 emissions and, since 2008, in Switzerland heating oil and natural gas are taxed in proportion to the CO_2 emitted when they are used in heating systems.

HEATING COST IN SWISS FRANCS PER YEAR



This CO_2 tax has increased from Fr. 12 per ton of CO_2 emitted in 2008 to Fr. 84 per ton of CO_2 in 2016. At the current rate, this corresponds to a tax on heating oil of around Fr. 420 for an annual heating bill of Fr. 1’320, while the tax on natural gas amounts to Fr. 250 for an annual heating bill of Fr. 1’320. For other fuels, including wood and electricity, the CO_2 tax is nil.

If your heating system is operating on heating oil and your annual heating bill amounts to Fr. 1'320, how high is the associated CO2 tax payment?

To answer this question, you can only enter integers. Type your answer below:

[   ] CHF

Fig. A11. Information screen – CO_2 tax (T_C and T_D).

Now please consider again the possibility that your current primary heating appliance needs replacement, and that the installation will necessarily take place in 2017. You have a choice between three alternative replacement options, such as the ones presented below.

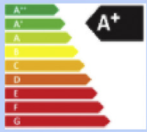
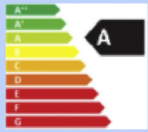
	Offer I	Offer II	Offer III
Heating technology	Boiler with natural gas	Boiler with wood pellets	Boiler with heating oil
Investment cost	Fr. 10'160	Fr. 17'030	Fr. 13'010
Energy label			

Fig. A12. Instructions for post-treatment choice task (C, T_A and T_C).

Now please consider again the possibility that your current primary heating appliance needs replacement, and that the installation will necessarily take place in 2017. You have a choice between three alternative replacement options, such as the ones presented below.

In addition, we now report an average total heating and warm water cost that you would have to pay. It is represented by the last row titled "yearly heating costs".

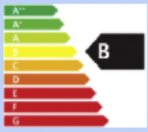
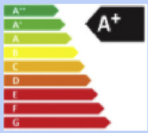
	Offer I	Offer II	Offer III
Heating technology	Boiler with natural gas	Boiler with wood pellets	Boiler with heating oil
Investment cost	Fr. 10'160	Fr. 17'030	Fr. 13'010
Energy label			
Annual heating costs	Fr. 1'710	Fr. 1'320	Fr. 1'530

Fig. A13. Instructions for post-treatment choice task with heating costs (T_B).

Now please consider again the possibility that your current primary heating appliance needs replacement, and that the installation will necessarily take place in 2017. You have a choice between three alternative replacement options, such as the ones presented below.

In addition, we now report an average total heating and warm water cost that you would have to pay, which includes the amount of CO_2 tax paid per year. It is represented by the last row titled "yearly heating costs".

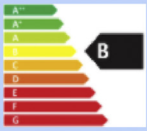
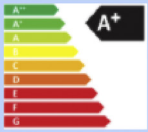
	Offer I	Offer II	Offer III
Heating technology	Boiler with natural gas	Boiler with wood pellets	Boiler with heating oil
Investment cost	Fr. 10'160	Fr. 17'030	Fr. 13'010
Energy label			
Annual heating costs	Fr. 1'710 (incl. Fr. 320 CO_2 tax)	Fr. 1'320 (no CO_2 tax)	Fr. 1'530 (incl. Fr. 490 CO_2 tax)

Fig. A14. Instructions for post-treatment choice task with heating costs and CO_2 tax (T_D).

In the following 6 questions, please select the replacement option you prefer, keeping in mind that the money spent on heating will not be available for other expenses by your household.

As in the previous questions, the only right answer is what you would choose in reality. It is important that you consider options carefully, as this research will contribute to inform energy policy in Switzerland.

Fig. A15. Instructions for post-treatment choice task (C, T_A-T_D).

	Offer I	Offer II	Offer III
Heating technology	Boiler with wood pellets	Heat pump using electricity	Boiler with natural gas
Investment cost	Fr. 17'030	Fr. 13'010	Fr. 23'090
Energy label	B	A+	A
Annual heating costs	CHF 1'710	CHF 1'320	CHF 1'530
	I	II	III
Which offer do you prefer?	○	○	○

Fig. A16. Example post-treatment choice task – Heating cost (T_B).

