# Essays on the Economics of Energy and Real Estate Management

Faculty of Economics and Business

Institute of Economic Research

University of Neuchâtel

PhD thesis in Economics

DEFENDED ON SEPTEMBER 4, 2020

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UNIVERSITÉ DE NEUCHÂTEL

**IMPRIMATUR POUR LA THÈSE**

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UNIVERSITÉ DE NEUCHÂTEL

FACULTÉ DES SCIENCES ÉCONOMIQUES

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Autorise l'impression de la présente thèse.

Neuchâtel, le 26 octobre 2020

Annik Dubied

La doyenne
Annik Dubied

*To my mother, Marianne.*

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# Résumé

Les rénovations énergétiques des bâtiments sont des buts fréquents des programmes publics visant à réduire la pollution. Pour une allocation efficace des ressources, les responsables politiques sont tenus de comparer pour chaque intervention les estimations des bénéfices avec des estimations du prix du carbone implicite (le coût social net de réduction des émissions de $CO_2$ par tonne). Dans cette thèse, j'utilise un portefeuille de 548 immeubles locatifs afin d'estimer les effets hétérogènes des différents types de rénovations sur la consommation d'énergie et le prix implicite du carbone. Mes résultats confirment que les mesures souvent subventionnées, telles que l'isolation de l'enveloppe et le remplacement des fenêtres, permettent de réaliser d'importantes économies d'énergie, tout en étant une stratégie coûteuse pour réduire les émissions. Des nouvelles technologies telles que les thermostats "smart" peuvent réaliser des économies à un coût faible.

Malgré tout, le niveau des investissements réalisés reste faible. Cette thèse comprend une expérience de choix discrets sur un échantillon de 511 propriétaires Les résultats montrent que la volonté des propriétaires d'investir dans l'efficacité énergétique va au-delà des économies financières, et que les choix ne sont pas affectés par les informations prévisionnelles sur les frais de chauffage. En complément, cette thèse comprend également une expérience de choix déclarés appliquée à 406 locataires afin d'estimer l'acceptabilité des augmentations de loyer en échange d'une meilleure efficacité énergétique. Les résultats montrent que le consentement moyen des locataires à payer pour l'efficacité énergétique est statistiquement et économiquement significative, et peut être stimulée davantage par des informations prévisionnelles sur les frais de chauffage. L'information sur la taxe $CO_2$ n'a pas d'effet incrémentiel.

**Mots-clés:** Politique climatique ; Prix implicite du carbone ; Efficacité énergétique ; Technologies à faible intensité de carbone ; Incitations divisées entre propriétaires et locataires ; Interventions informationnelles

**Classification JEL:** D1; D8; H23; Q4; Q55; Q58; R31

# Abstract

Building energy retrofits are popular targets of public incentive schemes to curb emissions. For an efficient allocation of resources, policy-makers are required to compare benefit estimates of avoided carbon emissions with reliable estimates of each intervention's associated implicit carbon price (i.e., the net social cost of reducing $CO_2$ emissions by one tonne). In this thesis, I use data for a unique portfolio of 548 multi-unit buildings to provide novel evidence on heterogeneous effects of alternative energy efficiency interventions on energy use and the implicit carbon price. My results confirm that frequently subsidized measures such as wall insulation and windows replacement achieve significant energy savings, yet turn out to be a relatively expensive strategy to abate $CO_2$. By contrast, findings for smart thermostats suggest that new technologies can achieve significant savings at a relatively low cost.

Despite public incentive schemes and the expected private and pro-social benefits, the level of realized investments remains low, and a burgeoning literature proposes ex-ante information to guide owners' investment decisions. In this context, this thesis also includes a discrete choice experiment on a sample of 511 homeowners to estimate their valuation of alternative replacement heating appliances. Results show that homeowners' willingness to invest in energy efficiency goes beyond financial savings, and that choices are unaffected by ex-ante information on heating costs. By contrast, this thesis also includes a stated choice multiple price list applied to 406 tenants in order to estimate acceptability of rent increases in exchange for improved energy efficiency of the heating system. Findings show that tenants' average willingness to pay for energy efficiency is statistically and economically significant, and can be stimulated further with ex-ante information on heating costs. Information on $CO_2$ tax payments has no incremental effect.

**Keywords:** Climate policy; Implicit carbon price; Energy efficiency; Low-carbon technologies; Owner-tenant split incentives; Informational interventions

**JEL classification:** D1; D8; H23; Q4; Q55; Q58; R31

# Acknowledgments

I would like to thank my supervisor Prof. Bruno Lanz for his continuous guidance and support during my PhD. His passion and dedication to both research and teaching have been a source of inspiration. I am also grateful to my PhD Committee with Prof. Mehdi Farsi, Prof. Philippe Thalmann, and Prof. Dorothée Charlier, for helping me improve the thesis.

In addition, I thank my dear colleagues from the University of Neuchâtel and other project partners for their intellectual and emotional support during those years. All the joking made this a fun experience to be remembered.

Finally, I am incredibly grateful to my family and friends for providing all the patience and distractions that were necessary to finish this thesis, and for always helping me remember what is most important. I owe a special thanks to my husband Avichal and my dad Jürg for their precious advice and for always believing in me.

# Introduction

Introducing a carbon price, i.e., a cost applied to carbon pollution, is the single most effective way for countries to curb carbon emissions. It provides an economic signal that encourages polluters to reduce the amount of greenhouse gas they emit into the atmosphere, and therefore allows the overall environmental goal to be achieved in the most flexible and least-cost way to society. Ideally, there should be a uniform carbon price across the world. In practice, however, carbon taxes are rare, local in nature, and have yet to be implemented effectively.[1] Buildings are responsible for about one quarter of Switzerland's greenhouse gas emissions (FOEN, 2018a), and building retrofits are popular targets of public incentive schemes to lower emissions.[2] In the absence of an *explicit* carbon price, investment behavior provides an *implicit* price of carbon. For an efficient allocation of resources, policy-makers can thus compare each intervention's estimates of avoided damages (i.e., the benefit of reducing $CO_2$ emissions by one tonne, Muller and Mendelsohn, 2009; Greenstone et al., 2013) with reliable estimates of the associated implicit carbon price (i.e., the net social cost of reducing $CO_2$ emissions by one tonne).

With the incentive scheme in place, policy-makers depend on property owners to invest. And despite the apparent private and pro-social returns and the public resources dedicated to stimulate investment, adoption of energy efficient and low-carbon technologies in the residential market is slow (e.g. Allcott and Greenstone, 2012; Gillingham and Palmer, 2014). In this context, a growing body of literature

[1] Carbon pricing in Switzerland, for instance, combines a $CO_2$ levy on thermal fuels (introduced at CHF 12 per tonne of $CO_2$ in 2008, and increased to CHF 96 in 2018) with an emissions trading price for large emitters (introduced at CHF 40 per tonne of $CO_2$ in 2008, and fallen to CHF 17 in 2020), while transport fuels are unaffected. Thalmann and Vielle (2019) show that the preferential treatment of large emitters and transport fuels raises the welfare cost of decarbonization.

[2] In Switzerland, one third of the revenues from the $CO_2$ levy has been earmarked for the federal and cantonal buildings programme, which provides subsidies to property owners that invest in energy efficiency, renewable energies, waste heat recovery, and the optimisation of building services technology (FOEN, 2018a).

highlights ex-ante information as a central aspect in guiding investors' decisions (Allcott and Wozny, 2014; Newell and Siikamäki, 2014; Jacobsen, 2015). However, while up-front investment costs in the residential market are borne by property owners, energy bills are generally paid by residents. For rental properties, this implies that tenants reap the benefits of the lower post-investment energy service cost. Accordingly, a separate strand of literature points to landlord-tenant split incentives (Gillingham et al., 2012; Davis, 2012) along with information asymmetries (i.e., the fact that tenants are uninformed about energy costs, Myers, 2018) as major barriers to take-up.

The Swiss housing stock comprises 1.8 million residential buildings, half of which are located in the five most populated cantons (i.e., Zurich, Bern, Vaud, Aargau and St.Gallen, see FSO, 2019c). While 57% of (purely) residential buildings are single-family homes (FSO, 2019b), only 23% of households live in these buildings (FSO, 2020). 37% of buildings were built after 1980 (44% of single-family homes and 35% of multi-family buildings, see FSO, 2019g). Almost 90% of residential buildings are heated by means of a central heating system covering one or more buildings, and less than 5% are connected to district heating. Almost two-thirds of buildings are heated with fossil fuels (39% heating oil and 21% natural gas), 18% with heat pumps, and 10% with wood (FSO, 2017b). In 2008, Switzerland introduced a $CO_2$ levy on fossil heating and process fuels (e.g., heating oil, natural gas). However, Burger et al. (2018) show that a substantial portion of citizens have a poor understanding of the tax.

As regards the Swiss residential rental market, tenants commonly pay heating costs separately from their rents, often in the form of down payments (the majority of tenants lives in apartment buildings without individual heating meters).[3] Landlords are legally enabled to pass on the cost of improved energy efficiency to tenants with higher rents, though the change might lead to increased tenant turnover costs (e.g., costs associated with vacancy, advertising, necessary refurbishment). While this incentivizes landlords to undertake renovations in between a change of tenants, the relatively low average tenant turnover in Switzerland will force many landlords to renovate their dwelling while it is still being occupied.[4] Given that the majority of Swiss households lives in multi-unit buildings

[3] Monthly net median rent in Switzerland amounted to CHF 1,322 per household in 2016 (FSO, 2018a). Net rents make about one quarter of disposable income in Switzerland, while the corresponding housing cost burden of homeowners (with mortgage) amounts to merely 10% (OECD, 2019).

[4] The average relocation rate in Switzerland has been estimated at 10.5% in 2017 (Homegate AG, 2017).

with a central heating system, replacement during tenant occupancy is practically inevitable.

The three chapters of this PhD thesis revolve around the role of information for the adoption of energy efficiency and low-carbon technology investments in the residential sector. The first chapter provides empirical estimates of the implicit price of carbon associated with alternative investments, and thereby provides policy-makers with credible information supporting the selection of interventions that merit promotion through public funding. The second and third chapter provide evidence on the impact of ex-ante financial information on private actors' willingness to adopt a particular technology.

Chapter I provides empirical evidence on the impacts of more than 400 building retrofits across 240 multi-unit buildings that are observed over 16 years and managed by a single Swiss company. I further exploit the fact that 308 buildings experienced no energy-related investments as well as the staggered adoption among treated buildings to mitigate selection bias associated with investment decisions. Based on evidence that treated and control buildings follow a common trend in the absence of energy efficiency investments, I document building-level energy savings, $CO_2$ abatement, and heating expenditure reductions. Detailed financial data further allows estimating the implicit carbon price of alternative energy efficiency investments.

Staggered difference-in-difference regressions demonstrate substantial heterogeneity in energy savings across alternative investments. Subsidized facade insulation, for instance, leads to 18 percent energy savings, while replacing a building's windows leads to five percent lower heating energy consumption. I also find considerable heterogeneity in the implicit carbon price associated with alternative interventions. Estimates range from around CHF -200 for the installation of smart thermostats to over CHF 1,000 per tonne of $CO_2$ for facade insulations, the latter of which is well above available estimates of avoided damages.

In Chapter II, I elicit homeowners' willingness to pay (WTP) for energy efficient and low-carbon technologies in the context of space heating appliances. A randomized control trial, which would allow elicitation of revealed preferences (i.e., behavior observed in real market transactions), is difficult to carry out in this setting because of the substantial up-front cost and the low replacement rate underlying the investments. I therefore elicit homeowners' preferences by means of a discrete choice experiment (DCE) applied to a sample of 511 Swiss owner-occupiers. DCEs are a class of nonmarket stated-preference valuation methods that involve asking individuals to state their preference over hypothetical alternative scenarios, goods, or services. They allow independent variation of attribute levels and elicitation of WTP for non-financial attributes, and provide full information about available choice sets. However, the method can induce hypothetical and strategic biases, which is why results have to be interpreted with caution. To identify the role of financial information for homeowners' choices, I exploit a novel within-between subject design that involves manipulating information in a two-stage experimental procedure and estimating preferences in WTP space.

Results show that homeowners are willing to invest on average CHF 13,540 for efficiency class $A^+$ relative to class B, and that WTP is not affected by information on heating cost savings.[5] However, mixed logit model results reveal heterogeneous preferences across respondents for different heating technologies. Furthermore, oil users' average WTP to switch to wood pellets or heat pumps (both relative to heating oil) is CHF -7,140 and CHF 1,180, respectively. Only about 25% of oil users are willing to pay an investment cost differential of CHF 10,000 (Energieheld Schweiz, 2020) for alternative low-carbon technologies. These results barely change even after respondents are informed about $CO_2$ tax payments associated with fossil fuels.

Chapter III identifies the role of ex-ante financial information for energy efficiency improvements in the context of landlord-tenant split incentives. In rental buildings, the multi-dimensional choice of a central heating appliance is made by the landlord, typically without consulting tenants. I therefore make use of a separate class of stated-preference choice experiments, namely a multiple price list (MPL) procedure, which offers a more realistic choice setting for tenants.[6] Similar to DCEs, the method may induce hypothetical and strategic biases, which is why the results of this chapter, too, should be interpreted with caution. I employ the MPL procedure to a sample of 406 Swiss tenants in order to quantify how tenants trade off rent increases and improved energy efficiency of their space heating system. I again exploit both within-subject information disclosure and between-subject variation in information contents to estimate the effect of information about expected energy bills reductions on tenants' valuation of energy efficiency.

Results suggest that in the baseline, tenants' average WTP for an efficiency

[5] 2017 exchange rate approx. CHF 1 = USD 1

[6] My (non-incentivized) MPL is motivated by the difficulty to harness revealed preferences in this setting, as observational data are constrained by supply-side restrictions such as rent control regulations, and a randomized control trial is again not practical due to the cost of the interventions I consider.

upgrade from B to $A^+$ is CHF 37.51 per month, which corresponds to about 3% of median rents in Switzerland. Moreover, salient ex-ante financial information increases tenants' average valuation of energy efficiency by about 53%. Quantile regressions show that the average upward shift reflects heterogeneous changes along the entire distribution. By comparison, information on energy bills variability dampens acceptable rent increase, and information on inclusive $CO_2$ tax payments has no incremental impact on choices.

To conclude, all three chapters of this thesis are based on primary data, and beyond answering important policy questions, they also fill a number of methodological gaps. In Chapter I, I exploit variation in the timing of investments to provide evidence that treated and control buildings follow the same trend in the absence of energy efficiency investments. In the same chapter, I propose the implicit price of carbon as a simple metric to compare alternative investment strategies from a policy perspective. In Chapters II and III, I exploit a novel within-between subject design that involves manipulating information in a two-stage choice experiment and using WTP space estimation to identify the role of information in reducing fossil fuel use.

# Chapter I

# Climate policy without a price signal: Evidence on the implicit carbon price of energy efficiency in buildings

This chapter is mainly based on a working paper co-authored by Bruno Lanz (University of Neuchatel). This research is part of the activities of SCCER-CREST (Swiss Competence Center for Energy Research), and financial support from Innosuisse under grant 19331.2 PFES-ES is gratefully acknowledged. We thank Anna Alberini, Sylvain Chabé-Ferret, Mehdi Farsi, Flourentzos Flourentzou, Matthew Kotchen, Joëlle Noailly, Sefi Roth, Tim Swanson, Philippe Thalmann, and the participants at various conferences for useful comments and discussions.

This paper has been published in the working paper series of UNINE IRENE (No. 20-03), MIT CEEPR (No. WP-2020-004), and SSCER CREST (No. WP2-2020/01). It was presented by Ghislaine Lang at the Annual Congress of the Swiss Society of Economics and Statistics (SSES) in Geneva (Switzerland), 2019, and the 24th Annual Conference of the European Association of Environmental and Resource Economists (EAERE) in Manchester (UK), 2019.

**Abstract**
Based on data for a portfolio of 548 multi-unit buildings observed over 16 years, we quantify the impacts of more than 400 energy efficiency interventions among 240 treated buildings. We exploit variation in the timing of investments to provide evidence that treated and control buildings follow the same trend in the absence of energy efficiency investments, and use staggered difference-in-differences regressions to document building-level energy savings, $CO_2$ abatement, and heating expenditure reductions. We find considerable heterogeneity in the price of carbon implicitly associated with alternative interventions, with estimates for frequently subsidized measures well above available benefit estimates for avoided emissions.

**Keywords** Regulation; implicit carbon price; energy efficiency investments; energy savings; staggered design; climate policy.
**JEL codes** H21; H23; Q41; Q49; Q58; R31.

# 1 Introduction

Market-based approaches to regulate externalities associated with $CO_2$ emissions generate a carbon price that signals which investments are worth pursuing. In practice, however, countries often pursue alternative policies that target specific investments to reduce fossil fuel use. One prominent example is the widespread promotion of energy efficiency investments in buildings through highly subsidized weatherization programs.[1] This approach to regulation implies that the price of carbon is implicitly defined by investment decisions (Gillingham and Stock, 2018). In turn, policy-makers are left with the difficult task of selecting interventions that are worth pursuing, in the sense that the associated implicit price of carbon (i.e., the net social cost of reducing $CO_2$ emissions by one tonne) is below estimates of avoided damages (Muller and Mendelsohn, 2009; Greenstone et al., 2013).

The purpose of this paper is to provide empirical evidence on the implicit carbon price of alternative energy efficiency investments in buildings, and illustrate the extent of heterogeneity across frequently targeted interventions. We employ data for a portfolio of 548 buildings managed by a single Swiss company, observed from 2001 to 2016, representing 12,820 units rented on the market (94% residential).[2] During the observation period, 240 buildings benefited from energy efficiency investments, and our data allow us to derive forensic evidence for the implicit carbon price across the following interventions: insulation of the facade, roof or attic, replacement of windows, installation of smart thermostats that optimize heating operations using real-time information (e.g., weather forecasts), replacement of the boiler, including fuel switching from heating oil to natural gas.[3]

The primitive to estimate the implicit price of carbon is energy savings, which determines both reductions of carbon emissions and financial savings associated with lower energy use.[4] One empirical challenge to identify energy savings is non-

[1] In developed countries, around 40 percent of energy use is associated with buildings (Fernandez, 2007), and the IEA (2017) estimates worldwide energy efficiency investment at USD 231 billion in 2016, with 133 billion in the buildings sector alone. Concrete policies promoting efficiency in buildings include the "Weatherization Assistance Program" in the U.S. and the "KfW Energy Efficiency Program" for energy efficient construction and refurbishment in Germany.

[2] Energy consumption patterns is known to differ across commercial and residential uses, see for example Costa and Kahn (2011) and Kahn et al. (2014). Our sample does not include purely commercial buildings, and we come back to the presence of a small share of commercial leases below.

[3] We also consider three interventions that do not directly target energy efficiency, but were included in a number of investment bundles, namely the installation of individual space heating meters, hot water meters, and solar thermal collectors.

[4] In all the buildings we consider, tenants share a single central heating appliance that operates on either heating oil or natural gas. As described below, we use standard conversion factors to

random assignment of energy efficiency investments, and in turn the estimation of a counterfactual baseline energy use (Fowlie et al., 2018; Burlig et al., 2017). In the setting we consider, building-level expenses in relation to heating fuel consumption are fully passed forward to tenants, so that property owners do not benefit directly from reduced heating costs (see Levinson and Niemann, 2004; Gillingham et al., 2012). Put differently, tenants who directly benefit from improved energy efficiency do not take investment decisions. This prevents direct self-selection extensively discussed in the evaluation of renovation programs targeting owner-occupied properties (Metcalf and Hassett, 1999; Allcott and Greenstone, 2017). Instead, investment decisions likely reflect expectations about indirect benefits, including property maintenance costs and market value (see Brounen and Kok, 2011; Eichholtz et al., 2013; Walls et al., 2017).

We further exploit the fact that 308 buildings experienced no energy-related investments. These buildings constitute a candidate control group to estimate counterfactual energy use among treated buildings in the absence of investments. Importantly, the timing of energy efficiency investments across buildings implies that treated buildings gradually enter the post-treatment period, which allows us to compare pre-treatment trends for treated and control buildings over fourteen years of data. In a nutshell, our data shows that, before energy efficiency investments, treated buildings use on average more energy per square meter relative to control. Moreover, the difference is approximately constant with time, which suggests that the evolution of energy use in control buildings provides relevant information to inform a counterfactual for treated buildings.[5]

In this context, we implement a staggered difference-in-differences estimation strategy (Autor, 2003; Stevenson and Wolfers, 2006), and we start by quantifying energy savings associated with individual energy efficiency interventions, controlling for year and buildings fixed effects, local weather shocks and fuel prices, as well as complementarity effects across interventions (Mulder et al., 2003). Providing evidence on heterogeneous energy savings associated with alternative energy efficiency investments is the first contribution of our work, and it is important because policies (e.g., subsidies for facade insulation or windows replacement) typically target interventions based on expected energy savings. Because of non-random treatment assignment, however, our estimates represent an average

quantify $CO_2$ emissions associated with each fuel.

[5] Note that average energy use in both treated and control buildings trends downward during the observation period. One implication is that energy use declines with time even without energy efficiency investments, which makes the use of a control group particularly important to identify the causal effect of interventions.

treatment effect on the treated (ATET), which potentially differs from the average treatment effect (ATE) and from the average treatment effect on the non-treated (ATENT). And because treated buildings use on average more energy relative to control, we test for treatment effect heterogeneity as a function of pre-treatment energy use. This allows us to provide evidence about energy savings for an average building in the portfolio (ATE) and for control buildings (ATENT).

We then exploit financial information on energy efficiency investments to quantify the implicit price of carbon associated with alternative interventions.[6] This delivers the main contribution of our work, and we proceed in two steps. First, we employ difference-in-differences regressions to estimate how CHF 1 invested in energy efficiency affects building-level $CO_2$ emissions. Second, we similarly quantify how each investment affects building-level annual heating expenditures. Together with standard engineering estimates on the lifetime of building elements and a discount rate (0% or 6%), we carry out inference on the implicit price of carbon. Intuitively, we construct a statistical counterpart to the often-cited "McKinsey curve" (McKinsey & Company, 2009), ranking energy efficiency interventions from the least to the most expensive.[7]

Overall, our empirical results demonstrate substantial heterogeneity in energy savings across alternative investments. For example, subsidized investments such as facade insulation and the replacement of windows are associated with energy savings of 18 and five percent on average, respectively. For these two interventions, point estimates for the implicit price of carbon are around CHF 1,000 per tonne of $CO_2$. This is an order of magnitude above the $CO_2$ tax prevailing in Switzerland (CHF 84/t$CO_2$ in 2016 FOEN, 2018b), and well in excess of estimated benefits of avoided emissions discussed in Greenstone et al. (2013, around USD 40/t$CO_2$, about the same in CHF). By contrast, roof insulation and the installation of smart thermostats decreases energy use by around 10 percent on average, but the implicit carbon price is significantly lower. For roof insulation estimates are around 200 CHF/t$CO_2$, whereas most specifications indicate *negative* estimates for smart thermostats, suggesting that these investments are optimal even in the absence of externalities. We also find, however, that energy savings for smart ther-

[6] Note that financial data refer to a common 2015 baseline, with an exchange rate of about CHF 1 = USD 1.

[7] We emphasize, however, that our estimates do not capture broader welfare impacts associated with energy efficiency investments, such as improved comfort for tenants and transaction costs for property owners (e.g., administrative costs). Evidence derived in the context of owner-occupied properties suggests that non-monetary costs and benefits are important (Fowlie et al., 2015; Allcott and Greenstone, 2017).

mostats tend to increase with pre-treatment energy use, so that the implicit price of carbon estimated for treated buildings is likely a lower bound for the corresponding population of non-renovated buildings.

Our work contributes to a growing literature quantifying the economic cost of reducing $CO_2$ emissions. A survey by Gillingham and Stock (2018) reports a range starting at -190 USD/t$CO_2$ for behavioral energy interventions (such as social comparison feedback; see Allcott and Mullainathan, 2010) and going up to 2900 USD/t$CO_2$ for transportation-related policies limiting emissions intensity (Holland et al., 2009). Gillingham and Stock (2018) discuss an estimate of 350 USD/t$CO_2$ for investments in buildings' energy efficiency, which is derived from Fowlie et al. (2018) in the context of the Weatherization Assistance Program offered to a sample of low-income homeowners in the U.S. state of Michigan. More specifically, results by Fowlie et al. (2018) refer to various bundles of interventions (including combinations of furnace replacement, roof and facade insulation, and infiltration reduction), and a weighted average of our preferred estimates is slightly above 380 CHF/t$CO_2$ (95% confidence interval: 247.28-518.27). Relative to Fowlie et al. (2018), we show that heterogeneity within the realm of buildings' energy efficiency interventions generates a range of implicit carbon prices corresponding to the much broader set if interventions considered in Gillingham and Stock (2018).

Our work is also related to a wider literature on imperfect information in the context of energy efficiency investments, one of the major components of the energy efficiency gap (Allcott and Greenstone, 2012; Gillingham and Palmer, 2014; Gerarden et al., 2017). For example, Joskow and Marron (1992) emphasize the use of realized energy savings (rather than *ex-ante* engineering projections) to evaluate energy efficiency programs, and mounting empirical evidence suggests that realized savings associated with energy efficiency in buildings generally fail to meet *ex-ante* projections (e.g., Grimes et al., 2016; Zivin and Novan, 2016; Liang et al., 2017; Burlig et al., 2017; Allcott and Greenstone, 2017; Fowlie et al., 2018).[8] One potential source of discrepancy between projected and realized savings is increased consumption of energy services (a rebound effect, see Gillingham et al., 2016).[9]

[8] See also Aroonruengsawat et al. (2012), Jacobsen and Kotchen (2013), Levinson (2016) and Kotchen (2017) for evidence on energy savings associated with buildings construction standards, and Davis et al. (2014) on a government program targeting refrigerator and air conditioner efficiency.

[9] Empirical evidence reported in Aydin et al. (2017) suggests that energy rebound is between 25 and 40 percent, whereas Davis (2008) and Fowlie et al. (2018) instead report insignificant

Relative to these studies, our data does not allow us to identify potential differences between projected and realized energy savings, or a rebound effect. Moreover, the context of our study is novel. First, whereas the bulk of the literature focuses on (semi-)detached properties, our results refer to apartment buildings. While these represent only 20 percent of dwellings in the U.S., among European countries the share amounts to 42 percent. Second, our data afford a rare investigation of energy efficiency investment behavior outside of specific policy programs (Metcalf and Hassett, 1999, is another exception). Despite these differences, our estimate of energy savings across interventions (around 12 percent on average) closely aligns with the above studies. Our paper instead documents heterogeneity across interventions often targeted by policies, and provides a first step in understanding implications for the associated implicit carbon price.

The paper proceeds as follows. Section 2 describes our data, identification strategy, and econometric approach. Section 3 presents our results. Section 4 briefly discusses our results and concludes.

## 2 Empirical strategy

This section first provides an overview of our data, including the nature and timing of energy efficiency investments. We then report evidence on trends in energy use among treated and control buildings, which provides the basis for our identification strategy. Finally, we lay out our econometric approach to estimate energy savings, $CO_2$ emissions abatement, and reductions in heating expenditures, and the associated implicit price of carbon.

### 2.1 Context and data overview

Our work is primarily based on accounting data tracking a portfolio of multi-unit buildings over time. The portfolio is managed by a single private company active in the market for pension funds and real estate investments. All 548 buildings in the portfolio are located in the western part of Switzerland (see Appendix A).

The main outcome of interest is annual building-level heating energy use, measured in kilowatt hours (kWh) of either heating oil or natural gas, where years run from July to July so as to cover the entire heating season (November to March). $CO_2$ emissions are calculated with standard conversion factors: 264 $gCO_2$/kWh

estimates. Instead, engineering projections may be overoptimistic and/or installation works may fail to meet expectations (see also Giraudet et al., 2018).

for heating oil and 202 $gCO_2$/kWh for natural gas (IPCC, 1996). We also observe building-level heating bills charged to tenants (in 2015 CHF), which comprise operation costs for the central heating system (e.g., including subscription fee to the services operating smart thermostats),[10] as well as a number of building-level characteristics such as total surface area, construction year, and the number of rented units. Moreover, while all the buildings in the portfolio are located in a relatively confined area and subject to similar climatic conditions, we use heating degree day data derived from the closest weather station (MeteoSwiss, 2019) to capture local demand shocks.[11]

For each building, we have information on the type and timing of energy efficiency investments. There are nine (possibly combined) interventions: (i) *facade insulation* is thermal insulation of a building's exterior wall or envelope; (ii) *roof insulation* denotes thermal insulation of a building's roof or attic; (iii) *windows replacement* refers to the replacement of the building's exterior windows, with improved thermal insulation; (iv) *smart thermostats* is the installation of a system that uses real-time information to optimize operations of the central heating appliance;[12] (v) *boiler replacement* stands for the replacement of the primary appliance supplying heat to the building, without switching fuel; (vi) *boiler replacement (oil-gas)* denotes the replacement of the primary appliance supplying heat to the building, including switching from heating oil to natural gas; (vii) *space heat meters* refers to the installation of unit-level meters for space heating consumption; and (viii) *hot water meters* is the same for hot water consumption; and (ix) *solar installation* is the installation of solar thermal collectors that contribute to the building's hot water supply.

The staggered timing of investments across buildings is illustrated in Table 1. Importantly, some of the interventions we consider may take several months to complete, even years for some of the larger investments. In our empirical anal-

[10]In the setting we consider, financial incentives associated with energy use are only indirect. First, all the tenants make monthly down payments for their use of heating energy until the actual use of heating oil or natural gas is billed in July each year. This implies a delay between energy use and energy bills. Second, a majority of tenants do not have an individual meter, and pay building-level energy costs in proportion to the volume of their property (see Kandul et al., 2019, for a discussion). Note that the installation of individual meters is included in the set of treatments we consider.

[11]Heating degree days measure the difference between the local average outdoor temperature on a given day and $20°C$ (the recommended indoor temperature by convention), cumulated over a particular heating season (defined as days with average temperature below $12°C$).

[12]More specifically, the system takes into account a variety of parameters such as the building's physical characteristics, geographical position, local weather situation and forecast to optimize the temperature of the heating system, including peak heat load control.

ysis, we distinguish between years before treatment, during treatment, and after treatment, so as to control for any work-related impacts on energy use during the intervention period. The timing in Table 1 refers to the beginning of the intervention.

In total, our data includes 402 interventions targeting 240 buildings, with 88 buildings receiving more than one intervention. As can be expected, the number of energy efficiency investments increases with time, with some interventions such as smart thermostats and solar thermal collectors starting later in time (2013 and 2012, respectively). The remaining 308 buildings have not undergone any energy-related intervention during the period we consider, and we refer to these buildings as our control group.[13]

For each intervention we also observe financial information on total investment cost (2015 prices), including subsidies where applicable, with two exceptions. First, individual meters and solar thermal collectors are not strictly speaking energy efficiency improvements, and we do not observe the associated investment cost. While we do observe the timing of installation for these interventions and can estimate energy savings, a lack of financial data implies that we cannot estimate the implicit price of carbon associated with these interventions. Second, investment cost data is missing for one instance of facade insulation, five installations of smart thermostats, and 13 boiler replacements (with fuel switching). In the estimation of the implicit price of carbon, we control for interventions with missing financial data with a set of separate treatment dummies capturing the timing of interventions.

Note that the timing of renovation (or rather, the age of the building element at the time of replacement) has a direct impact on its cost-effectiveness, and thus on the implicit price of carbon. First, and to the extent that pre-treatment energy use is an increasing function of a particular building component's obsolescence, the timing of renovations might affect post-treatment energy savings (relative to pre-treatment energy use). While we do not observe the age of each building component, we test for treatment effect heterogeneity as a function of pre-treatment energy use. Second, and given that energy efficiency improvements often involve replacement of the building component in question (as opposed to a simple *upgrade*), energy efficiency improvements involve an opportunity cost that is a func-

[13]Note that we can only identify the impact of interventions for which we have at least one observation before the treatment and one observation after the treatment. This leads us to treat buildings with interventions in 2001 or 2016 as part of the control group.

Table 1: Staggered investments across interventions and years

| | '02 | '03 | '04 | '05 | '06 | '07 | '08 | '09 | '10 | '11 | '12 | '13 | '14 | '15 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Facade insulation* | 1 | 1 | 1 | 1 | 5 | 2 | 3 | 6 | 2 | 7 | 2 | 0 | 5 | 2 | 38 |
| *Roof insulation* | 0 | 0 | 0 | 1 | 5 | 1 | 1 | 5 | 5 | 10 | 3 | 0 | 5 | 2 | 38 |
| *Windows replacement* | 1 | 2 | 2 | 0 | 5 | 2 | 2 | 7 | 17 | 11 | 11 | 0 | 8 | 3 | 71 |
| *Smart thermostats* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 15 | 22 | 39 |
| *Boiler replacement* | 4 | 3 | 5 | 2 | 4 | 6 | 5 | 7 | 5 | 10 | 17 | 18 | 11 | 22 | 119 |
| *Boiler replacement (oil-gas)* | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 1 | 5 | 1 | 2 | 10 | 13 | 26 | 64 |
| *Space heat meters* | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 1 | 0 | 2 | 0 | 3 | 11 |
| *Hot water meters* | 3 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 2 | 1 | 0 | 2 | 0 | 1 | 14 |
| *Solar installation* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 3 | 8 |
| Total | 10 | 6 | 8 | 4 | 24 | 14 | 12 | 32 | 36 | 41 | 36 | 37 | 58 | 84 | 402 |

*Notes*: This table reports the number and types of interventions over time for all 548 buildings in our data (240 treated), corresponding to the beginning of the intervention.

tion of the remaining lifetime of the replaced building element.[14] Due to data limitations, we assume this opportunity cost to be zero.[15] This implies that our measure of the implicit carbon price includes the potentially avoided (anyway occurring) refurbishment cost that is not related to the improvement of building energy performance.[16]

## 2.2 Identification: Pre-treatment trends in energy use

The objective of this section is to motivate our strategy to identify causal evidence on energy savings and the implicit price of carbon associated with alternative investments in energy efficiency. Intuitively, we use observed outcomes for control buildings to inform a counterfactual post-treatment trajectory for energy use in treated buildings. This difference-in-differences strategy requires an assumption that, without energy efficiency investments, energy use among treated and control buildings follow the same trend.

We start by briefly discussing summary statistics for our sample, reported in Table 2, together with a comparison of treated and control buildings (using pre-

[14]According to Achtnicht and Madlener (2014), the vast majority of homeowners waits until a particular building element reaches the end of its useful life before contemplating replacement.

[15]We do not observe the decomposed investment cost for each energy efficiency improvement separately from building element replacement, nor the age of building elements.

[16]Streicher et al. (2020) show that this approach leads to relatively conservative estimates of cost-effectiveness. Compared to other methods, our approach therefore tends to overestimate the implicit price of carbon.

treatment values where relevant).[17] Overall, treated buildings use more energy per square meter, are slightly older, contain smaller apartments, and command lower rents relative to control. These differences, which presumably reflect expected profitability associated with energy efficiency investments, are not necessarily a threat to identification. Instead, we need credible evidence that control buildings provide a plausible counterfactual for treated buildings in the absence of investments.

The parallel trend assumption underlying our identification strategy is documented in Figure 1. Specifically, we report average building-level annual energy use (in kWh/$m^2$) over time for treated and control buildings. Given the staggered nature of investments (see Table 1), treated buildings that enter the during-treatment period drop out of the pre-treatment trend, so that the number of buildings in the treatment group declines with time (after 2014 the number of pre-treatment observations falls to zero, and is therefore not reported). In addition, some buildings enter or exit the portfolio during the observation period (unbalanced panel), so that the number of observations in the control group also varies.[18]

Two main observations emerge. First, pre-treatment differences in average energy use between treated and control buildings remain stable with time. One remarkable feature of the data is that evidence of a parallel trend can be documented even though treated buildings enter the during-treatment period. Below we use this feature of the data to provide more formal regression-based evidence that, in the absence of investments, the pre-treatment changes in the difference between treated and control buildings is not statistically significantly different from zero.

The second observation is that pre-treatment energy use for both groups of buildings trends downward. While explaining this trend is beyond the scope of our analysis, a number of comments are in order. First, our data covers a relatively long period of time, and climate change can be observed in the form of milder temperatures experienced during the heating season.[19] Second, a $CO_2$ tax

[17]Buildings included in the portfolio are not meant to be representative of the underlying population of buildings. In particular, as compared to 2016 data from FSO (2019d), they tend to be slightly more recent and contain significantly more units (see notes in Table 2).

[18]See Appendix B for the corresponding figure derived for a subsample of 285 buildings that remain in the portfolio over the entire horizon. We come back to potential sample selection issues in the robustness section by providing empirical results for the balanced dataset.

[19]From 2001 to 2016, long-term average temperature series from MeteoSwiss (2019) suggest that annual outdoor temperatures increased from 5.46°$C$ to 6.07°$C$, and from 1.37°$C$ to 1.87°$C$ in the winter.