	Offer I	Offer II	Offer III
Heating technology	Boiler with wood pellets	Boiler with natural gas	Boiler with heating oil
Investment cost	Fr. 30'140	Fr. 10'160	Fr. 17'030
Energy label	B	A+	A
Annual heating costs	CHF 1'710 (no CO_2 tax)	CHF 1'320 (incl. Fr. 250 CO_2 tax)	CHF 1'530 (incl. Fr. 490 CO_2 tax)
	I	II	III
Which offer do you prefer?	○	○	○

Fig. A17. Example post-treatment choice task – Heating cost and CO_2 tax (T_D).

Appendix B. Sample composition

Table B1
Summary statistics for the sample of homeowners.

	N	Mean	Std. dev.	Min	Max
Age (in years)	511	55.79	(13.52)	21.00	85.00
University indicator	511	0.44	(0.50)	0.00	1.00
Household income[a]	443	4.46	(1.16)	1.00	6.00
Dwelling size (in m^2)	508	171.87	(84.84)	10.00	999.00
Oil heating indicator	511	0.47	(0.50)	0.00	1.00
Gas heating indicator	511	0.29	(0.45)	0.00	1.00
Individual meter for heating	511	0.86	(0.35)	0.00	1.00
Annual heating costs (in CHF)[b]	198	1919.54	(963.75)	250.00	5500.00

[a] Monthly gross household income is coded as: 1 – CHF 3000 or less; 2 – CHF 3000–4459; 3 – CHF 4500–5999; 4 – CHF 6000–8999; 5 – CHF 9000–12,000; 6 – CHF 12,000 or more.
[b] Annual household expenditures for heating, as per the latest energy bill available.

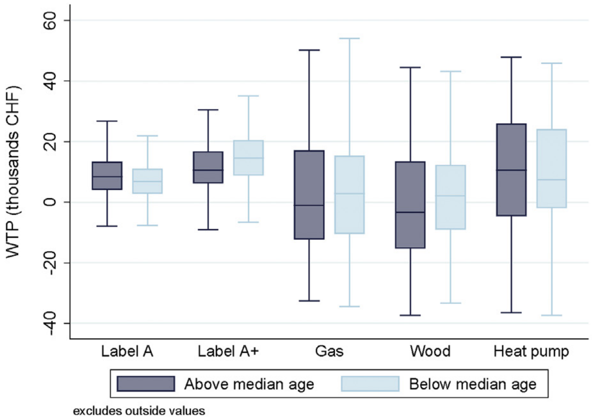
Table B2
Summary statistics across control and treatment conditions.

	C	T_A	T_B	T_C	T_D
Age (in years)	55.16	56.42	56.45	54.58	56.17
University indicator	0.51	0.45	0.37	0.43	0.44
Household income[a]	4.53	4.22	4.70	4.42	4.48
Dwelling size (in m^2)	165.96	175.63	168.26	170.15	179.72
Oil heating indicator	0.52	0.44	0.55	0.37	0.43
Gas heating indicator	0.25	0.29	0.27	0.27	0.37
Individual meter for heating	0.86	0.79	0.88	0.88	0.89
Annual heating costs (in CHF)[b]	1688.63	1883.52	1881.04	2082.16	2038.55
Observations	103	100	104	97	106

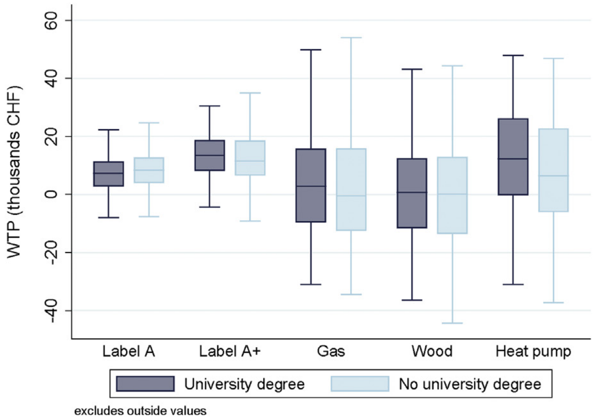
[a] Monthly gross household income is coded as: 1 – CHF 3000 or less; 2 – CHF 3000–4459; 3 – CHF 4500–5999; 4 – CHF 6000–8999; 5 – CHF 9000–12,000; 6 – CHF 12,000 or more.
[b] Annual household expenditures for heating, as per the latest energy bill available.

Appendix C. Additional figures

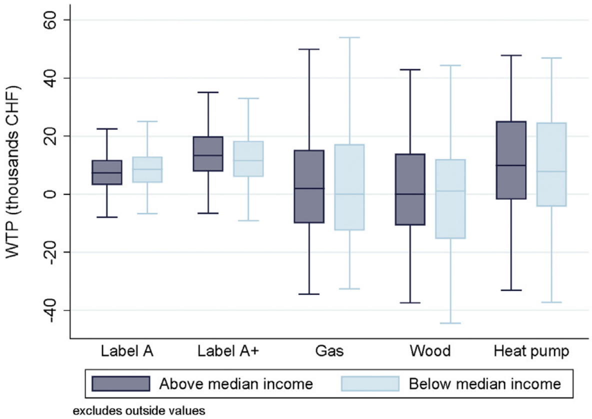
Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.reseneeco.2021.101231.



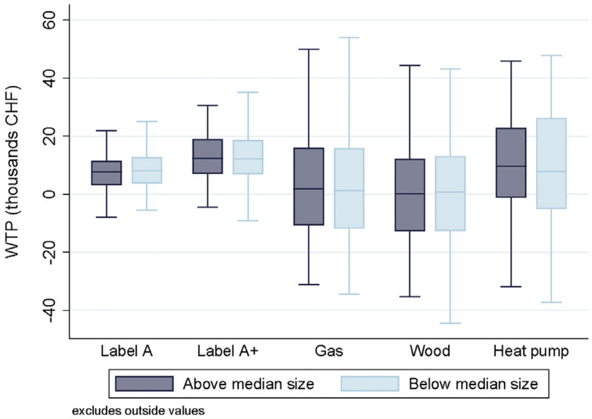
(a) Age (in years)



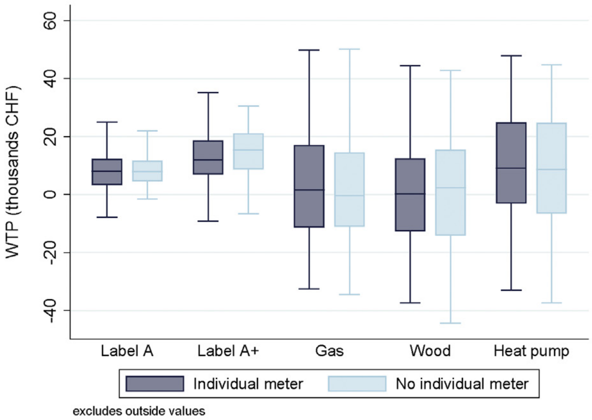
(b) University indicator



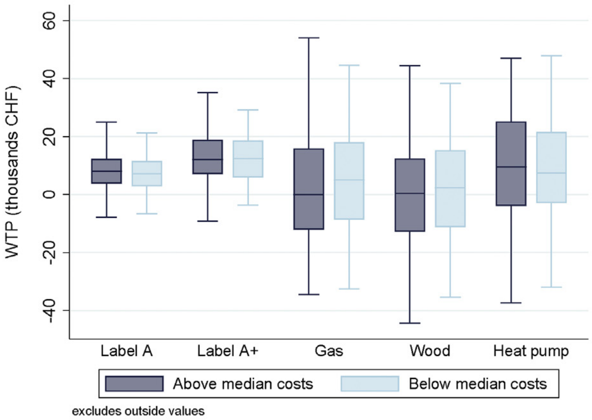
(c) Household income



(d) Dwelling size (in m^2)