Table 2: Summary statistics for buildings

| | All buildings | | | | Treated buildings | Control buildings | Diff. | (t-stat.) |
|---|---|---|---|---|---|---|---|---|
| | Mean | St. Dev. | Min | Max | Pre-treat. mean | Mean | | |
| Annual energy use (kWh/$m^2$) | 171.64 | 48.53 | 19.74 | 422.19 | 190.82 | 156.70 | 34.12*** | (8.70) |
| Total surface area ($m^2$) | 1736.90 | 1260.16 | 228.00 | 12130.00 | 1825.72 | 1667.68 | 158.03 | (1.46) |
| Construction year[a] | 1972.58 | 25.50 | 1870.00 | 2016.00 | 1968.87 | 1975.48 | -6.61** | (-3.03) |
| Number of units[b] | 23.36 | 16.43 | 3.00 | 167.00 | 24.73 | 22.30 | 2.43 | (1.72) |
| Avg. unit size[c] | 3.22 | 0.65 | 1.18 | 5.50 | 3.13 | 3.28 | -0.15** | (-2.68) |
| Monthly rent[d] (CHF/$m^2$) | 16.26 | 3.10 | 6.61 | 45.28 | 15.57 | 16.81 | -1.24*** | (-4.74) |
| Heating degree days[e] | 2863.04 | 265.92 | 0.00 | 4371.00 | 2883.82 | 2845.65 | 38.17 | (1.64) |
| Commercial units (%) | 0.06 | 0.11 | 0.00 | 0.93 | 0.06 | 0.05 | 0.01 | (1.19) |

*Notes*: 548 buildings are observed, with 240 in the treatment group and 308 in the control group. For treated buildings we report pre-treatment averages. [a]Average construction year of buildings in Switzerland: 1963.3 (FSO, 2019d). [b]Total number of residential and/or commercial leases; average for Switzerland: 4.9 (FSO, 2019d). [c]Average number of rooms per unit; average for Switzerland: 3.3 (FSO, 2019d). [d]Average monthly rent for Switzerland: 13.7 CHF/m$^2$ (FSO, 2019d). 2015 prices; exchange rate approx. CHF 1 = USD 1. [e]Heating degree days measure the difference between the local average outdoor temperature in a given day and 20°$C$, cumulated over a given heating season (see footnote 11). *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

on heating oil and natural gas has been levied since 2008, starting at CHF 12/t$CO_2$ and gradually reaching CHF84/t$CO_2$ in 2016 (FOEN, 2018b). Indeed, the market price of heating oil and natural gas has increased by 43.6 and 30.3 percent respectively (FSO, 2019f), and our analysis controls for potential fuel price effects (aside from year fixed effects).[20]

For our purpose, evidence of a downward trend implies that buildings' energy use is expected to decline even in the absence of energy efficiency investments. It follows that this trend is important for identifying energy savings and the implicit price of carbon associated with energy efficiency investments.

## 2.3 Econometric estimation

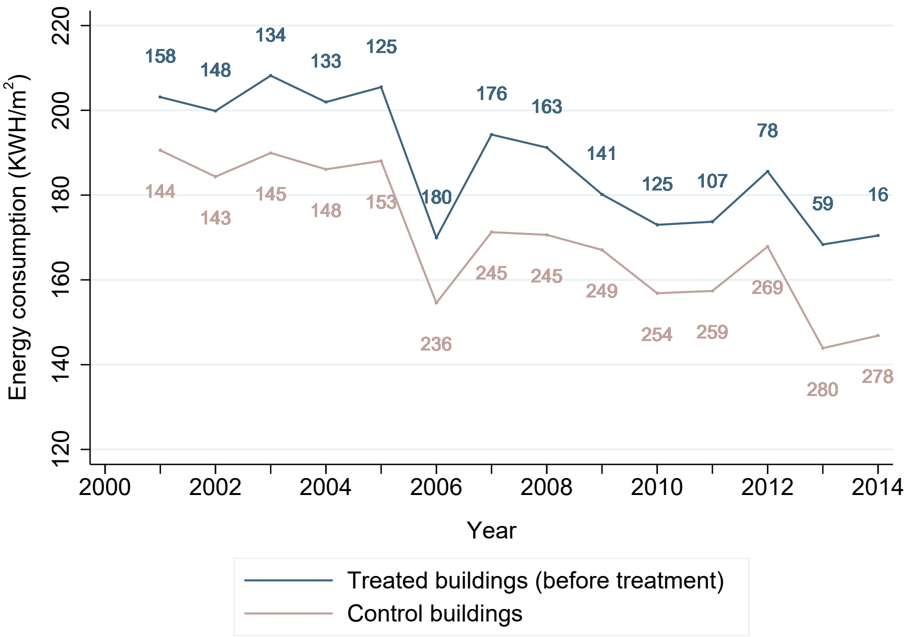
Based on evidence that treated and control buildings follow the same trend in the absence of energy efficiency investments, we now lay out a simple staggered difference-in-differences strategy to quantify the impact of energy efficiency interventions on energy use, $CO_2$ emissions, and heating expenditures, and in turn provide evidence on the associated implicit price of carbon.

Formally, we denote energy use for building $i$ and year $t$ as $e_{it}$ (in kWh/m$^2$), and write our baseline regression model as:

$$\ln(e_{it}) = \beta T_{it} + \mu D_{it} + \gamma W_{it} + \alpha_i + \alpha_t + \epsilon_{it} \,, \tag{1}$$

[20]In Appendix B, we provide graphical evidence of an almost equal downwoard trend in pre-treatment energy use for the balanced subsample. It follows that a change in the composition of the portfolio (e.g., through the purchase or construction of more efficient buildings in connection with more stringent regulation) does not explain the extent of the trend.

Figure 1: Trends in pre-treatment energy use for treated and control buildings




*Notes:* This figure reports pre-treatment average energy use (in kWh/$m^2$) for treated and control buildings over time, together with the number of buildings used to calculate group-specific averages (i.e., the number of observations per group per year). In the treatment group, the number of pre-treatment observations decreases with time as buildings enter the during-treatment period. The number of control buildings also varies with time, reflecting entry in and exit from the portfolio of buildings. From 2015 onwards, all buildings in the treatment group have entered the during-treatment period.

where $T_{it}$ is a post-treatment indicator equal to one if the works associated with investment in building $i$ is completed in $t$, $D_{it}$ is a during-treatment indicator equal to one if an intervention in building $i$ has started but is not completed in $t$, $W_{it}$ is a vector of control variables that includes the log of building-level heating degree days and log of fuel prices (either heating oil or natural gas), $\alpha_i$ and $\alpha_t$ are fixed effects for buildings and years respectively, and $\epsilon_{it}$ is an error term. The coefficient $\beta$ measures the change in energy use after an intervention is completed, averaged over all post-treatment periods, relative to an estimated counterfactual outcome.

While Equation (1) is the main workhorse of the existing literature, it averages the impact of heterogeneous energy efficiency investments both across interventions and over time. For our purpose, we use it in the context of an event-study regression (e.g., Autor, 2003), and estimate treatment effects for each pre-treatment and post-treatment years (the coefficient for the last pre-treatment period is normalized to zero). This provides a formal test of pre-treatment parallel trends, and also allows us to relate our results to existing empirical evidence cited above documenting energy savings for renovation bundles.[21]

In order to capture heterogeneous energy savings across different interventions, indexed by $k$, we augment the baseline specification as follows:

$$\ln(e_{it}) = \alpha_i + \alpha_t + \sum_k (\beta_k T_{kit} + \mu_k D_{kit}) + \gamma W_{it} + \epsilon_{it} \,, \tag{2}$$

where the coefficients $\beta_k$ measure energy savings associated with each intervention. We further consider two extensions. First, we include interaction terms capturing all observed combinations of interventions $T_{kit}$. These terms control for potential complementarity effects across retrofits applied to the same building, so that $\beta_k$ quantifies the impact of each individual intervention. Second, we investigate possible treatment effect heterogeneity as a function of pre-treatment energy use. To do so, we interact post-treatment dummies $T_{kit}$ with pre-treatment average energy use, and normalize the interaction term with respect to either the sample average or the average of the control group. While equation 2 estimates an ATET, in these specifications the main effects $\beta_k$ capture energy savings for buildings with pre-treatment energy use corresponding to the sample-average (ATE) and to the average of non-renovated buildings (ATENT), respectively.

Next, we derive evidence about the implicit price of carbon for each intervention. For this purpose, we employ a set of continuous post-treatment variables $I_{kit}$ that are zero in pre-treatment and during-treatment years, and equal to investment cost (CHF per $m^2$) associated with intervention $k$ and building $i$ in each post-treatment year. Alternatively, these variables can be viewed as an interaction between the set of post-treatment dummies $T_{kit}$ and investment costs per $m^2$.[22] Regression for $CO_2$ emissions (in kg $CO_2/m^2$) can be written as:

$$\textit{co2}_{it} = \alpha_i + \alpha_t + \sum_k (\theta_k I_{kit} + \mu_k D_{kit}) + \gamma W_{it} + \epsilon_{it} \,, \tag{3}$$

where $\theta_k$ can be interpreted as the marginal change in $CO_2$ emissions in relation to a CHF 1 investment in intervention $k$. Similarly, the regression for annual heating

[21]We also consider results for an even-study regression where the dependent variable is in levels, corresponding to Figure 1. This does not allow us to discriminate across functional forms.

[22]As mentioned previously, we control for interventions with missing financial data by including a set of post-treatment dummies $T_{kit}$.

costs (in CHF/m$^2$) is given by:

$$cost_{it} = \alpha_i + \alpha_t + \sum_k (\lambda_k I_{kit} + \mu_k D_{kit}) + \gamma W_{it} + \epsilon_{it} \,, \qquad (4)$$

where $\lambda_k$ captures the marginal change in annual heating cost associated with CHF 1 invested in intervention $k$. We note that regressions in levels facilitate the estimation of the implicit price of carbon, and we come back to implications for the parallel trend assumption and the associated event-study regressions below.

We then combine estimates resulting from equations (3) and (4), together with standard assumptions about the lifetime of each building element and discount rates, to carry out statistical inference on the implicit price of carbon associated with intervention $k$ (in CHF/t $CO_2$). See Appendix C for the details.

We close this section by listing robustness checks on equations (2-4) and the resulting implicit price of carbon. Specifically, we derive results for three alternative subsamples. First, we exclude buildings that use natural gas and focus on those that use heating oil as their pre-treatment heating fuel. Note that, among this sample, some buildings initially use heating oil but switch to natural gas following replacement of the central heating appliance. Second, we estimate the implicit price of carbon for the subsample of buildings that contain residential leases only. This allows us to document whether the presence of a small share of commercial leases affects our results. Lastly, we consider the set of buildings that are present in the portfolio over the entire period of observation (i.e., balanced sample). This provides evidence about a potential sample selection effect.

# 3 Estimation results

This section reports empirical results. First, we quantify the impact of energy efficiency investments on buildings' energy use, and document heterogeneity in energy savings across interventions. Second, we estimate the implied change in $CO_2$ emission reductions and energy expenditures, and derive the implicit price of carbon associated with alternative energy efficiency investments. Finally, we report results for three subsamples of buildings.

## 3.1 Energy efficiency investments and energy use

We start with an event-study regression for the log of annual building-level energy use on a set of pooled pre- and post-treatment dummies, control variables, building and year fixed effects, as well as during-treatment dummies (equation 1). Regression coefficients associated with energy efficiency interventions are reported graphically in Figure 2, together with cluster-robust 95% confidence intervals (see Appendix D for the corresponding regression table). These coefficients measure the change in energy use relative to control for a given pre- or post-treatment year, where the coefficient for the last pre-treatment period is normalized to zero.

For all years leading up to an intervention, coefficient estimates are not statistically significantly different from zero. This provides further support for the parallel trend assumption discussed previously. By contrast, all post-treatment coefficients are negative and statistically significantly different from zero. This indicates that, following an energy efficiency investment, energy use sharply declines relative to control, with energy savings of around 12 percent on average and stable with time. The scale of energy savings is broadly in line with other studies (for example, Liang et al., 2017 report savings of 8 percent for residential buildings and 12 percent for commercial buildings, and Fowlie et al., 2018 reports energy savings of 10 to 20 percent on average).

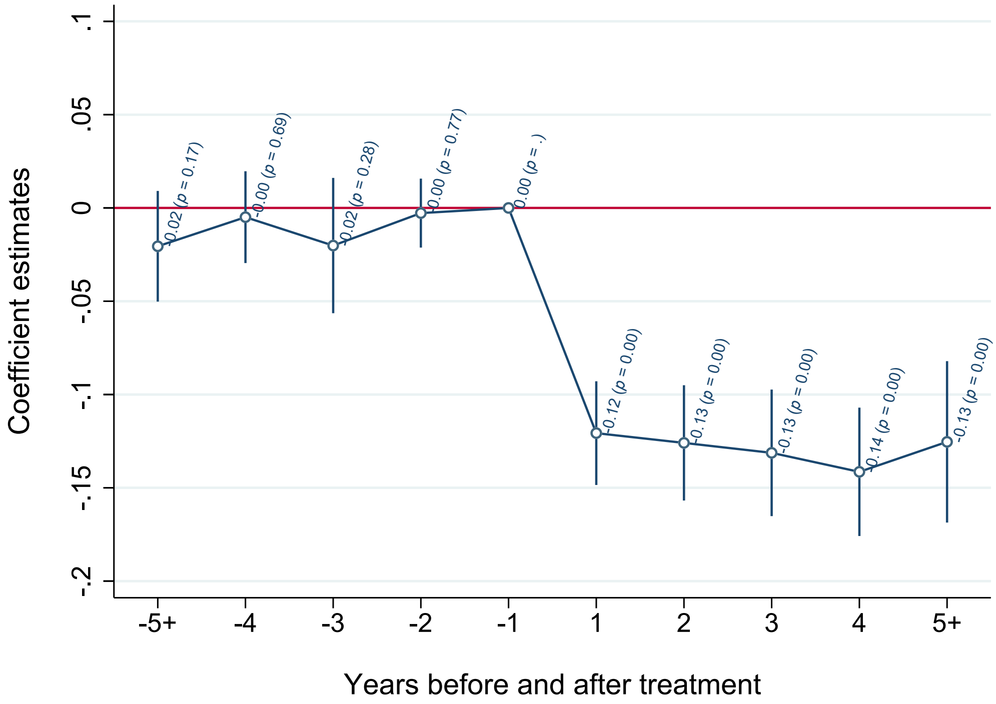
Table 3 documents how energy savings vary across interventions (equation 2). In columns (1) and (2) we report OLS regression estimates without and with control variables, respectively. In column (3) we add interaction terms capturing complementarities across interventions. In columns (4) and (5), we add a set of interaction terms between each treatment dummy and *pre*-treatment average energy use standardized at the sample average and at the average of control buildings, respectively. In all regressions, we control for building and year fixed effects and include during-treatment dummies. Cluster-robust standard errors are reported in parentheses.

Results show that estimates are broadly consistent across columns (1) to (3), and confirm large heterogeneity in energy savings across interventions. Facade insulation delivers the largest energy savings (around 20% reduction in energy use on average), followed by solar thermal collectors and smart thermostats. Energy savings implied by roof insulation and windows / boiler replacement (without fuel switching) are below ten percent. We find little evidence that switching from oil to gas or installing individual meters have an impact on energy use.[23]

The extent of complementarities between interventions is illustrated in Figure

[23]One potential reason for the lacking impact of installing individual meters is that the number of treated observations is not large enough to estimate treatment effects with statistical precision. However, given that we are able to estimate a statistically significant effect of installing solar thermal collectors (for which we observe less treated units), in any case the effects of (sub-)metering are likely to be relatively close to zero.

Figure 2: Panel fixed effects event study results for pooled energy efficiency investments




*Notes:* The graph displays point estimates, 95% confidence intervals and p-values from an event-study regression of the log of buildings' annual energy use per $m^2$ on pre- and post-treatment dummies for pooled energy efficiency interventions, control variables, building and year fixed effects, and during-treatment dummies. The last pre-treatment period ($t = -1$) is defined as the reference category. Inference is derived from standard errors clustered at the building-level (N=548). See D for the corresponding results table.

3, which uses estimates in Table 3, column 3, to compute *total* effect size for a subset of observed combinations of interventions.[24] Results suggest that adding all relevant interaction terms does not affect estimated energy savings significantly as compared to a sum of main effects only. This is in line with the observation that energy savings associated with individual interventions are not significantly affected by the inclusion of interaction terms for multiple interventions (column 2 vs. 3). In other words, complementarities between interventions appear to be modest.

Lastly, estimates reported in columns (4) and (5) suggest that pre-treatment

[24]For example, energy savings associated with a total effect size of -0.53 is $\exp(-0.53) - 1$, or a decline in energy use of about 41 percent.

Table 3: Energy efficiency investments and heterogeneous energy savings

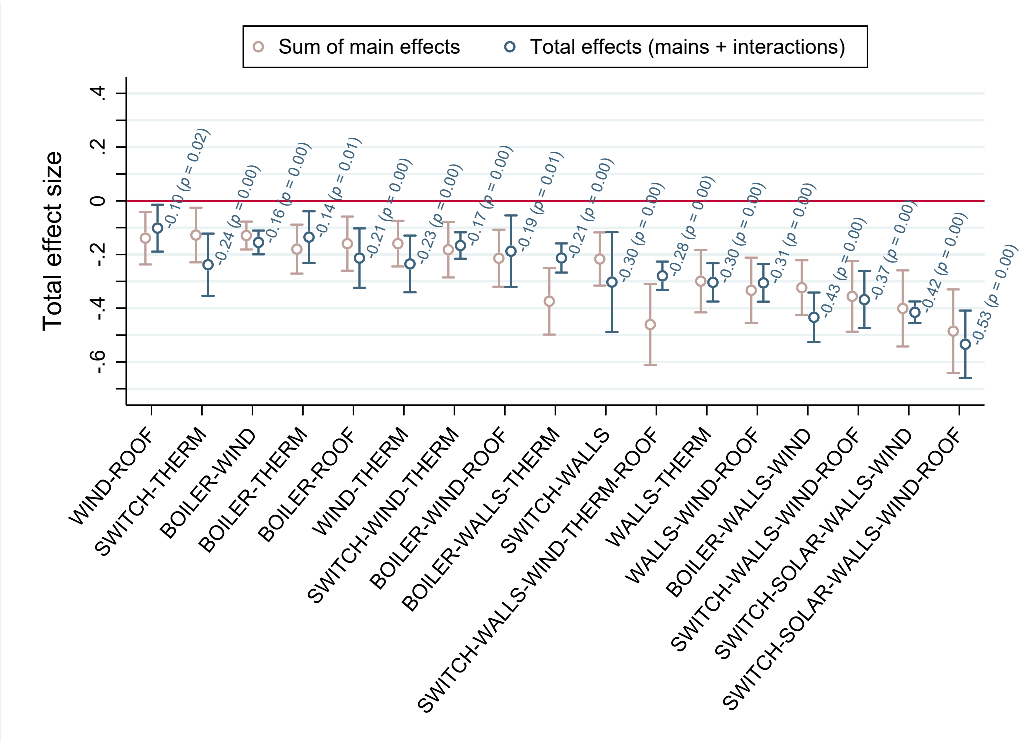
| | Individual treatments | Time-varying controls | Treatment interactions | Energy use interaction evaluated at | |
|---|---|---|---|---|---|
| | | | | sample average | control group average |
| | (1) | (2) | (3) | (4) | (5) |
| *Facade insulation* | -0.21*** | -0.21*** | -0.19*** | -0.18*** | -0.17*** |
| | (0.04) | (0.04) | (0.04) | (0.04) | (0.04) |
| *Roof insulation* | -0.08** | -0.08** | -0.08* | -0.08 | -0.07 |
| | (0.03) | (0.03) | (0.05) | (0.05) | (0.06) |
| *Windows replacement* | -0.06*** | -0.06*** | -0.05*** | -0.06*** | -0.06*** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| *Smart thermostats* | -0.10*** | -0.09*** | -0.11** | -0.10*** | -0.06 |
| | (0.03) | (0.03) | (0.04) | (0.04) | (0.05) |
| *Boiler replacement* | -0.08*** | -0.07*** | -0.07*** | -0.06** | -0.04 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.03) |
| *Boiler replacement (oil-gas)* | -0.04 | -0.02 | -0.02 | 0.001 | 0.02 |
| | (0.02) | (0.02) | (0.03) | (0.03) | (0.03) |
| *Space heat meters* | 0.08 | 0.08 | 0.03 | 0.09 | 0.06 |
| | (0.06) | (0.06) | (0.07) | (0.08) | (0.06) |
| *Hot water meters* | -0.06 | -0.05 | -0.04 | -0.11 | -0.07 |
| | (0.06) | (0.06) | (0.06) | (0.07) | (0.06) |
| *Solar installation* | -0.16*** | -0.16*** | -0.13** | -0.20** | -0.22* |
| | (0.06) | (0.06) | (0.05) | (0.09) | (0.12) |
| Control variables | no | yes | yes | yes | yes |
| Treatment interactions | no | no | yes | yes | yes |
| x pre-treatment energy use | | | | | |
| Sample average | no | no | no | yes | no |
| Control group average | no | no | no | no | yes |
| Observations | 7,047 | 7,047 | 7,047 | 7,047 | 7,047 |
| Buildings (clusters) | 548 | 548 | 548 | 548 | 548 |
| Adj. R-squared | 0.20 | 0.21 | 0.21 | 0.21 | 0.21 |