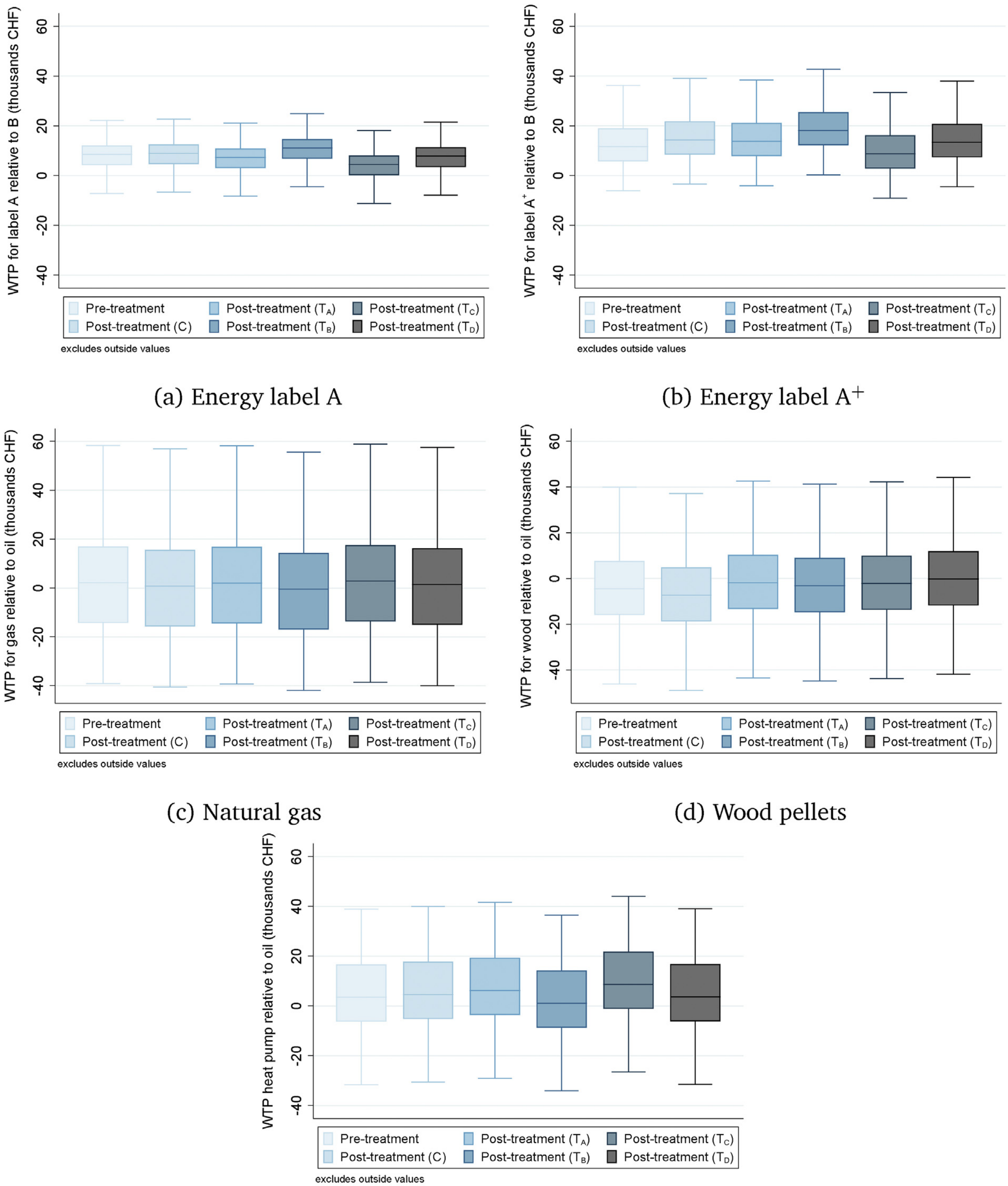


(e) Individual meter for heating



(f) Annual heating costs (in CHF)

Fig. C1. Distributions of simulated individual-specific WTP by household characteristics (before treatment). *Notes:* The boxplots summarize the distribution of simulated individual-specific WTP before treatment separately for various subsamples. The lines in the box represent the 25th, 50th and 75th percentile, while the whiskers extend to include lower and upper adjacent values to the respective quartiles. 2017 exchange rate CHF 1 ≈ USD 1.



(a) Energy label A

(b) Energy label A$^+$

(c) Natural gas

(d) Wood pellets

(e) Heat pump

Fig. C2. Distributions of fossil fuel users' simulated individual-specific WTP by treatment status. *Notes:* The boxplots summarize the distribution of simulated individual-specific WTP before and after treatment, where the latter are conditioned on treatment conditions. Only current heating oil and natural gas users are included. The lines in the box represent the 25th, 50th and 75th percentile, while the whiskers extend to include lower and upper adjacent values to the respective quartiles. 2017 exchange rate CHF 1 ≈ USD 1.

References

Achtnicht, M., Madlener, R., 2014. Factors influencing German house owners' preferences on energy retrofits. Energy Policy 68, 254–263.
Alberini, A., Bigano, A., 2015. How effective are energy-efficiency incentive programs? Evidence from Italian homeowners. Energy Econ. 52, S76–S85.
Alberini, A., Banfi, S., Ramseier, C., 2013. Energy efficiency investments in the home: Swiss homeowners and expectations about future energy prices. Energy J. 34, 1.
Allcott, H., Greenstone, M., 2012. Is there an energy efficiency gap? J. Econ. Perspect. 26 (1), 3–28.
Allcott, H., Knittel, C., 2019. Are consumers poorly informed about fuel economy? Evidence from two experiments. Am. Econ. J.: Econ. Policy 11 (1), 1–37.
Allcott, H., Taubinsky, D., 2015. Evaluating behaviorally motivated policy: experimental evidence from the lightbulb market. Am. Econ. Rev. 105 (8), 2501–2538.
Allcott, H., Wozny, N., 2014. Gasoline prices, fuel economy, and the energy paradox. Rev. Econ. Stat. 95 (5), 779–795.
Bakaloglou, S., Charlier, D., 2019. Energy consumption in the French residential sector: how much do individual preferences matter? Energy J. 40, 3.
Banfi, S., Farsi, M., Filippini, M., Jakob, M., 2008. Willingness to pay for energy-saving measures in residential buildings. Energy Econ. 30 (2), 503–516.
Bansal, P., Daziano, R.A., Achtnicht, M., 2018a. Comparison of parametric and semiparametric representations of unobserved preference heterogeneity in logit models. J. Choice Modell. 27, 97–113.
Bansal, P., Daziano, R.A., Achtnicht, M., 2018b. Extending the logit-mixed logit model for a combination of random and fixed parameters. J. Choice Modell. 27, 88–96.
Bazzani, C., Palma, M.A., Nayga Jr., R.M., 2018. On the use of flexible mixing distributions in WTP space: an induced value choice experiment. Aust. J. Agric. Resour. Econ. 62 (2), 185–198.
Blasch, J., Filippini, M., Kumar, N., 2019. Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances. Resour. Energy Econ. 56, 39–58.
Brent, D., Ward, M., 2018. Energy efficiency and financial literacy. J. Environ. Econ. Manag. 90, 181–216.
Burger, P., Schubert, I., Van Dijk, J., Puntiroli, M., Volland, B., Weber, S., Farsi, M., 2018. Consommation d'énergie des ménages en Suisse: Principaux résultats de l'enquête sur la consommation énergétique des ménages. Switzerland, Basel.
Campbell, D., Boeri, M., Doherty, E., Hutchinson, W.G., 2015. Learning, fatigue and preference formation in discrete choice experiments. J. Econ. Behav. Organ. 119, 345–363.
Caputo, V., Scarpa, R., Nayga Jr., R.M., 2017. Cue versus independent food attributes: the effect of adding attributes in choice experiments. Eur. Rev. Agric. Econ. 44 (2), 211–230.
Caputo, V., Scarpa, R., Nayga Jr., R.M., Ortega, D.L., 2018. Are preferences for food quality attributes really normally distributed? An analysis using flexible mixing distributions. J. Choice Modell. 28, 10–27.
Charness, G., Gneezy, U., Kuhn, M.A., 2012. Experimental methods: between-subject and within-subject design. J. Econ. Behav. Organ. 81 (1), 1–8.
Council of European Union, 2013. Commission Delegated Regulation (EU) No. 811/2013. Brussels, Belgium.
Day, B., Bateman, I.J., Carson, R.T., Dupont, D., Louviere, J.J., Morimoto, S., Scarpa, R., Wang, P., 2012. Ordering effects and choice set awareness in repeat-response stated preference studies. J. Environ. Econ. Manag. 63 (1), 73–91.
EIA, 2015. Residential Energy Consumption Survey (RECS). U.S. Energy Information Administration (EIA), Washington, DC.
Energieheld Schweiz, 2020. Preise und Einbau - Kosten für eine Heizung in der Schweiz. Emmen, Switzerland.
EnergieSchweiz, 2020. Heizkostenrechner. Swiss Federal Office of Energy (SFOE), Bern, Switzerland.
Eurostat, 2017. Energy Consumption in Households. Luxembourg.
Federal Council, 2012. Ordinance on the Reduction of CO2 Emissions (CO2 Ordinance). Bern, Switzerland.