*Notes*: The dependent variable is the log of buildings' annual energy use in kWh/m$^2$, see equation (2). Column (1) reports OLS estimates for post-intervention dummies ($T_{kit}$), controlling for during-treatment dummies, building fixed effects, and year fixed effects. Column (2) adds control variables (log-heating degree days and log-fuel prices). Column (3) adds the full set of treatment interactions (i.e., all observed combinations of interventions). Column (4) adds an interaction between each treatment variable and standardized pre-treatment energy use evaluated at the sample average, while column (5) reports the same but instead normalizes interaction terms at the average of the control group. Standard errors are clustered at the building-level and reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

energy use has a statistically significant (negative) effect on energy savings in the case of smart thermostats and boiler replacement (without fuel switching). This implies that energy savings evaluated for control buildings (ATENT) are significantly smaller as compared to results for the treatment group (ATET). For other interventions, we find little evidence that pre-treatment use affects energy savings, which suggests that ATET and ATENT do not differ significantly.[25]

[25]Given that more energy efficient buildings by definition have less room for further efficiency improvements, this last result might seem surprising at first. Even if log-transformation of our dependent variable implies that energy savings are anyway expressed relative to pre-treatment energy use, it is conceivable that the relationship between pre-treatment efficiency and savings extends to percentage terms. We stress, however, that our analysis of marginal effects merely serves to compare ATET to ATENT, and thus only covers the relatively small interval of average pre-treatment energy use for treated (about 190 kWh/m$^2$) and control buildings (about 160

Figure 3: Total energy savings for observed combinations of interventions




*Notes:* This figure provides point estimates, 95% confidence intervals and p-values (obtained via the delta method) for selected combinations of energy efficiency investments, derived from regression results reported in Table 3, column 3. WALLS is *facade insulation*, ROOF is *roof insulation*, WIND is *windows replacement*, THERM is *smart thermostats*, HEAT is *boiler replacement*, SWITCH is *boiler replacement (oil-gas)* and SOLAR is *solar installation*.

## 3.2 $CO_2$ emissions, heating expenditures, and the implicit carbon price

We now turn to evidence on $CO_2$ emissions abatement and heating expenditures in relation to financial data on energy efficiency investments, and later derive implications for the implicit price of carbon. In Table 4, columns (1) and (2) provide regression results for equations (3) and (4), respectively.[26] More specifically, column (1) regresses $CO_2$ emissions (in kg $CO_2$/m$^2$) on investment costs for all treatments considered ($I_{kit}$, in CHF/m$^2$), and column (2) regresses annual heating expenditures (in CHF/m$^2$) on the same. In both regressions we control

kWh/m$^2$).

[26]In D, Table D1, we report results for a set of event-study regressions, suggesting that pre-treatment trends for $CO_2$ emissions and energy expenditures among treatment and control buildings are parallel. Table D1 also reports results for a specification using log-transformed outcome variables, which yield similar conclusions.

Table 4: $CO_2$ emissions, heating costs, and estimates for the implicit carbon price

| | Regression results | | Estimates for the implicit price of carbon (CHF/t$CO_2$) | | | |
|---|---|---|---|---|---|---|
| | $CO_2$ emissions (kg/m$^2$) | Heating cost (CHF/m$^2$) | Average use lifetime $\delta = 0\%$ | Average use lifetime $\delta = 6\%$ | Heavy use lifetime $\delta = 0\%$ | Heavy use lifetime $\delta = 6\%$ |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| *Facade insulation* | -0.01*** | -0.003*** | 939.50*** | 1,161.96*** | 1,113.75*** | 1,328.45*** |
| | -0.003 | (0.0006) | (287.65) | (303.42) | (331.35) | (346.80) |
| *Roof insulation* | -0.07*** | -0.03*** | -53.35 | 190.48*** | 59.15 | 270.67*** |
| | (0.02) | (0.01) | (75.30) | (69.14) | (89.33) | (93.52) |
| *Windows replacement* | -0.02*** | -0.01* | 655.24** | 850.10*** | 1,281.77*** | 1,435.77*** |
| | (0.01) | (0.003) | (312.22) | (284.87) | (490.33) | (473.02) |
| *Smart thermostats* | -5.37*** | -1.99*** | -358.76*** | -227.92*** | -352.56*** | -254.57*** |
| | (1.31) | (0.64) | (91.44) | (59.08) | (91.27) | (67.05) |
| *Boiler replacement* | -0.08*** | -0.02*** | 38.30 | 198.60*** | 136.72 | 275.78*** |
| | (0.02) | (0.01) | (75.10) | (58.30) | (88.78) | (77.21) |
| *Boiler replacement (oil-gas)* | -0.13*** | 0.01 | 263.54*** | 216.50*** | 326.25*** | 285.45*** |
| | (0.01) | (0.01) | (51.19) | (25.39) | (53.78) | (32.35) |
| Observations | 7,047 | 7,047 | | | | |
| Buildings (clusters) | 548 | 548 | | | | |
| Adj. R-squared | 0.45 | 0.66 | | | | |

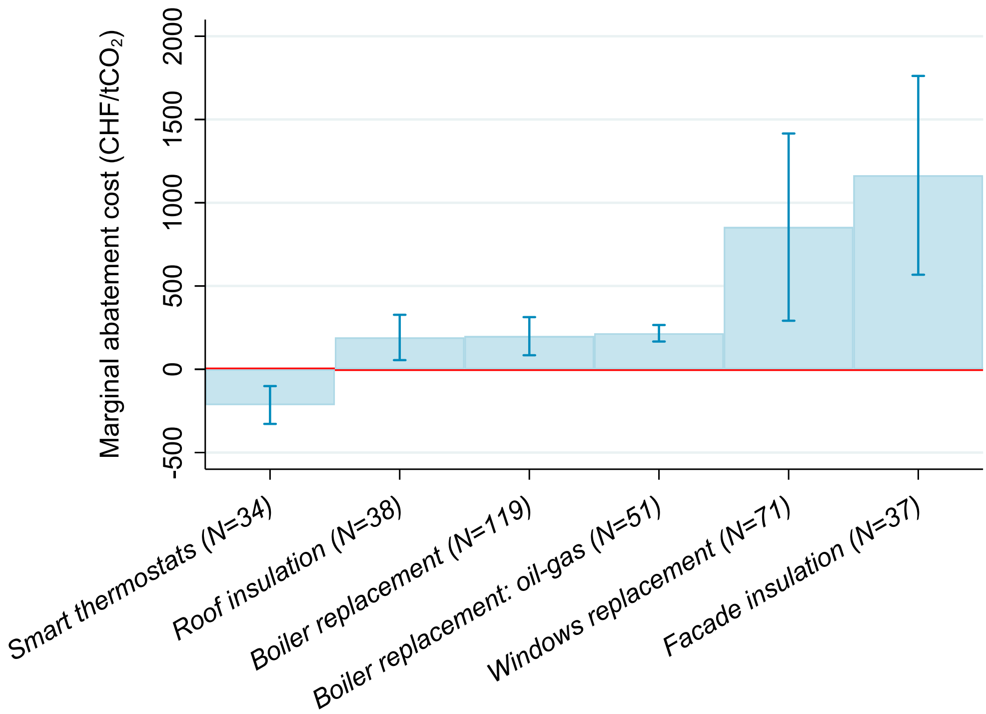
*Notes*: Column (1) is a regression of annual $CO_2$ emissions (in kg $CO_2$/m$^2$) on post-treatment investment cost variables ($I_{kit}$, in CHF/m$^2$). Column (2) is a regression of annual heating costs (in CHF/m$^2$) on post-treatment investment cost variables ($I_{kit}$, in CHF/m$^2$). Prices refer to a 2015 baseline; exchange rate approx. CHF 1 = USD 1. Both regressions control for building and year fixed effects, during-treatment dummies, control variables, interaction terms between treatments, and post-treatment dummies for interventions with missing financial data. Standard errors are clustered at the building-level and reported in parentheses. Based on columns (1) and (2), columns (3) to (6) report estimates for the implicit price of carbon, with standard errors obtained via the delta method reported in parentheses. Assumptions about lifetime assumptions for each investment are provided in Appendix C, Table C1. Columns (3) and (5) provide undiscounted results ($\delta = 0\%$), and columns (4) and (6) use a discount rate of six percent ($\delta = 6\%$). *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

for building and year fixed effects, during-treatment dummies, control variables, interaction terms for multiple interventions, and include post-intervention dummies for interventions with missing financial data. Standard errors clustered at the building level are reported in parentheses.

Results in column (1) indicate that all energy efficiency investments considered imply a statistically significant reduction in $CO_2$ emissions. However, the scale of emission reductions differs widely across interventions. For example, investing in exterior wall insulation leads to a reduction of emissions by 0.01 kg $CO_2$/CHF, whereas investing in smart thermostats instead decreases $CO_2$ emissions by 5.37 kg/CHF invested. Importantly, the ranking across interventions implied by these results sharply differs from the corresponding ranking for energy savings (see, e.g., Table 3, column 3).

Column (2) further shows that most energy efficiency investments have a statistically significant impact on heating expenditures. The reduction in heating-related expenditures is largest for the installation of smart thermostats, with a

Figure 4: Ranking for the implicit price of carbon across interventions




*Notes:* The graph displays point estimates and 95% confidence intervals for estimates of the implicit price of carbon. See Table 4, column (4), for the corresponding results. Prices refer to a 2015 baseline; exchange rate approx. CHF 1 = USD 1.

reduction of CHF 1.99/CHF invested, even though annual operational expenses (subscription costs) partly offset financial savings associated with lower energy use. By contrast, investments in windows replacement is only marginally statistically significant, and boiler replacement with fuel switching is found to have a positive impact on heating expenses, which reflects the slightly higher cost of natural gas relative to heating oil (although the point estimate is not statistically significantly different from zero).

Next, we exploit results from columns (1) and (2) to derive estimates for the implicit price of carbon associated with each intervention. Results are reported in columns (3) and (4) for average lifetime assumptions and in columns (5) and (6) for heavy-use lifetimes (see C, Table C1, for the details), with odd columns reporting undiscounted results and even columns using a six percent discount rate. For each estimate of the implicit carbon price, we use the delta method to obtain robust standard errors and report these in parentheses. In Figure 4, we further illustrate the ranking across interventions based on estimates reported in column (4). This can be interpreted as a version of the marginal abatement cost curve by McKinsey & Company (2009) based on realized energy savings instead of engineering projections.

Estimates suggest that the implicit price of carbon for facade insulation and windows replacement are particularly high in comparison to other interventions. This holds across the range of assumptions considered in Table 4. While the relatively wide 95% confidence bounds suggest considerable within-intervention heterogeneity in implicit carbon prices, these are quite distinct from estimates associated with roof insulation, boiler replacement (with and without fuel switching), and smart thermostats.[27]

By contrast, we estimate that the implicit price of carbon associated with smart thermostats is negative across all specifications considered. The implicit carbon price for roof insulation is also negative (not statistically different from zero) for a lifetime of 80 years and a discount rate of zero, but stands at around CHF 200/t$CO_2$ for a 6 percent discount rate. Similarly, the implicit price of carbon associated with boiler replacement is somewhere between zero and CHF 300/t$CO_2$.

In sum, there is large heterogeneity in the implicit price of carbon, and the ranking of interventions does not correlate with estimates for energy savings reported previously. A weighted average across interventions based on the frequency of renovations suggest an implicit carbon price associated with energy efficiency in buildings of 382.77 CHF/t$CO_2$ (95% confidence interval: 247.28-518.27). This estimate is relatively close to a value of 350 USD/t$CO_2$ discussed in Gillingham and Stock (2018) in reference to energy efficiency in buildings, although both the setting (Fowlie et al., 2018) and some of the underlying assumptions are quite different.

## 3.3 Further evidence on energy savings and the implicit carbon price

This section provides further evidence on heterogeneous energy savings and implications for the implicit carbon price for three alternative subsamples: (i) buildings that use heating oil (Table 5); (ii) buildings with residential leases only (Table 6);

[27]While our decomposition into separate interventions represents an improvement compared to many previuos studies, our results suggest that in order to identify precise estimates for facade insulation and windows replacement, these interventions need to be disaggregated even further (into double and triple glazing or with respect to thickness of facade insulation, for instance).

Table 5: Energy savings, $CO_2$ emissions, heating costs, and implicit carbon prices for buildings using heating oil

| | Energy use (kWh/m$^2$) | $CO_2$ emissions (kg/m$^2$) | Heating cost (CHF/m$^2$) | Implicit price of $CO_2$ |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Facade insulation* | -0.19*** | -0.01*** | -0.003*** | 1,208.41*** |
| | (0.05) | (0.003) | (0.0007) | (332.30) |
| *Roof insulation* | -0.08 | -0.10*** | -0.04*** | 116.77* |
| | (0.07) | (0.02) | (0.01) | (62.26) |
| *Windows replacement* | -0.04** | -0.02*** | -0.005** | 1,008.54** |
| | (0.02) | (0.01) | (0.002) | (415.70) |
| *Smart thermostats* | -0.15*** | -3.33** | -1.83*** | -336.75 |
| | (0.03) | (1.47) | (0.60) | (207.49) |
| *Boiler replacement* | -0.05*** | -0.08*** | -0.01* | 260.18*** |
| | (0.02) | (0.02) | (0.01) | (89.90) |
| *Boiler replacement (oil-gas)* | 0.01 | -0.11*** | 0.01 | 261.46*** |
| | (0.03) | (0.01) | (0.01) | (43.09) |
| Observations | 5,012 | 5,012 | 5,012 | |
| Buildings (clusters) | 334 | 334 | 334 | |
| Adj. R-squared | 0.46 | 0.53 | 0.75 | |

*Notes*: This table focuses on the subsample of buildings that use heating oil. Column (1) reports OLS estimates for a regression of log-annual energy use in kWh/m$^2$ on post-intervention dummies ($T_{kit}$). Column (2) is a regression of annual $CO_2$ emissions in kg $CO_2$/m$^2$ on investment cost (in CHF/m$^2$). Column (3) is a regression of annual heating costs (in CHF/m$^2$) on investment cost (in CHF/m$^2$). Prices refer to a 2015 baseline; exchange rate approx. CHF 1 = USD 1. All regressions control for building and year fixed effects, during-treatment dummies, control variables, treatment interactions, and post-treatment dummies for interventions with missing financial data. Standard errors are clustered at the building-level and reported in parentheses. Based on columns (2) and (3), column (4) reports estimates for the implicit price of carbon assuming average building element lifetimes and a $\delta = 6\%$ discount rate. Cluster-robust standard errors are reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

and (iii) buildings that remain in the portfolio over the entire observation period (Table 7). In each table, column (1) reports regression results for energy savings (equation 2), column (2) focuses on $CO_2$ emissions in relation to investment cost (equation 3), and column (3) provides evidence on heating expenditures (equation 4). In all regressions, we include control variables, building and year fixed effects, during-treatment dummies, interaction terms controlling for multiple interventions, and post-treatment dummies for interventions with missing financial data. Next, column (4) uses estimates from columns (2) and (3) to estimate the implicit price of carbon based on an assumption of average lifetime for building elements and a six percent discount rate. Cluster-robust standard errors are reported in parentheses throughout. Appendix E provides summary statistics for each subsample.

We start with the sample of 334 buildings that use heating oil, including 168 treated buildings, with some of them switching to natural gas during the period

Table 6: Energy savings, $CO_2$ emissions, heating costs, and implicit carbon prices for purely residential buildings

| | Energy use (kWh/m$^2$) | $CO_2$ emissions (kg/m$^2$) | Heating cost (CHF/m$^2$) | Implicit price of $CO_2$ |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Facade insulation* | -0.20*** | -0.01*** | -0.002*** | 1,774.08*** |
| | (0.08) | (0.002) | (0.0008) | (592.51) |
| *Roof insulation* | -0.09 | -0.09*** | -0.03*** | 134.33* |
| | (0.06) | (0.03) | (0.01) | (71.25) |
| *Windows replacement* | -0.05** | -0.02*** | -0.01* | 763.46** |
| | (0.02) | (0.01) | (0.005) | (303.58) |
| *Smart thermostats* | -0.08 | -2.52* | -0.65 | -147.75 |
| | (0.06) | (1.50) | (0.68) | (164.67) |
| *Boiler replacement* | -0.06*** | -0.08*** | -0.02*** | 232.53*** |
| | (0.02) | (0.02) | (0.01) | (68.13) |
| *Boiler replacement (oil-gas)* | -0.01 | -0.11*** | 0.01 | 249.37*** |
| | (0.03) | (0.01) | (0.01) | (42.60) |
| Observations | 4,209 | 4,209 | 4,209 | |
| Buildings (clusters) | 322 | 322 | 322 | |
| Adj. R-squared | 0.24 | 0.49 | 0.69 | |

*Notes*: This table focuses on the subsample of buildings with residential leases only. Column (1) reports OLS estimates for a regression of log-annual energy use in kWh/m$^2$ on post-intervention dummies ($T_{kit}$). Column (2) is a regression of annual $CO_2$ emissions in kg $CO_2$/m$^2$ on investment cost (in CHF/m$^2$). Column (3) is a regression of annual heating costs (in CHF/m$^2$) on investment cost (in CHF/m$^2$). Prices refer to a 2015 baseline; exchange rate approx. CHF 1 = USD 1. All regressions control for building and year fixed effects, during-treatment dummies, control variables, treatment interactions, and post-treatment dummies for interventions with missing financial data. Standard errors are clustered at the building-level and reported in parentheses. Based on columns (2) and (3), column (4) reports estimates for the implicit price of carbon assuming average building element lifetimes and a $\delta = 6\%$ discount rate. Cluster-robust standard errors are reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

of interest. Results reported in Table 5 for energy savings, $CO_2$ abatement and changes in energy expenditures align closely with corresponding estimates for the full sample (Table 3, column 3). In turn, point estimates and the ranking for implicit carbon prices are also very similar. One noteworthy difference is the negative estimate for smart thermostats, which is not statistically significantly different from zero.