Federal Council, 2016. Imposition of the CO2 Levy on Heating and Process Fuels. Bern, Switzerland.
Franceschinis, C., Scarpa, R., Thiene, M., Rose, J., Moretto, M., Cavalli, R., 2016. Exploring the spatial heterogeneity of individual preferences for ambient heating systems. Energies 9 (6), 407.
FSO, 2017. Heating System and Energy Sources. Federal Statistical Office (FSO), Bern, Switzerland.
FSO, 2019a. Construction and Housing. Federal Statistical Office (FSO), Bern, Switzerland.
FSO, 2019b. Sonderauswertung zur Haushaltsbudgeterhebung 2015-2017: Haushaltseinkommen und -ausgaben nach Bewohnertyp. Federal Statistical Office (FSO), Bern, Switzerland.
FSO, 2019c. Sonderauswertung zur Strukturerhebung: Wohnverhaeltnisse. Federal Statistical Office (FSO), Bern, Switzerland.
FSO, 2020. Bau- und Wohnungswesen: Panorama. Federal Statistical Office (FSO), Neuchâtel, Switzerland.
Gerarden, T.D., Newell, R.G., Stavins, R.N., 2017. Assessing the energy-efficiency gap. J. Econ. Lit. 55 (4), 1486–1525.
Gillingham, K., Palmer, K., 2014. Bridging the energy efficiency gap: policy insights from economic theory and empirical evidence. Rev. Environ. Econ. Policy 8 (1), 18–38.
Hartman, R.S., Doane, M.J., Woo, C.-K., 1991. Consumer rationality and the status quo. Quart. J. Econ. 106 (1), 141–162.
Hole, A.R., Kolstad, J.R., 2012. Mixed logit estimation of willingness to pay distributions: a comparison of models in preference and wtp space using data from a health-related choice experiment. Emp. Econ. 42 (2), 445–469.
Houde, S., Aldy, J.E., 2017. The Efficiency Consequences of Heterogeneous Behavioral Responses to Energy Fiscal Policies. NBER Working Paper No. 17282.
IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Jaccard, M., Dennis, M., 2006. Estimating home energy decision parameters for a hybrid energy – economy policy model. Environ. Model. Assess. 11 (2), 91–100.
Jacobsen, G.D., 2015. Do energy prices influence investment in energy efficiency? Evidence from energy star appliances. J. Environ. Econ. Manag. 74, 94–106.
Johnston, R.J., Boyle, K.J., Adamowicz, W., Bennett, J., Brouwer, R., Cameron, T.A., Hanemann, W.M., Hanley, N., Ryan, M., Scarpa, R., Tourangeau, R., Vossler, C.A., 2017. Contemporary guidance for stated preference studies. J. Assoc. Environ. Resour. Econ. 4 (2), 319–405.
Kuhfeld, W.F., Tobias, R.D., Garratt, M., 1994. Efficient experimental design with marketing research applications. J. Market. Res. 31 (4), 545–557.
Kwak, S.-Y., Yoo, S.-H., Kwak, S.-J., 2010. Valuing energy-saving measures in residential buildings: a choice experiment study. Energy Policy 38 (1), 673–677.
Lang, G., Lanz, B., 2020. Climate Policy Without A Price Signal: Evidence on the Implicit Carbon Price of Energy Efficiency in Buildings. MIT CEEPR Working Paper 2020-004.
Lang, G., Lanz, B., 2021. Energy efficiency, information, and the acceptability of rent increases: a multiple price list experiment with tenants. Energy Econ., 105007 (in press).
Lanz, B., Wurlod, J.-D., Panzone, L., Swanson, T., 2018. The behavioral effect of Pigovian regulation: evidence from a field experiment. J. Environ. Econ. Manag. 87, 190–205.
Li, S., Linn, J., Muehlegger, E., 2014. Gasoline taxes and consumer behavior. Am. Econ. J.: Econ. Policy 6 (4), 302–342.
Louviere, J.J., Hensher, D.A., Swait, J.D., 2000. Stated Choice Methods: Analysis and Applications. Cambridge University Press.
McFadden, D., 1974. Conditional logit analysis of qualitative choice behavior. In: Frontiers in Econometrics. Academic Press.
McFadden, D.L., 1984. Econometric analysis of qualitative response models. Handb. Econometr. 2, 1395–1457.
McFadden, D., Train, K., 2000. Mixed MNL models for discrete response. J. Appl. Econometr. 15 (5), 447–470.
Michelsen, C.C., Madlener, R., 2012. Homeowners' preferences for adopting innovative residential heating systems: a discrete choice analysis for Germany. Energy Econ. 34 (5), 1271–1283.