Table 6 reports results for the sample of 322 purely residential buildings, including 131 treated buildings. Overall, point estimates tend to be less precisely estimated, implying again that the negative estimate associated with smart thermostats is not statistically significantly different from zero. Nevertheless, the ranking for the implicit price of carbon remains. This suggests that the small share of commercial leases in the buildings we consider (around 6 percent on average) do not affect overall results significantly.

Lastly, results for the balance subsample, reported in Table 7, refer to 285 build-

Table 7: Energy savings, $CO_2$ emissions, heating costs, and implicit carbon prices for the balanced subsample

| | Energy use ($kWh/m^2$) | $CO_2$ emissions ($kg/m^2$) | Heating cost ($CHF/m^2$) | Implicit price of $CO_2$ |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Facade insulation* | -0.21*** | -0.01*** | -0.003*** | 1,158.48*** |
| | (0.06) | (0.003) | (0.0007) | (324.97) |
| *Roof insulation* | -0.08 | -0.10*** | -0.03*** | 121.11* |
| | (0.07) | (0.02) | (0.01) | (63.01) |
| *Windows replacement* | -0.03* | -0.02** | -0.004** | 1,088.40** |
| | (0.02) | (0.01) | (0.002) | (472.93) |
| *Smart thermostats* | -0.14*** | -12.39** | 1.83 | 101.14 |
| | (0.03) | (5.32) | (1.43) | (107.37) |
| *Boiler replacement* | -0.05*** | -0.07*** | -0.01 | 299.17*** |
| | (0.02) | (0.02) | (0.01) | (98.26) |
| *Boiler replacement (oil-gas)* | -0.003 | -0.10*** | 0.003 | 265.52*** |
| | (0.03) | (0.01) | (0.01) | (48.31) |
| Observations | 4,560 | 4,560 | 4,560 | |
| Buildings (clusters) | 285 | 285 | 285 | |
| Adj. R-squared | 0.49 | 0.56 | 0.77 | |

*Notes*: This table focuses on the subsample of buildings that are observed from 2001 to 2016 (balanced panel). Column (1) reports OLS estimates for a regression of log-annual energy use in $kWh/m^2$ on post-intervention dummies ($T_{kit}$). Column (2) is a regression of annual $CO_2$ emissions in kg $CO_2/m^2$ on investment cost (in $CHF/m^2$). Column (3) is a regression of annual heating costs (in $CHF/m^2$) on investment cost (in $CHF/m^2$). Prices refer to a 2015 baseline; exchange rate approx. CHF 1 = USD 1. All regressions control for building and year fixed effects, during-treatment dummies, control variables, treatment interactions, and post-treatment dummies for interventions with missing financial data. Standard errors are clustered at the building-level and reported in parentheses. Based on columns (2) and (3), column (4) reports estimates for the implicit price of carbon assuming average building element lifetimes and a $\delta = 6\%$ discount rate. Cluster-robust standard errors are reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

ings (151 treated) observed over 16 years. Results for energy savings are overall very similar, although as expected standard errors are slightly larger. Moreover, the ranking of implicit carbon prices is similar, with the exception of boiler replacement measures. One important difference, however, is a positive impact of smart thermostats on heating cost (statistically indistinguishable from zero), presumably on account of the subscription fees. In turn, the point estimate for the implicit price of carbon associated with smart thermostat is positive, although not statistically significantly different from zero.

# 4 Discussion and conclusion

In this paper, we have used data for a portfolio of multi-unit buildings to provide novel evidence on heterogeneous impacts of energy efficiency as a carbon abatement strategy. Our data includes a rich array of alternative interventions, allowing us to document heterogeneity in energy savings and to carry out statistical inference on the implicit price of carbon associated with alternative energy efficiency interventions. Given a non-random treatment assignment, our identification strategy relies on the staggered nature of investments to motivate the use of buildings with no intervention as a control group.

In order to foster an efficient allocation of resources in the absence of an *explicit* carbon price, policy-makers often resort to public incentive schemes targeting specific abatement measures. In this context, investments provide an *implicit* price of carbon (i.e., the net social cost of reducing $CO_2$ emissions by one tonne) that policy-makers can use to determine the least-cost way to reduce $CO_2$ emissions and then compare it to available benefit estimates of avoided carbon emissions. Our results confirm that frequently subsidized measures such as facade insulation and windows replacement achieve significant energy savings, with respectively 19 and five percent on average. We also find, however, that these interventions are an expensive strategy to abate $CO_2$. By contrast, installing smart thermostats is relatively cheap, with some of our specifications even suggesting a negative implicit carbon price.[28]

Our results illustrate policy-makers' difficulty to select specific abatement measures to promote. First, we find that the range of implicit carbon prices in the narrow domain of energy efficiency in buildings is large, and that most estimates are above estimated benefits of avoided emissions (around USD 40/t$CO_2$, Greenstone et al., 2013). This confirms the importance of empirical work on the cost of $CO_2$ abatement in order to evaluate policy decisions. Second, our results for smart thermostats suggest that new technologies can achieve significant energy savings at a relatively low cost. A natural tendency for policy-makers to favor established abatement strategies (e.g., for which we have *ex-post* data) will fail to incentivize these emerging abatement opportunities.

While our results show consistency with other settings, we close by emphasizing that evidence on the implicit price of carbon is by construction context-dependent (Gillingham and Stock, 2018). Given a lack of global carbon pricing policy in the near future, further work on the impact of specific abatement investment seems warranted. For example, our analysis abstracts from important welfare impacts such as improved comfort for tenants (e.g., less variability in in-

[28] We emphasize that negative estimates are found to be sensitive to the use of alternative subsamples, and that energy savings for this particular intervention may be lower for buildings in the control group. In sum, smart thermostats are consistently found to be the cheapest option for carbon abatement, but the implicit carbon price associated with this specific intervention is likely to be higher among non-renovated buildings.

door temperature levels) or lower maintenance costs for property owners. The timing of renovation (with respect to the economic lifetime of building elements) also has a direct impact on cost-effectiveness of interventions. And energy efficiency investments have distributional implications, notably through changes in rents. These considerations all have implications for investment decisions and for the design of public policies, and are left for future research.

# Chapter II

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

This chapter is mainly based on a working paper co-authored by Mehdi Farsi (University of Neuchatel), Bruno Lanz (University of Neuchatel), and Sylvain Weber (University of Neuchatel). This research is part of the activities of SCCER CREST (Swiss Competence Center for Energy Research), which is financially supported by Innosuisse. We thank Meredith Fowlie, Paul Burger, Philippe Thalmann, and the participants at various conferences for useful comments and discussions.

This paper has been published in the working paper series of UNINE IRENE (No. 20-07) and SSCER CREST (No. WP2-2020/04). We are currently in the process of revising and resubmitting it to *Resource and Energy Economics*. It was presented by Ghislaine Lang at the 25th Annual Conference of the European Association of Environmental and Resource Economists (EAERE) in Berlin (Germany), 2020 (carried out virtually), and it was accepted to be presented by Ghislaine Lang at the Annual Congress of the Swiss Society of Economics and Statistics (SSES) in Zurich (Switzerland), 2020 (cancelled).

**Abstract**

We elicit homeowners' willingness to pay (WTP) for energy efficiency and low-carbon technologies in the context of replacement heating appliances. We exploit a novel within-between subject design that involves manipulating information in a two-stage discrete choice experiment (DCE) and using 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. By contrast, we identify large heterogeneity in preferences for different heating technologies (i.e., oil, gas, wood, heat pump), and that on average, oil users' WTP for switching to low-carbon technologies does not cover respective investment cost differentials. Finally, our difference-in-difference results show that the provision of information about private and pro-social benefits of investments barely increases WTP for energy efficienct and low-carbon technologies.

**Keywords** Energy efficiency; Low-carbon technologies; Informational interventions; Product familiarity; Discrete choice experiments; WTP space estimation.
**JEL codes** D1; D8; H23; Q4; Q5; R31.

# 1 Introduction

In the last two decades, low-carbon technologies have been at the center of global policy makers' efforts to meet rising $CO_2$ emissions targets. Despite the public resources dedicated to foster private investment, however, adoption of low-carbon technologies is slow, and explanations generally point to market failures, behavioral biases, and modeling errors (see e.g. Allcott and Greenstone, 2012; Gillingham and Palmer, 2014; Gerarden et al., 2017). In the residential context, imperfect information (Newell and Siikamäki, 2014; Allcott and Taubinsky, 2015; 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 declared barriers to the take-up of novel technologies. While every building element requires replacement at some point (so that intertia eventually expires), a growing body of literature shows that even during replacement decisions, homeowners prefer to adopt a familiar technology (Sopha et al., 2010; Michelsen and Madlener, 2012, 2016). In light of the fact that most of today's 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 experimental evidence on how homeowners' willingness to pay (WTP) toward alternative heating appliances are affected by information. In particular, we design a discrete choice experiment (DCE, Louviere et al., 2000; Train, 2009) that simulates a hypothetical scenario in which the respondents' heating system 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 in our experiment all reside in Switzerland and own the house in which they live. Considering a replacement decision and experimentally fixing the

[1] In the U.S., 57.7% of all homes use natural gas as their main heating fuel (U.S. Energy Information Administration, 2015). In the E.U., 43.1% of residential buildings are heated with natural gas, and 14.0% with heating oil (based on Eurostat, 2017a). In Switzerland, 39.4% of residential buildings are heated with heating oil, and 20.7% with natural gas (FSO, 2017b).

[2] While stated preference studies allow independent variation of attribute levels and elicitation of WTP for non-financial attributes, and provide full information about available choice sets, they can induce hypothetical and strategic biases. A randomized control trial, however, which would allow elicitation of revealed preferences, is difficult to carry out in our setting because of the substantial up-front cost and the low replacement rate underlying our investments. Despite the standard measures we employ in order to encourage homeowners to disclose their true preferences (such as reminding them about budget constraints and consequentiality of choices, as we discuss later), the main contribution of our study lies in comparisons between and within subjects.

level of comfort across alternatives permits the isolation of homeowners' preferences for these specific product attributes and thus disentangling preferences for the familiar technology from mere inertia.

The main contribution of this paper is the use of a novel two-by-two experimental design, inspired by Allcott and Taubinsky (2015) and Allcott and Knittel (2019),[3] which features both within and between variation (Charness et al., 2012) in exposure to information. In a nuthsell, our experimental *within*-subject design includes two sets of choice tasks with an information script in-between. After the baseline choice tasks (featuring only the energy label, technology, and investment cost), subjects are randomly assigned to a treatment intervention informing them about financial implications related to their decisions. In particular, the treatment conditions focus on two aspects: i) private returns to investments (via heating cost savings), and pro-social implications of choices (via $CO_2$ tax payments). Subjects are then asked to complete a second set of choice tasks allowing us to identify the impact of information on willingness to pay (WTP).

Our experimental variation *between* subjects 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.[4] Within these treatment conditions, we vary the degree of salience of the information, thereby complementing the findings of Newell and Siikamäki (2014) and 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). Varying the salience of $CO_2$ tax payments allows us to contribute to the 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).[5]

Space heating is responsible for roughly a third of residential energy end-uses (IPCC, 2014), and is expected to deliver large $CO_2$ emissions reductions in the coming decades. As a result, increasing the diffusion of energy efficient and low-carbon technologies is one of the central measures promoted by policy makers to

[3] Our experimental design also builds on the works of Scarpa and Willis (2010), Kwak et al. (2010), and Newell and Siikamäki (2014).
[4] 2017 exchange rate approx. CHF 1 = USD 1
[5] On the topic of tax salience, see also Chetty et al. (2009); Finkelstein (2009); Sexton (2015).

reduce fossil fuel use in residential buildings. However, the vast majority of homeowners waits until a particular building component reaches the end of its useful life before contemplating replacement (Achtnicht and Madlener, 2014), and the comparatively long useful life expectancy of heating appliances (see e.g. Rapson, 2014; Volland et al., 2020) implies that homeowners are temporarily *locked-in* a particular technology. Moreover, a growing body of research shows that even when equipment replacement is imperative, one of the key determinants of homeowners' choice is the type of technology that is already installed at their dwelling (e.g. Sopha et al., 2010; Michelsen and Madlener, 2012, 2016).[6]

Common behavioral explanations for consumers' tendency to consume the product that they consumed previously, particularly in the context of heating systems, are 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 costs (see e.g. Alberini et al., 2013). The second contribution of the present paper is to provide evidence on homeowners' preferences for the familiar technology when these three important aspects associated with switching from one technology to another are experimentally fixed. In particular, the experiment is designed so that up-front investment costs in the decision tasks are inclusive of 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).

The experiment was administered to an online panel of 511 respondents each completing six pre-treatment and six post-treatment choice tasks. We find that homeowners' baseline 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 5,850 for 15-year undiscounted, 2017 energy prices). It appears that a significant proportion of respondents consider more than mere financial benefits when making efficiency choices. Our difference-in-difference results show further that respondents' valuations remain roughly unchanged even after they are informed about financial implications of their choices on heating costs. This

[6] Note that the concept of familiarity preferences builds on a related line of research that emphasizes the role of product familiarity (a consumer's subjective evaluation about his or her knowledge about a product on the basis of previous experience, Park and Lessig, 1981) for consumer choices in general (see e.g. Tversky and Kahneman, 1974; Giacalone and Jaeger, 2016; Galbreth and Ghosh, 2019).

suggests that underinvestment in energy efficiency is not caused by homeowners' lack of knowledge regarding expected benefits of choices.

By contrast, results indicate that a significant share of homeowners is not willing to pay investment cost differentials associated with low-carbon technologies. In particular, only about 50% (30%) of respondents are willing to pay more for a heat pump appliance (wood pellet-based boiler) than for a boiler operating on heating oil, and only about 70% (50%) are willing to pay an investment cost premium of CHF 10,000 in exchange for a heat pump appliance (wood pellet-based boiler). We find that this can be explained in part with a distinct preference for the familiar technology, which we identify across most user types. This pronounced preference for the status quo technology prevails even after respondents are exposed to information about $CO_2$ tax payments levied on fossil fuels. In particular, this type of information appears to *decrease* average WTP for low-carbon technologies, although point estimates are economically small (compared to actual costs).

Our findings complement a burgeoning literature that studies the role of costs (up-front and operating costs as well as various types of public funding, see e.g. Alberini et al., 2013; Alberini and Bigano, 2015), comfort (e.g. Bakaloglou and Charlier, 2019; Schleich et al., 2020), and ex-ante information (see Allcott and Wozny, 2014, Chapter 3) for a successful promotion of low-carbon technologies. In particular, we contribute to the studies that challenge the importance of imperfect information and inattention for energy efficiency purchase decisions (Allcott and Taubinsky, 2015; Jacobsen, 2015; Allcott and Knittel, 2019), 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 show 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 on homeowners' preferences for low-carbon technology and energy efficiency. The experiment includes three parts: (i) six baseline DCE choice tasks, (ii) random assignment to one of four information treatments or the control group, and (iii) six endline 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 F.[7]

## 2.1 Discrete choice experiment

In the first part of the experimental sequence, we ask participants to imagine that the primary heating appliance of their dwelling requires replacement, and to consider which option would be best suited for their household as one of the options would need to be installed in any case. We emphasize that, apart from what is mentioned explicitly, appliances perform equally well, meet general requirements, and are expected to have the same operating life of 15 years. In addition, we explain to homeowners that the installation of the new appliance 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.[8] 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 bias sometimes 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

[7] 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.

[8] 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."

Figure 1: Baseline choice task


preference literature (see Johnston et al., 2017), we also make use of budget constraint reminders.[9] 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 F, Figures F1 to F4.

Subsequently, we ask subjects to consider a multi-dimensional choice between different heating appliances (see Figure 1). In particular, we ask them to choose from three unlabeled product 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 ranges from $A^{++}$ (most efficient) to G (least efficient); (ii) the heating technology; and (iii) up-front investment cost.[10]

Table 1 provides an exhaustive overview of attributes and levels applied in the experiment. In addition to being motivated by previous literature, which shows

[9] 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."

[10] Relative to other survey techniques, DCEs may require an advanced degree of cognitive effort. In order to reduce potential for complexity-induced inconsistencies, we pay considerable attention to the presentation of a sound choice context, carefully explain the choice tasks with examples, keep the number of alternatives-by-attributes comparable or below other studies in the field (e.g. Scarpa and Willis, 2010; Achtnicht and Madlener, 2014; Newell and Siikamäki, 2014), and test respondents' understanding of choice context and tasks with a pilot study.

that the chosen attributes matter in similar contexts, the range of efficiency grades, technologies, and investment cost levels, is realistic compared to the options available on the local market at the time of the survey.[11] We generated an experimental design based on D-efficiency (Kuhfeld et al., 1994)[12] and piloted the levels selected to ensure that they yield meaningful options for respondents. After the pilot, we revised the experimental design for the main survey using a Bayesian D-efficency criteria.

In detail, our experimental design focusses on energy labels B, A, and $A^+$ (see Table 1), arguably the most common classes in the marketplace at the time of the survey for the technologies we consider.[13] 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 at the market (see Table 1), two of which are typical fossil fuel-based technologies (boiler with heating oil and boiler with natural gas), and two of which can be considered renewable energy sources in Switzerland (boiler with wood pellets, and heat pump using electricity).[14] 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, 2019e).

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

[11] In particular, our baseline scenario reflects the fact that in the current marketplace, homeowners are generally left 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 the energy efficiency label and chosen technology (i.e., the energy source).

[12] A full factorial experimental design for the attributes and levels described above yields $4x5x3 = 60$ combinations of alternatives. This design is beneficial as it allows to identify the main effect of each attribute, as well as the effect of interactions between all attributes. However, as our primary interest lies in the main effect of each attribute (irrespective of changes in other attribute levels), we adopt a fractional factorial design (Louviere et al., 2000) with a total of 36 combinations of alternatives.

[13] 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).

[14] Wood pellets are a renewable and carbon neutral by-product of wood processing companies (at combustion, only as much $CO_2$ is emitted as the tree had absorbed while growing). In Switzerland, the vast majority of pellets are sourced either locally or from neighboring countries. As for heat pumps, note that the Swiss electricity mix mainly consists of hydro (60%) and nuclear power (34%).

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.

market. Depending on the current system in place (as mentioned earlier, changing heating technologies involves an extra cost), 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, and for a new air-water heat pump from CHF 29,000 to CHF 42,000 (Energieheld Schweiz, 2020).

## 2.2 Informational interventions

Table 2 summarizes the five treatment conditions to which respondents are randomly allocated after completing the six baseline choice tasks. Each condition consists of an information screen plus the six subsequent endline 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 Figures F9 to F11).

In order to foster effective transmission of information to respondents, we take two specific steps inspired by Allcott and Taubinsky (2015) and Allcott and Knittel (2019). On the one hand, interventions include both verbal and visual (via a simple 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.

Table 2: Overview of informational treatment and control interventions

| Indicator | Treatment name | Information screen | Endline choice task |
|---|---|---|---|
| $C$ | Control | Neutral | Baseline |
| $T_A$ | Heating cost | Heating cost | Baseline |
| $T_B$ | Heating cost salient | Heating cost | Baseline + annual heating cost |
| $T_C$ | $CO_2$ tax | $CO_2$ tax | Baseline |
| $T_D$ | $CO_2$ tax salient | $CO_2$ tax | Baseline + annual heating cost incl. $CO_2$ tax |

*Notes*: In each treatment group, subjects go through six baseline 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 baseline DCE tasks (conditions $C$, $T_A$, and $T_C$) or some variation of it (conditions $T_B$ and $T_D$).

After completion of the quiz question, homeowners receive instructions for the second set of choice tasks. In some treatment conditions we modify the choice task design in order to reinforce salience of the information provided. As a result, participants either face the same choice tasks as they did in the baseline, or a marginally modified version of them (see Table 2). In the following subsections, we detail our various treatment and control conditions.

**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.[15]

The control group receives neutral (*placebo*) information that is designed not to affect homeowners' choices, while at the same time not appearing as completely out of context. Specifically, respondents are provided with information detailing the age of the Swiss building stock (information screen *Neutral*, Figure F9). After completing the one-question quiz, participants face a new series of six choice tasks designed similarly as the ones in the baseline sequence (see Figure 1).

[15]The parallel trend assumption underlying our identification strategy is documented in Appendix G, Figure G1.

### 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 Figure F10). This allows testing the importance of specific financial information for investors' choices. The information screen conveys an average expenditure of CHF 1,710 per year for a standard appliance with efficiency label B and CHF 1,320 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).[16]

Treatment conditions $T_A$ and $T_B$ provide the same information screen (and quiz question), but they differ in the design of the endline choice tasks. Homeowners in treatment group $T_B$ face the same choice set design as in the baseline, so that endline 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, we expect treatment $T_A$ to increase respective WTP as compared to the baseline.[17] This treatment is labeled *Heating cost*.

Homeowners in treatment group $T_B$, labeled *Heating cost salient*, complete an endline choice task which explicitly displays an estimate of heating costs associated with each alternative (see Figure 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).[18] In particular, alternatives containing efficiency grades B, A, and A$^+$, are associated with annual heating costs of CHF 1,710, CHF 1,530, and CHF 1,320, 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

[16]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 et al., 2013; Lang and Lanz, 2018). The specific numbers used in our experimental intereventions merely support our objective of quantifying how information on financial savings affects homeowners' WTP.

[17]We note that in this context, both financial and energy literacy have been declared barriers to energy efficiency investments, see Blasch et al. (2019) and Brent and Ward (2018).

[18]This format is conceptually similar to U.S. energy efficiency labels for water heating systems studied by Newell and Siikamäki (2014).

intervention. If salience matters in this context, we would expect endline WTP for energy efficiency to be higher in treatment group $T_B$ than in treatment group $T_A$, i.e., $WTP^{label}(T_A) < WTP^{label}(T_B)$.

**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 Figure F11). At the time of the experiment, the tax amounts to CHF 84 per ton of $CO_2$ (The Federal Council, 2016), and is imposed on all fossil heating and process fuels (mainly oil and natural gas, see The Federal Council, 2012).[19] Importantly, respondents are informed that low-carbon technologies (wood pellets and heat pumps in our setting) are not taxed, signaling that they imply less or no (direct) $CO_2$ emissions.

Treatments $T_C$ and $T_D$ again differ in terms of whether or not the $CO_2$ tax information is displayed in the endline choice task. In treatment $T_C$, participants face the baseline choice task design reported in Figure 1, and endline 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, we expect treatment $T_C$ to increase WTP of low-carbon technology choices as compared to the baseline.[20] This treatment is labelled *$CO_2$ tax*.

In treatment $T_D$, the endline choice task integrates 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 shown in Figure 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 1'710 as per above) include CHF 550 in $CO_2$ tax payments for heating oil and CHF 320 for natural gas. For effi-

[19] $CO_2$ tax 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 (The Federal Council, 2016).

[20] Specifically for Switzerland, Burger et al. (2018) show that a substantial portion of citizens have a poor understanding of the $CO_2$ tax, as only 67% of fossil fuel users are aware that they are subject to $CO_2$ tax payments, and only 39% of renewable energy users correctly assume that they are not (and only 14% of respondents understand the tax redistribution mechanism).

Figure 2: Endline choice task with heating costs ($T_B$)

| | Offer I | Offer II | Offer III |
|---|---|---|---|
| Heating technology | Boiler with heating oil | Heat pump using electricity | Boiler with natural gas |
| Investment cost | Fr. 17'030 | Fr. 10'160 | Fr. 30'140 |
| Energy label | A+ | A | B |
| Annual heating costs | CHF 1'320 | CHF 1'530 | CHF 1'710 |

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

ciency grade A, the heating costs (CHF 1'530) include CHF 490 in taxes for heating oil and CHF 290 for natural gas. Finally, for efficiency label A$^+$, the heating costs (CHF 1'320) 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. Similar to above, if salience matters for the formation of homeowners' preferences regarding $CO_2$ tax payments, then endline WTP for both energy efficiency and low-carbon technologies of treatment group $T_D$ should be higher than corresponding endline 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 environemntal motives play a role in the formation of homeowners' preferences, we would expect respondents' endline 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., $WTP^{label}(T_B) < WTP^{label}(T_D)$.

Figure 3: Endline choice task with heating costs and $CO_2$ tax ($T_D$)


## 2.3 Implementation

We script our DCE with *Qualtrics* and inform the design with a comprehensive pilot study. The main survey is implemented 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).[21] Out of 5,015 subjects that participate in the wider study, a total of 511 homeowners are randomly assigned to our experiment. We focus on owners of detached (60%), semi-detached (22%), and terraced houses (18%). Apartment owners are excluded

[21]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 30min 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.

from the experiment.

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 H1, Appendix H), our sample is in line with figures from the Federal Statistical Office (FSO) on the Swiss population of *homeowners* (FSO, 2019h,i) 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 6,000-8,999 compared to CHF 8,029 in Switzerland). The fact that our sample includes larger dwellings (172m$^2$ compared to 138m$^2$ in Switzerland) with higher annual heating costs (CHF 1,920 against CHF 1,042 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, 2019e), 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).[22]

In Table H2 of Appendix H, 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.[23]

# 3 Econometric framework

In this section, we describe how we use DCE data to estimate WTP for energy efficiency and heating technologies, and explain how we exploit within and between variations among subjects to quantify the impact of several informational interventions on choices.

## 3.1 Estimating homeowners' willingness to pay

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*) rather than the product itself. In turn, ob-

[22]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.

[23]In particular, one participant only completed the baseline choice tasks, and one participant only completed the endline choice tasks, so that we end up with a total of 510 respondents for each treatment period.

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

In choice situation $t$, respondent $n$ selects alternative $j$ which maximizes their utility, i.e. $U_{njt} > U_{nit}$ $(\forall j \neq i)$. In our setting, individual $n$ is asked to choose twelve times ($t \in 1, 2, ..., 12$) 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, $t \leq 6$ indicates observations before treatment, and $t > 6$ indicates observations after treatment. Then, the deterministic portion of utility $V_{njt}$ can be expressed as follows:

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

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 $\beta_n$ $(\in \beta_n^A, \beta_n^{A^+})$, $\gamma_n$ $(\in \gamma_n^{gas}, \gamma_n^{wood}, \gamma_n^{pump})$, and $\delta_n$, are the marginal utility parameters of interest and can be estimated from observed choices before ($t \leq 6$) and after treatment ($t > 6$). In particular, the coefficients in $\beta_n$ are measured relative to the reference category *label B*, while coefficients in $\gamma_n$ are measured relative to the reference category *heating oil*. Moreover, taste parameters $\theta_n$ $(\in \beta_n, \gamma_n, \delta_n)$ are distributed across participants with density $f(\theta \mid \Omega)$, the mixing distribution. We follow the literature in assuming that $\beta_n$ and $\gamma_n$ follow a normal distribution, whereas $\delta_n$ is log-normal.

We facilitate interpretation of the results as well as subsequent estimation of treatment effects (in WTP space) by modelling choices directly in WTP space (Train and Weeks, 2005), which allows making assumptions regarding the distribution of (marginal) WTP directly (Train and Weeks, 2005).[24] In order to specify our model in WTP space, the utility function is scaled with the cost coefficient $\delta_n$.

[24]Alternatively, modelling in preference space requires assuming a distribution for the separate coeffcients and deriving WTP for 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 defined moments (Train and Weeks, 2005; Hole and Kolstad, 2012).

Specifically, we estimate:

$$V_{njt} = \delta_n \left( \beta_n^A \, label_{njt}^A + \beta_n^{A^+} \, label_{njt}^{A^+} + \gamma_n^{gas} \, gas_{njt} + \gamma_n^{wood} \, wood_{njt} + \gamma_n^{pump} \, pump_{njt} + cost_{njt} \right), \tag{2}$$

where the notation follows the logic laid out above, although here the set of normally distributed coefficients of interest becomes $\delta_n \times \beta_n$ and $\delta_n \times \gamma_n$, and can be directly interpreted as average (marginal) WTP before ($t \leq 6$) and after treatment ($t > 6$).[25] This particular set of coefficients is labelled $\theta_n^{wtp}$.

In order to accommodate random preference heterogeneity at the individual level, we employ a mixed logit (MXL) model for individual choice probabilities (Revelt and Train, 1998; McFadden and Train, 2000).[26] The MXL probability that individual $n$ selects alternative $i$ in choice situation $t$ before treatment is given by:

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

where $f(\theta^{wtp} \mid \Omega)$ is the density function of $\theta^{wtp}$, and $\Omega$ ($\in \Omega_0, \Omega_1$) refers to the parameters of the distribution. In particular, $\Omega_0$ and $\Omega_1$ represent parameters of the distribution before ($t \leq 6$) and after treatment ($t > 6$), respectively.

Given that the choice probabilities in the MXL model have no closed-form, we estimate the parameters with simulated maximum likelihood (Train, 2009). In particular, we approximate the choice probabilities through simulation and insert the simulated probabilities into the log-likelihood function, which allows us to maximize the following simulated log-likelihood function:

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

where $\theta_n^{wtp[r]}$ refers to the $r$-th draw for individual $n$ from the distribution of $\theta^{wtp}$. We estimate the parameters based on $R = 300$ Halton draws.

[25]Note that in this specification, the estimated investment cost parameters represent the mean ($\delta_{mean}$) and standard deviation ($\delta_{sd}$) of the natural logarithm of the cost coefficient. The mean and standard deviation of the coefficient itself are given by $exp(\delta_{mean} + 0.5 * \delta_{sd}^2)$ and $exp(\delta_{mean} + 0.5 * \delta_{sd}^2) \times \sqrt{exp(\delta_{sd}^2) - 1}$, respectively (Train, 2009).

[26]The alternative multinomial logit (MNL) model imposes heavy structure on the data due to the property of 'irrelevance of independent alternatives'. Furthermore, as we show later, controlling for unobserved heterogeneity in tastes increases the explanatory power of our model considerably.

Finally, we use the method of Revelt and Train (2000) to simulate *individual-level* WTP parameters $\hat{\theta}_n^{wtp}$ (i.e., $\widehat{\delta_n \times \beta_n}$ and $\widehat{\delta_n \times \gamma_n}$). More precisely, we calculate individual-specific WTP parameters by conditioning on homeowners' observed choices and on the estimated sample distributions of tastes from equation (2):

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

where $\theta_n^{wtp[r]}$ refers to the $r$-th draw for individual $n$ from the estimated distribution of $\theta^{wtp}$, and we estimate the parameters based on $R = 300$ Halton draws. Given that we estimate equation (2) separately for $t \leq 6$ and $t > 6$, we generate two simulated WTP estimates per individual and attribute level, one before and one after the informational intervention.

## 3.2 Identifying the effect of information

Based on the simulated individual-level WTP estimates for each attribute level before and after treatment, we can identify individual-level treatment effects of information. To achieve this, we estimate a set of linear difference-in-difference regressions in which individual $n$'s simulated WTP for a particular attribute level $k$ ($\in label^A, label^{A^+}, gas, wood, pump$) in period $p$ ($\in 0, 1$), denoted $\hat{\theta}_{knp}^{wtp}$, is a function of post-treatment indicators $T_{knp}$:

$$\hat{\theta}_{knp}^{wtp} = \alpha_{kn} + \alpha_{kp} + \lambda_k T_{knp} + \epsilon_{knp}\,, \tag{3}$$

where $T_{knp}$ is a set of post-treatment indicators equal to one if individual $n$ completed a particular information treatment in period $p$, $\alpha_{kn}$ and $\alpha_{kp}$ are individual and a time fixed effect, respectively, and $\epsilon_{knp}$ is an error term. The vector of coefficients in $\lambda_k$ can be interpreted as average treatment effects and provides direct evidence on how information affects WTP.

As an extention, we explore the importance of familiarity (which has been confirmed in an imperfect information setting, see e.g. Michelsen and Madlener, 2012) once homeowners are fully informed about financial implications of their choices. In particular, we estimate heterogeneity in average treatment effects of information with respect to the status quo heating technology. To achieve this, we estimate equation (3) separately for fossil fuels users, i.e., the subsample of households that heat their own house with either heating oil or natural gas.

# 4 Experimental results

This section reports the main results from our analysis. We first provide evidence on homeowners' WTP for energy efficiency and heating technologies in heating appliance replacement decisions, separately for observations before and after treatment. We then exploit simulated individual-level WTP estimates to provide evidence on homeowners' preferences for the existing technology, and exploit within- and between-subject variations in information disclosure to identify the impact of information on subjects' WTP. Finally, we account for the interaction of financial information and familiarity by identifying the effect of information on fossil fuel users.

## 4.1 Mixed logit model of homeowners' WTP

Our main MXL model results are reported in Table 3.[27] Columns (1) and (2) report pre-treatment ($t \leq 6$) mean and standard deviation estimates for equation (2). More precisely, we report WTP space results (in thousands CHF) for the normally distributed attributes *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*. Columns (3) and (4) report the same results for choices made after the informational interventions ($t > 6$).[28] We report standard errors clustered at the respondent-level in parentheses.

Results in Table 3, columns (1) and (2), show that before our informational interventions, homeowners' average WTP for an appliance certified with energy

[27]In Appendix I, we document corresponding estimation results for the multinomial logit (MNL) model in WTP space. Coefficient estimates are close in magnitude to the MXL model, with the exception of homeowners' average WTP for natural gas relative to oil, which is statistically significant both before (column 1) and after treatment (column 2), and homeowners' average WTP for wood pellets relative to oil, which achieves statistical significance after treatment (column 2). The main conclusions drawn from the MNL model are the same as for the MXL model. We note that controlling for unobserved heterogeneity in tastes increases the explanatory power of our model considerably (BIC and Pseudo $R^2$ for the main specification estimated with a MNL model are 6,050 and 0.10, while they are 4,928 and 0.28 for the corresponding MXL model), and that a likelihood ratio test reveals that it results in a statistically significant improvement in model fit (p-value=0.0000).

[28]At this stage, variability in WTP induced by the different treatment conditions is captured in the unobserved heterogeneity term ($\varepsilon_{njt}$).

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

| | Before treatment | | After treatment | |
|---|---|---|---|---|
| | Mean | Std.-dev. | Mean | Std.-dev. |
| | (1) | (2) | (3) | (4) |
| Energy label A | 7.29*** | 8.99*** | 7.99*** | 6.17*** |
| | (1.02) | (1.49) | (0.78) | (1.07) |
| Energy label $A^+$ | 13.54*** | 10.67*** | 14.19*** | 10.84*** |
| | (1.02) | (1.32) | (0.97) | (1.15) |
| Natural gas | 1.13 | 23.94*** | 1.03 | 20.05*** |
| | (1.43) | (2.43) | (1.67) | (2.10) |
| Wood pellets | -0.98 | 20.14*** | 1.80 | 16.02*** |
| | (1.85) | (2.15) | (1.23) | (1.74) |
| Heat pump | 8.18*** | 20.78*** | 9.76*** | 17.02*** |
| | (1.71) | (2.32) | (1.20) | (1.56) |
| Investment cost | -1.59*** | 0.47* | -1.45*** | 0.39 |
| | (0.19) | (0.25) | (0.13) | (0.27) |
| Observations | 9,108 | | 9,096 | |
| Subjects (clusters) | 510 | | 510 | |
| Log-Pseudolikelihood | -2,409.28 | | -2,309.99 | |
| AIC | 4,842.55 | | 4,643.97 | |
| BIC | 4,927.95 | | 4,729.36 | |
| Pseudo $R^2$ | 0.28 | | 0.31 | |

*Notes*: Column (1) reports mixed logit mean WTP estimates (in thousands CHF) before treatment, and column (2) shows corresponding standard deviation estimates. Column (3) reports mixed logit mean WTP estimates after treatment, and column (4) shows 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. Estimates refer to the mean and standard deviation of a normally distributed attribute underlying the log-normally distributed cost coefficient, as well as the cost coefficient itself (see equation 2). Standard errors are clustered at the respondent-level and reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

label A instead of B is CHF 7,290, and for label $A^+$ it is CHF 13,540. On average, they do not have a statistically significant preference for boilers operating on natural gas or wood pellets relative to heating oil, but are willing to spend CHF 8,180 more for a heating appliance powered by a heat pump using electricity. All standard deviation estimates for the five attributes are highly statistically significant and relatively large in magnitude, indicating substantial heterogeneity in tastes across respondents. This pattern is particularly pronounced for the technology attributes, where the standard deviations exceed the mean estimates by a large margin (so that WTP of a non-negligible portion of respondents actually has the opposite sign). WTP estimates after our informational interventions, which are reported in columns (3) and (4), are close to the corresponding results before treatment.[29]

A graphical display of these results is provided in Figure 4, where we report kernel densities for our attributes based on the simulation of individual-level WTP before and after treatment based on equation (2). In particular, Figure 4 displays the kernel distributions of respondents' WTP for each attribute (level), conditional on (pooled) treatment status. In addition, we display the underlying mean estimates before and after treatment that are reported in Table 3. Specifically, panel (a) displays the kernel distribution of respondents' individual-specific WTP for energy label A (relative to B). Respondents' WTP for energy label $A^+$ is displayed in panel (b). Panels (c-e) show the kernel densities of respondents' WTP for natural gas, wood pellets, and heat pumps (relative to heating oil), respectively.

Figure 4, panels (a) and (b) show that the majority of respondents have positive WTP values for efficiency grades A and $A^+$ (relative to B). By contrast, panels (c-e) show that approximately 50% of homeowners are unwilling to pay an investment cost premium for either a boiler based on natural gas or wood pellets, and about one third of respondents are unwilling to pay a premium for a heat pump appliance using electricity (all relative to heating oil). In sum, Figure 4 reconfirms the conclusions drawn from Table 3. At the aggregate level, homeowners' preferences barely change after treatment. Before we exploit changes at the individual-level in Section 4.3, in the following section we discuss simulated baseline WTP estimates in more detail.