Michelsen, C.C., Madlener, R., 2016. Switching from fossil fuel to renewables in residential heating systems: an empirical study of homeowners' decisions in Germany. Energy Policy 89, 95–105.
Myers, E., 2020. Asymmetric information in residential rental markets: Implications for the energy efficiency gap. J. Public Econ. 190, 104251.
Newell, R.G., Siikamäki, J., 2014. Nudging energy efficiency behavior: the role of information labels. J. Assoc. Environ. Resour. Econ. 1 (4), 555–598.
Rapson, D., 2014. Durable goods and long-run electricity demand: evidence from air conditioner purchase behavior. J. Environ. Econ. Manag. 68 (1), 141–160.
Revelt, D., Train, K., 1998. Mixed logit with repeated choices: households' choices of appliance efficiency level. Rev. Econ. Stat. 80 (4), 647–657.
Revelt, D., Train, K., 2000. Customer-Specific Taste Parameters and Mixed Logit: Households' Choice of Electricity Supplier. University of California at Berkely Working Paper No. E00-274.
Rouvinen, S., Matero, J., 2013. Stated preferences of Finnish private homeowners for residential heating systems: a discrete choice experiment. Biomass Bioenergy 57, 22–32.
Ruokamo, E., 2016. Household preferences of hybrid home heating systems – a choice experiment application. Energy Policy 95, 224–237.
Sallee, J.M., 2014. Rational inattention and energy efficiency. J. Law Econ. 57 (3), 781–820.
Scarpa, R., Franceschinis, C., Thiene, M., 2020. Logit mixed logit under asymmetry and multimodality of WTP: a Monte Carlo evaluation. Am. J. Agric. Econ.
Scarpa, R., Willis, K., 2010. Willingness-to-pay for renewable energy: primary and discretionary choice of British households' for micro-generation technologies. Energy Econ. 32 (1), 129–136.
Schleich, J., Faure, C., Guetlein, M.-C., Tu, G., 2020. Household Preferences for New Heating Systems: Insights from a Multi-Country Discrete Choice Experiment. Working Paper Sustainability and Innovation No. S 05/2020.
SFOE, 2019. Schweizerische Elektrizitätsstatistik 2019. Swiss Federall Office of Energy (SFOE), Ittigen, Switzerland.
Sopha, B.M., Klöckner, C.A., Skjevrak, G., Hertwich, E.G., 2010. Norwegian households' perception of wood pellet stove compared to air-to-air heat pump and electric heating. Energy Policy 38 (7), 3744–3754.
Stolyarova, E., Le Cadre, H., Osso, D., Allibe, B., 2015. Stated Preferences for Space Heating Investment. Working Paper.
Train, K., 2016. Mixed logit with a flexible mixing distribution. J. Choice Modell. 19, 40–53.
Train, K.E., 2009. Discrete Choice Methods With Simulation. Cambridge university press.
Train, K., Weeks, M., 2005. Discrete choice models in preference space and willingnessto-pay space. Applications of Simulation Methods in Environmental and Resource Economics, 1–16.
Volland, B., Farsi, M., Lasvaux, S., Padey, P., 2020. Too Little Too Late: An Empirical Study of Renovation of Building Elements. IRENE Working Paper 20-02.
Vossler, C., Doyon, M., Rondeau, D., 2012. Truth in consequentiality: theory and field evidence on discrete choice experiments. Am. Econ. J.: Microecon. 4 (4), 145–171.
Weber, S., Burger, P., Farsi, M., Martinez-Cruz, A.L., Puntiroli, M., Schubert, I., Volland, B., et al., 2017. Swiss Household Energy Demand Survey (SHEDS): Objectives, Design, and Implementation. IRENE Working Paper 17-14.
Wüest Partner, A.G., 2020. Methodenbericht zum Modell für die Abschätzung der Klimaverträglichkeit von Immobilienanlagen (CO2-Rechner). Zurich, Switzerland.