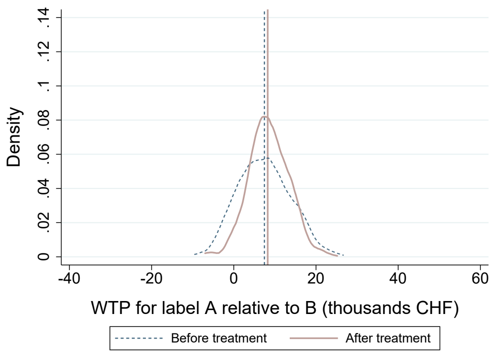
## 4.2 Baseline preferences and the role of familiarity

In Table 4, we report mean and standard deviation estimates of simulated individual-specific WTP based on equation (2). We report baseline WTP in panel (a) and endline WTP in panel (b). The first column shows estimates for the full sample followed by four specific subgroups. In particular, we report estimates separately for selected status quo heating appliance users (i.e., oil users, natural gas users, wood users, and heat pump users).

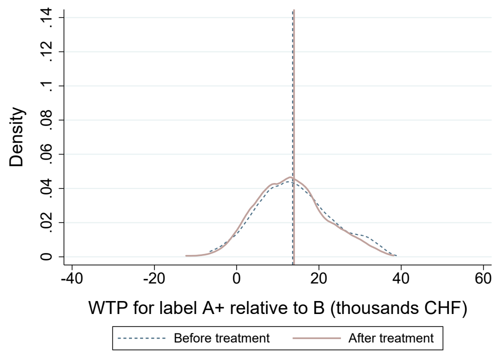
As for Table 4, panel (a), mean and standard deviation WTP estimates for the full sample are close to the underlying distribution parameters reported in Table 3,

[29]The corresponding mean and standard deviation estimates of the *investment cost* parameter are -0.23 (0.07) and 0.11 (0.10) respectively for observations before treatment, and -0.25 (0.06) and 0.10 (0.10) after treatment (standard errors in parentheses).

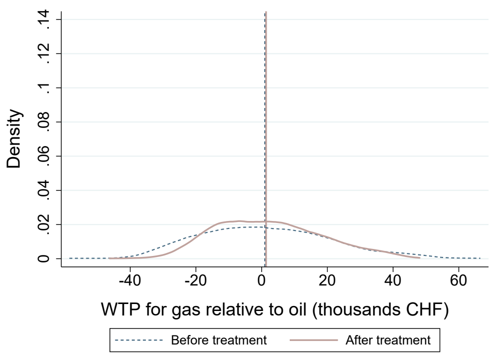
Figure 4: Density distributions of individual-specific WTP by treatment status



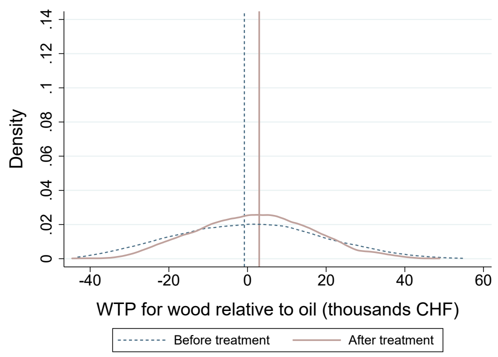

(a) Energy label A



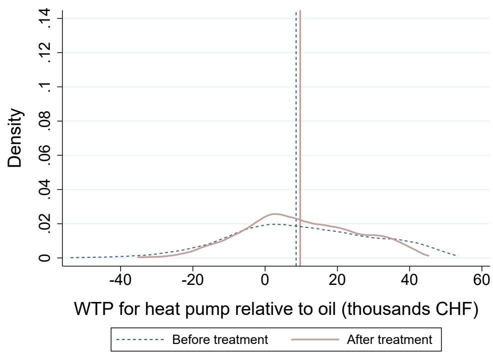

(b) Energy label A$^+$




(c) Natural gas




(d) Wood pellets




(e) Heat pump

*Notes:* Each kernel density estimate uses Epanechnikov kernel function with an optimal bandwidth. The vertical lines represent the corresponding mean estimates before and after treatment of the underlying mixed logit esimations reported in Table 3. Only one line is visible in panel (c) because the difference in means cannot be identified at the chosen axis scale.

columns (1) and (2). Mean estimates for efficiency labels vary barely across status quo user technologies. By contrast, among the specific user groups considered, natural gas users have the highest average WTP for natural gas (CHF 17,770), wood pellet users for wood pellets (CHF 12,640), and heat pump users for heat pumps (CHF 28,360). Furthermore, heating oil users' average WTP estimates are the lowest for all three reported technologies (CHF -8,320 for natural gas, CHF -7,140 for wood pellets, and CHF 1,180 for heat pump), and natural gas users' average WTP is second lowest for low-carbon technologies (CHF 5,260 for wood pellets and CHF 12,720 for heat pump). In addition, we note that average WTP estimates for heat pump appliances are relatively high (compared to other, non-status quo technologies) for all user types. Standard deviation estimates are relatively high for all attributes (especially technologies) and across all status quo user types. Mean and standard deviation WTP estimates after treatment, reported in panel (b), are close to estimates before treatment.

In Figure 5, we report kernel densities for individual-specific WTP before treatment, separately for specific status quo technology user groups. More precisely, panels (a) and (b) show the distribution of respondents' baseline WTP for energy efficiency grades A and $A^+$ (relative to B), respectively, conditional on whether the respondents' current heating appliance is based on heating oil, natural gas, or other users. Panel (c) displays the kernel distribution of respondents' baseline WTP for natural gas (relative to heating oil) separately for oil users, gas users (who are the *status quo users* in this case), and other technologies. The kernel distribution of homeowners' baseline WTP for wood pellets is displayed in panel (d), and for heat pumps in panel (e), again separately for respondents currently heating their dwelling with heating oil, the technology in question (i.e., *status quo users*), and other users. Note that in each panel, the subcategory *Others* is by construction composed of different user categories. For each panel and user group we also display the corresponding median estimates.

Figure 5, panels (a) and (b), shows that both heating oil users' and natural gas users' preferences for energy efficiency are close to those of the remainder of the sample. By contrast, kernel functions in panels (c-e), displaying WTP for heating technologies, are relatively more dispersed. By revealing that median WTP estimates of *status quo users* are substantially higher than those of other respondents throughout, panels (c-e) illustrate the previously cited status quo or familiarity effects inherent in homeowners' heating technology choices. In other words, the graph shows that a substantial portion of gas, wood, and heat pump users is biased towards the existing (or familiar) technology. Moreover, oil users' median WTP to switch to other, lower-carbon technologies is either negative or close to zero in all cases, and their distribution is slightly more dispersed toward

Table 4: Simulated WTP by status quo technology and treatment status (thousands CHF)

| | Full sample | | Heating oil users | | Natural gas users | | Wood pellet users | | Heat pump users | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Std.-dev. | Mean | Std.-dev. | Mean | Std.-dev. | Mean | Std.-dev. | Mean | Std.-dev. |
| *(a) Before treatment* | | | | | | | | | | |
| Energy label A[a] | 7.05 | (6.04) | 7.07 | (5.93) | 7.05 | (6.38) | 7.60 | (8.56) | 6.44 | (4.85) |
| Energy label A+[a] | 13.73 | (8.20) | 14.33 | (8.58) | 12.91 | (8.35) | 12.82 | (6.31) | 13.76 | (6.94) |
| Natural gas[b] | 0.89 | (20.28) | -8.32 | (17.16) | 17.77 | (16.97) | -6.01 | (13.10) | -3.12 | (13.19) |
| Wood pellets[b] | 0.29 | (17.44) | -7.14 | (16.98) | 5.26 | (15.21) | 12.64 | (15.95) | 7.32 | (12.40) |
| Heat pump[b] | 10.00 | (18.20) | 1.81 | (17.25) | 12.72 | (14.65) | 16.29 | (15.66) | 28.36 | (12.34) |
| *(b) After treatment* | | | | | | | | | | |
| Energy label A[a] | 8.19 | (4.24) | 8.31 | (4.34) | 8.01 | (4.41) | 9.20 | (5.24) | 7.71 | (3.20) |
| Energy label A+[a] | 13.31 | (8.19) | 13.84 | (8.47) | 12.52 | (8.38) | 12.29 | (5.83) | 13.43 | (7.36) |
| Natural gas[b] | 1.81 | (17.43) | -6.13 | (14.61) | 16.47 | (14.57) | -3.91 | (11.42) | -1.76 | (11.48) |
| Wood pellets[b] | 1.75 | (14.28) | -4.39 | (13.72) | 5.86 | (12.61) | 12.22 | (13.39) | 7.35 | (10.03) |
| Heat pump[b] | 9.86 | (15.31) | 2.99 | (14.44) | 12.13 | (12.48) | 15.04 | (13.30) | 25.34 | (10.44) |
| Observations | 511 | | 238 | | 148 | | 23 | | 54 | |

*Notes*: Simulated individual-specific WTP estimates (in thousands CHF) relative to the reference category. [a]Relative to label B. [b]Relative to heating oil.

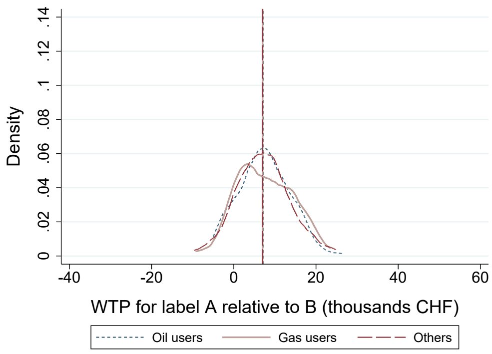
lower valuations than that of the reminder of the sample. This reconfirms a certain ceteris paribus unwillingness to switch technology among a large proportion of oil users.[30]

## 4.3 The impact of information on individual choices

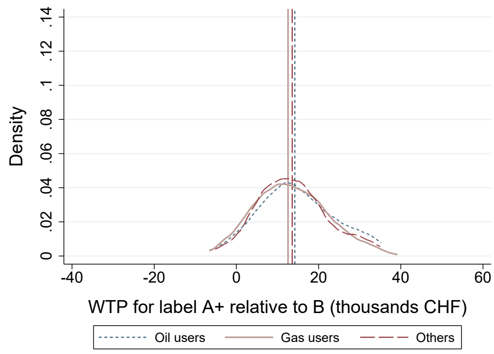
In Table 5, we report OLS regression results for equation (3), which identifies the average treatment effect of information on the change in WTP at the respondent-level, controlling for both individual and a time fixed effect. The dependent variables in columns (1) and (2) are respondents' simulated WTP for energy label A and $A^+$ (both relative to B), respectively. The dependent variables in columns (3-5) are simulated WTP estimates for natural gas, wood pellets, and heat pumps, respectively (all relative to heating oil). There are two observations per respondent, i.e., one before and one after treatment. We cluster standard errors at the respondent-level and report them in parentheses.

[30]Appendix J shows that on the aggregate level, kernel densities for observations after treatment, separated by the status quo technology, are very similar to distributions before treatment displayed in Figure 5.

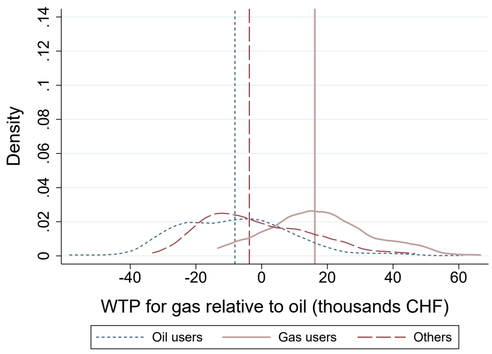
Figure 5: Density distributions of individual-specific WTP by status quo heating technology (before treatment)



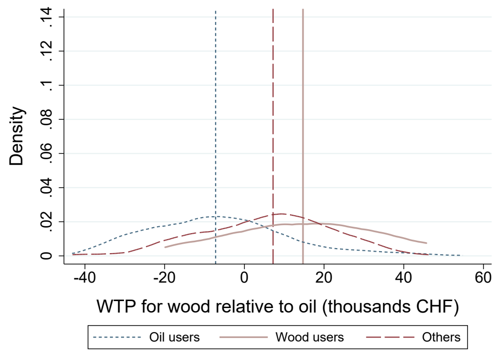

(a) Energy label A



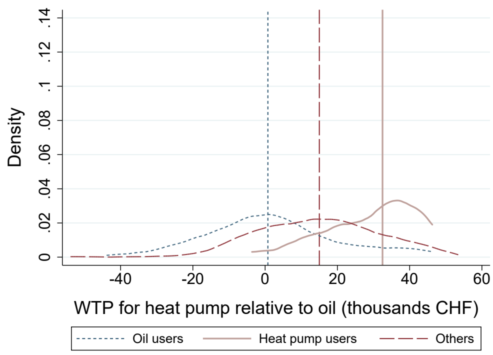

(b) Energy label $A^+$




(c) Natural gas




(d) Wood pellets




(e) Heat pump

*Notes:* Each kernel density estimate uses Epanechnikov kernel function with an optimal bandwidth. The vertical lines represent the corresponding estimates for the median.

Results in Table 5 show that our informational interventions did not influence homeowners' choices as expected. On the one hand, we find that subjecting respondents to information about expected heating cost savings associated with

Table 5: Average treatment effect of information on simulated WTP (thousands CHF)

| | Energy label A | Energy label A$^+$ | Natural gas | Wood pellets | Heat pump |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Heating cost ($T_A$) | 0.26 | 0.32 | -0.53 | -1.33** | -1.01** |
| | (0.31) | (0.23) | (0.56) | (0.53) | (0.50) |
| Heating cost salient ($T_B$) | 0.22 | -0.17 | -0.66 | -0.11 | 0.10 |
| | (0.33) | (0.23) | (0.54) | (0.57) | (0.48) |
| $CO_2$ tax ($T_C$) | 0.34 | -0.26 | -1.14** | -1.58*** | -0.79 |
| | (0.36) | (0.24) | (0.56) | (0.55) | (0.50) |
| $CO_2$ tax salient ($T_D$) | 0.18 | 0.12 | -1.19** | -1.64*** | -0.59 |
| | (0.34) | (0.24) | (0.57) | (0.58) | (0.50) |
| Observations | 1,022 | 1,022 | 1,022 | 1,022 | 1,022 |
| $R^2$ | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 |

*Notes*: Column (1) reports OLS estimates from regressing simulated WTP (in thousands CHF) for a heating appliance with energy label A (relative to label B) on a set of post-treatment indicators $T_{knp}$ (see equation 3). The dependent variable in column (2) is simulated WTP for an appliance with energy label A$^+$ (relative to label B). The dependent variables in columns (3-5) are simulated WTP for a boiler operating with natural gas, wood pellets, and a heat pump using electricity, respectively (all relative to heating oil). In all specifications we control for both individual and a time fixed effect (=1 after treatment). Standard errors are clustered at the respondent-level and reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

high-efficiency choices (treatment conditions $T_A$ and $T_B$) does not affect their average WTP for these choices in a statistically significant manner (columns 1 and 2). By contrast, treatment condition $T_A$ leads to a statistically significant decrease in average WTP for wood pellets by CHF 1,330 (column 4) and for heat pumps by CHF 1,010 (column 5). On the other hand, informing homeowners about carbon tax payments associated with fossil fuel technologies (treatment conditions $T_C$ and $T_D$) fails to increase their average WTP for lower-carbon technologies (columns 3-5). By contrast, both treatment conditions $T_C$ and $T_D$ *decrease* average WTP for these technologies. In particular, treatment conditions $T_C$ and $T_D$ decrease WTP for natural gas (column 3) by CHF 1,140 and CHF 1,190, respectively, and for wood pellets (column 4) by CHF 1,580 and CHF 1,640, respectively. Treatment effect estimates for heat pumps are imprecisely measured. Overall, we find no consistent evidence that information on heating costs increases homeowners' WTP for energy efficiency, nor that information on carbon tax payments incentivizes low-carbon technology choices. We also find no evidence that salience matters in the chosen settings.

Table 6: Average treatment effect of information on fossil fuel users (thousands CHF)

| | Energy label A (1) | Energy label $A^+$ (2) | Natural gas (3) | Wood pellets (4) | Heat pump (5) |
|---|---|---|---|---|---|
| Heating cost ($T_A$) | 0.51 | 0.55** | -0.87 | -1.04 | -0.85 |
| | (0.37) | (0.28) | (0.68) | (0.63) | (0.59) |
| Heating cost salient ($T_B$) | 0.33 | -0.05 | -0.91 | -0.34 | 0.14 |
| | (0.38) | (0.26) | (0.64) | (0.64) | (0.53) |
| $CO_2$ tax ($T_C$) | 0.69 | -0.15 | -1.56** | -1.31* | -0.24 |
| | (0.42) | (0.30) | (0.69) | (0.70) | (0.60) |
| $CO_2$ tax salient ($T_D$) | 0.35 | 0.28 | -1.27* | -1.46** | -0.59 |
| | (0.37) | (0.27) | (0.66) | (0.68) | (0.56) |
| Observations | 772 | 772 | 772 | 772 | 772 |
| $R^2$ | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |

*Notes*: Column (1) reports OLS estimates from regressing simulated WTP (in thousands CHF) for a heating appliance with energy label A (relative to label B) on a set of post-treatment indicators $T_{knp}$ (see equation 3). Only current heating oil and natural gas users are included in the regression. The dependent variable in column (2) is simulated WTP for an appliance with energy label $A^+$ (relative to label B). The dependent variables in columns (3-5) are simulated WTP for a boiler operating with natural gas, wood pellets, and a heat pump using electricity, respectively (all relative to heating oil). In all specifications we control for both individual and a time fixed effect (=1 after treatment). Standard errors are clustered at the respondent-level and reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

Table 6 reports further estimation results based on equation (3). The structure of the Table follows the logic of Table 5, except that here we only consider the subsample of homeowners who currently heat their dwelling with heating oil or natural gas ($N = 386$). Results are qualitatively similar to the overall sample, except for the impact of informing homeowners about implications of energy efficiency choices on heating costs (treatment condition $T_A$), which slightly increases fossil fuel users' average WTP for energy label $A^+$ (relative to B) by CHF 550 (column 2). The effect is economically small and disappears once the information is made salient to respondents (treatment condition $T_B$). In sum, similar to the full sample of homeowners we find that informing fossil fuel users about private returns associated with efficiency choices barely affects average WTP. Subjecting them to information about pro-social beneifts of low-carbon technologies not only fails to incentivize these choices, but actually leads to lower corresponding WTP on average.

# 5 Discussion and conclusion

In order to achieve its $CO_2$ reduction targets, Switzerland partly relies on homeowners, who are expected to invest in energy efficiency and low-carbon energy sources. However, while these types of investments have the potential to reduce $CO_2$ emissions substantially, the level of realized investment remains low. In this paper, we conduct 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.

Our findings show that homeowners are willing to invest on average CHF $7,290$ for efficiency class A boilers and CHF $13,540$ for class $A^+$ (both relative to B), implying that the average homeowner values energy efficiency beyond simply financial returns. In addition, WTP is not affected by information about financial savings. Provided that our experimental intervention was successful in eliminating or reducing the distortion in homeowners' choices resulting from biased beliefs about (or inattention to) financial implications of various alternatives (see also Allcott and Taubinsky, 2015), this result could be explained by the fact that a large portion of homeowners was already well informed about expected energy savings at the baseline.[31] Alternatively, our results might imply that homeowners are *rationally* inattentive to energy efficiency as discussed by Sallee (2014).[32] In either case, the potential to trigger energy efficiency investments with information targeting homeowners' financial savings appears to be low. This finding is in line with recent literature challenging the importance of imperfect information and inattention for energy efficiency purchase decisions (Allcott and Taubinsky, 2015; Jacobsen, 2015; Allcott and Knittel, 2019). By contrast, there is mounting empirical evidence of owner-tenant information asymmetries (e.g. Myers, 2018), and we investigate imperfect information market failure among tenants in Chapter III.

We further identify large heterogeneity in preferences for different heating technologies (i.e., oil, gas, wood, and heat pump), and find suggestive evidence

[31]While a potential sample selection bias affecting absolute levels of energy literacy cannot be ruled out (the subject pool that respondents were drawn from consists of self-subscribers, and the experiment was placed in the second wave of a repeated survey on energy behavior in general), we find homeowners to exhibit a comparatively higher degree of energy literacy than a sample of tenants participating in the same umbrella survey (see Chapter III). In particular, about 50% of homeowners answered seven out of ten questions correctly that focus on energy demand, electricity consumption and renewables, while only about 40% of tenants managed to do the same.

[32]Sallee (2014) finds that differences in energy efficiency barely matter when consumers have strong preferences regarding other product attributes.

that a significant share of respondents associates disutility with switching to a new technology. In particular, our findings show that oil users' average WTP to switch to wood pellets or heat pumps (relative to heating oil) is CHF $-7,140$ and CHF $1,180$, respectively. Only about 25% of oil users consent to pay an investment cost differential of CHF $10,000$ (Energieheld Schweiz, 2020) for a low-carbon technology. The average ceteris paribus preference for the familiar technology holds even when i) appliance replacement is imperative, ii) there are no extra transaction costs related to switching, and iii) $CO_2$ tax payments emphasize pro-social consequences of fossil fuel-based technologies. While identifying the drivers of these rigid familiarity preferences warrants further research, we conclude that promoting and incentivizing specific low-carbon technologies might be more effective than subsidizing appliances with higher energy efficiency grades, and policies are likely to benefit from targeting and segmentation (e.g., based on the currently installed heating system).

# Chapter III

# Energy efficiency, information, and the acceptability of rent increases: A survey experiment with tenants

This chapter is mainly based on a working paper co-authored by Bruno Lanz (University of Neuchatel). The research is part of the activities of SCCER CREST (Swiss Competence Center for Energy Research), which is financially supported by Innosuisse. We thank Valéry Bezençon, Paul Burger, Mehdi Farsi, Flourentzos Flourentzou, Timo Goeschl, Gérard Greuter, Serhiy Kandul, Valerie Karplus, Linda Lemarié, Philippe Thalmann, Sylvain Weber, and the participants at various conferences for useful comments and discussions.

This paper has been published in the working paper series of UNINE IRENE (No. 18-04), MIT CEEPR (No. WP-2018-014), and SSCER CREST (No. WP2-2018/02). It has recently been revised and resubmitted to *Energy Economics*. It was presented by Ghislaine Lang at the 8th Atlantic Workshop on Energy and Environmental Economics (AWEEE) in A Toxa (Spain), 2018, and the 9th Workshop for Docotral Candidates and Master Students by the Swiss Association of Energy Economics Student Chapter (SAEE) in Zurich (Switzerland), 2017.

**Abstract**
This paper studies the role of imperfect information and attentional biases in the context of energy efficiency investments in rented properties and associated split incentives. We design a multiple price list representing owners' decision to replace the central heating appliance, and employ both within-subject information disclosure and between-subject variation in information provision to quantify how tenants trade off energy efficiency and rent increases. Our findings suggest that information on expected energy bills reductions increases tenants' valuation of energy efficiency by 53% on average. A set of quantile regressions further indicates that the average upward shift reflects heterogeneous changes along the entire distribution, mainly increasing the dispersion toward higher valuations. By contrast, information on energy bills variability dampens acceptable rent increase, and information about $CO_2$ tax payments has no incremental impact on choices. Our results highlight the importance of credible ex-ante estimates of financial savings associated with energy efficiency investments.

**Keywords** Split incentives; Informational interventions; Energy efficiency; Rented properties; Survey experiments; Multiple price lists.
**JEL codes** D1; D8; H23; Q4; Q5; R31.

# 1 Introduction

Despite positive private and social returns expected from energy efficiency investments, the adoption of energy efficient technologies is slow, and considerable resources are being directed to policies stimulating take-up (e.g. Allcott and Greenstone, 2012; Gillingham and Palmer, 2014). Considering residential energy consumption, rented dwellings represent a particularly challenging case. If tenants pay for energy bills, property owners have little incentives to invest in energy efficiency of their properties, whereas tenants have little incentives to invest themselves in a property they do not own. The resulting landlord-tenant split incentives constitute a major barrier to the improvement of energy efficiency in the stock of residential buildings (Gillingham et al., 2012; Davis, 2012).[1] Higher up-front investment costs associated with energy efficiency are borne by property owners, whereas tenants benefit from a reduction in the implicit price of energy services. For property owners, generating a positive return on these investments requires increasing rents, although they may encounter difficulties in signaling the value of future energy savings to tenants, leading to information asymmetries as documented in Myers (2018). This makes information a central aspect in tenants' acceptance of rent increases in exchange for lower energy bills.

In this paper, we study a hypothetical situation in which the owner of a rented property has to replace the central heating appliance, and can either install a standard option (efficiency label B, Council of European Union, 2013) or a more energy efficient one (labeled $A^{+}$).[2] Holding the level of comfort fixed across alternatives, we design a stated choice multiple price list (MPL) (Andersen et al., 2006; Anderson et al., 2007) in which we expose tenants to a monthly "price" (rent increase) for the efficient technology, starting at zero and then sequentially increasing it. Subjects choose the efficient option until the proposed rent increase is deemed to be too high and the standard replacement option is chosen instead

[1] In the U.S. about 35% of dwellings are renter-occupied (U.S. Census Bureau, 2016), around 30% in the E.U. (Eurostat, 2017b), and in China about 11% (Yang and Chen, 2014). Empirical evidence comparing energy consumption in owner-occupied and rented properties suggests tenants face significantly higher energy bills (see e.g. Bird and Hernandez, 2012; Charlier, 2015; Melvin, 2018).

[2] Our stated preferences MPL is motivated by the difficulty to harness revealed preferences in this setting, as observational data are constrained by supply-side restrictions such as rent control regulations, and a randomized control trial is not practical due to the cost of the interventions we consider. As we discuss in detail below, we take a number of steps to mitigate hypothetical bias and incentivize truthful preference revelation. Nevertheless, our results on the acceptable level of rent increase should be interpreted with caution, and our attention is mainly directed towards between- and within-subjects comparisons quantifying the role of information provision.

(with no associated rent increase).[3] After a baseline MPL task, which reflects perceived differences derived from mandatory energy efficiency labels, we quantify the impact of alternative informational interventions on tenant's valuation of improved energy efficiency. To do so, we follow Newell and Siikamäki (2014) and Allcott and Taubinsky (2015) and randomly assign subjects to alternative treatments that provide information about financial implications of their choices. We then employ a second MPL task to measure how within-subject information disclosure affects the acceptability of rent increases, and in turn the landlord-tenant split incentives problem. Furthermore, a between-subject comparison across information conditions provides forensic evidence on the role of financial savings information, energy bills variability, and $CO_2$ tax payments, based on illustrative figures derived from the Swiss context.

Our experimental design is motivated by the need to inform policies that incentivize energy efficiency investments in existing dwellings. Indeed, improving space heating efficiency in the stock of buildings is one of the key measures put forward by many governments in an attempt to reduce environmental externalities associated with fossil fuel consumption. Space heating is thought to offer large potential energy savings (IPCC, 2014) and the U.S., for example, plans to reduce buildings' energy use per square foot by 30% in 2030 relative to 2010 (U.S. Department of Energy, 2015), while China includes the improvement of buildings' energy efficiency in its national energy consumption targets (National Development and Reform Commission, 2017).[4] Importantly, heating systems have a relatively long average lifetime, so that space heating choices represent long-term investments (see Rapson, 2014).[5] Because property owners are "locked-in" a specific technology, evidence contributing to the design of policies targeting energy efficiency

[3] Also widely applied, discrete choice experiments allow preference elicitation among multi-attribute alternatives. In Chapter II, we employ a discrete choice experiment with a sample of home owners and test for the impact of information on preferences for alternative heating replacement options. In rental buildings, however, the multi-dimensional choice of a central heating appliance is made by the landlord, typically without consulting tenants. When studying tenants' willingness to contribute to the appliance's energy efficiency, the MPL procedure offers a more realistic choice setting.

[4] Space heating represents 32% of final residential building energy consumption in 2010, the largest share across end-uses (additional large contributors are cooking and water heating, see IPCC, 2014). The IEA (2011) further reports that 63% of buildings' potential energy savings in 2050 come from the residential sector, with space heating representing 39% of residential buildings' potential energy savings.

[5] A U.S. study by Seiders et al. (2007), for instance, estimates that gas boilers operate for 21 years on average, oil furnaces 15-20 years, and heat pumps 16 years. Most homeowners wait until building components reach the end of their useful life before considering renovation or replacement (Jakob, 2007; Achtnicht and Madlener, 2014).

investments is crucial.

In the context of the residential rental market, up-front investment costs associated with energy efficiency are paid by landlords, whereas tenants benefit from a reduction in the price of energy services. For landlords, generating a positive return on investments thus requires increasing rents. While they are legally enabled to pass on the cost of improved energy efficiency to tenants with higher rents, the change might lead to increased tenant turnover costs inflicted on the landlord (e.g., costs associated with vacancy, advertising, necessary refurbishment). While this incentivizes landlords to undertake renovations during a change of tenants, the relatively low average tenant turnover in Switzerland will force many landlords to renovate their dwelling while it is still being occupied by tenants.[6] Moreover, in a country where the majority of households live in multi-unit buildings with a central heating system, replacement of the heating appliance during tenant occupancy is practically inevitable.[7]

Previous research has identified a number of market distortions associated with energy efficiency investments (see Gerarden et al., 2017), and growing empirical evidence suggests that imperfect information and attentional biases are significant barriers to energy efficiency improvements (e.g. Allcott and Wozny, 2014; Jacobsen, 2015; Allcott and Knittel, 2017). In a landlord-tenant setting, Myers (2018) provides empirical evidence that tenants are uninformed about energy costs, and in turn that asymmetric information reduces energy efficiency investments. In line with this, in this paper we assess the potential to influence tenants' valuations of energy efficiency with financial information. Our experimental design delivers willingness to pay (WTP) space evidence about how simple efficiency labels are perceived by tenants, and quantifies the incremental impact of specific financial information on their choices. Relative to existing studies, a major contribution of our work is to provide experimentally controlled evidence on the role of information in a landlord-tenant split incentive context.

In particular, our experimental design identifies the impact of information along two important dimensions. First, recent research highlights financial and energy literacy as barriers to energy efficiency investments (see e.g. Brent and Ward, 2018), and emphasizes the importance of financial information in fostering

[6] The average relocation rate in Switzerland has been estimated at 10.5% in 2017 (Homegate AG, 2017), which is similar to annual tenant turnover rates estimated for Austria (12%), Spain (10%), Sweden (10%), and Germany (8.5%, see Aberdeen Standard Investments, 2019).

[7] In Switzerland, approximately 77% of households live in multi-unit buildings (FSO, 2020), and almost 90% of residential buildings are heated by means of a central heating system covering one or more buildings (FSO, 2017b).

consumers' ability to make rational and efficient choices (as opposed to physical units, see Blasch et al., 2019). Building on these results, we study how illustrative information about financial savings associated with reduced energy consumption affects tenants' acceptance of rent increases. More specifically, a set of experimental conditions informs tenants that choosing option $A^+$ over B (approximately 30% higher energy efficiency, see Council of European Union, 2013) would reduce energy bills by CHF 40 per month (about USD 42). Within the conditions, we further vary salience of financial savings, thereby adding to the results of Newell and Siikamäki (2014) who study the context of owner-occupied properties. Moreover, because there is ample uncertainty about realizations of future energy bills, which implies that risk averse tenants hold a higher valuation for energy efficiency improvements, for another subset of tenants we couple illustrative financial savings figures to information about variability of energy bills over time.

Second, we test whether salience of $CO_2$ tax payments incorporated in energy bills has an impact on acceptable rent increases, leveraging the existing $CO_2$ tax on fossil heating fuels in Switzerland (CHF 84 or USD 87 per ton of $CO_2$ in 2017, see The Federal Council, 2012). More specifically, we design a set of conditions where we vary the salience of financial savings and reduced $CO_2$ expenditures related to their choices, allowing us to examine consumers' responses to tax-inclusive prices as compared to purely financial information. We thereby contribute to a growing literature on the behavioral effect of salience of externality-correcting taxes (see e.g. Li et al., 2014; Houde and Aldy, 2017; Lanz et al., 2018).

Our experimental survey is administered to an online panel of 406 Swiss tenants, the majority of which bears the energy cost of their dwelling separately from monthly rents.[8] Our results indicate that, in the baseline, around 70% of tenants in our sample are willing to accept a rent increase if their landlord replaces their existing heating appliance with an energy efficient option as opposed to a standard one. Quantitatively, average WTP for efficiency grading label $A^+$ vs. B is CHF 37.51 per month (about CHF 450 or USD 470 per year), roughly 3% of median rents in Switzerland. Providing financial information about expected energy bills associated with each option leads to an average endline WTP estimate of CHF 64.87 per month (about CHF 780 or USD 810 per year), which exceeds financial savings. This implies that a large share of our sample holds motives

[8] In Switzerland, tenants commonly pay heating costs for their dwelling separately from their rents, often in the form of down payments. In our sample, only 1% of tenants state that the energy cost is included in their rents, while 85% report paying it separately from their rents. 13% of tenants do not know the billing method (note that this group's WTP estimates are statistically indistinguishable from the remainder of the sample).

beyond purely financial concerns. Moreover, while informing tenants about CHF 1 in expected energy savings translates into CHF 1.73 in possible rent increases on average, adding information about past variability in energy bills reduces this number to around CHF 1.40, thus dampening the impact. By contrast, we find that information about $CO_2$ tax payments has no incremental impact on tenants' valuation of energy efficiency. Our results thus suggest a differentiation between financial and pro-social preferences.

While average treatment effects are important, a policy interest persists in the impact on the tails of the WTP distribution (an ideal informational intervention incentivizes the lowest quantiles to correct their expectations of ex-post benefits upwards). In order to document heterogeneity in how the treatment effect of financial information varies across the distribution of valuations, we report results from a set of quantile regressions. Results show that, while values for mean and median treatment effect estimates are very similar, the average treatment effect reflects heterogeneous changes along the entire WTP distribution. Specifically, we document that the upward shift in WTP reflects an increased frequency of high energy efficiency valuations in particular, with lower quantiles remaining unaffected. In other words, providing tenants with information on expected energy bills reductions results in a WTP distribution that is more dispersed toward the right.

Our results also complement a small number of studies on tenants' preferences towards energy efficiency investments. Banfi et al. (2008) and Phillips (2012) employ discrete choice experiments to study tenants' preferences towards specific combinations of energy efficiency investments in Switzerland and New Zealand respectively, with mixed results. While Banfi et al. (2008) find that Swiss tenants' valuation of energy efficiency improvements such as window replacement and installing a ventilation system is generally higher than the corresponding investment costs, Phillips (2012) suggests that willingness to accept rent increases in exchange for an energy efficiency improvement of the heating system is economically insignificant. These results show that improved comfort plays an important role in tenants' choices, something we control for in our experimental design, and confirm that tenants may be ill-informed about financial savings associated with their investments. Studying a sample of university tenants in Ireland, Carroll et al. (2016) show that WTP for energy efficiency is substantially higher at the lower end of the energy efficiency distribution, but find no statistically significant WTP for improvements in buildings with energy efficiency grade B or above. Relative to Carroll et al. (2016), our contribution is to consider a replacement decision, thereby isolating the impact of energy efficiency on tenants' valuation of renting services. We also build on Hoppe (2012) and Glumac et al. (2013), who conduct in-depth (case study) analyses of specific renovation projects in the Netherlands, showing that rent increases are an important driver of ex-post acceptability. Our work instead emphasizes the role of ex-ante information for tenants' acceptance of rent increases. We show that obtaining and providing realistic measures of energy savings prior to renovation is an important step to foster the adoption of energy efficient technologies in a split-incentive context (see Fowlie et al., 2018; Burlig et al., 2017; Liang et al., 2018).

The paper proceeds as follows. In Section 2, we present a simple conceptual framework that allows us to identify the impact of information on WTP. Section 3 describes our experimental design, including MPL procedures, and provides the details of alternative informational interventions. Section 4 presents our results. Concluding comments are provided in Section 5.

# 2 Conceptual framework

Our survey experiment focuses on owners' decisions to *replace* the appliance supplying heat to the central heating system and, in that context, on the choice between a standard and an energy efficient appliance. Our main objectives are then to estimate (i) tenants' acceptance of rent increases in exchange for increased efficiency of their central heating system; and (ii) whether additional information about energy savings and $CO_2$ taxes affects tenants' WTP. In this section, we first lay out a simple conceptual framework representing tenants' decisions, which allows us to introduce some useful notation. Second, we describe our empirical strategy to quantify the impact of information on observed choices.

## 2.1 A model of tenants' decisions: Notation

As mentioned above, our identification strategy builds on Allcott and Taubinsky (2015). We consider a set of tenants indexed by $i$ who are consulted for a choice between an efficient heating system ($E$) and a standard heating system ($S$). The two alternatives $j \in (E, S)$ are associated with prices $p_j$, and $p = p_E - p_S$ denotes relative prices. Both alternatives are financed by rents and are thus expressed in monthly outlays.[9] We define tenant $i$'s utility from selecting $j$ as $u_{ij}$, and denote relative utility as $u_i = u_{iE} - u_{iS}$. Notionally, a utility maximizing tenant would select $E$ if and only if $u_i > p$, that is, relative surplus from selecting the efficient system is greater than the associated increase in rents.

Given this notation, the objective of this study is to identify $u_i$. In particular, as discussed extensively below, we use a MPL procedure to identify the relative prices at which subjects switch from choosing option $E$ to option $S$. This is achieved by offering a sequence of $t$ choices between options $E$ and $S$, where relative prices $p^t$ vary in the form of increased monthly rents. Therefore, if tenant $i$ prefers efficient option $E$ at price $p^1$, but instead chooses the standard option $S$ at price $p^2$, then the MPL task reveals that this particular tenant's relative valuation $u_i$ lies within the interval [$p^1$,$p^2$].

Importantly, $u_i$ includes all perceived differences between efficient ($E$) and standard ($S$) heating systems. In general, considering different heating systems involves expectations about potential cost savings, non-monetary costs associated with installation, different levels of comfort, differences in lifetime duration of appliances, or social benefits associated with lower energy use, among many other things (see Fowlie et al., 2015). As an attempt to fix subjects' heterogeneous expectations and thereby control for these potential confounders, we frame the experimental survey to focus exclusively on energy efficiency gains as measured by a simple energy label that is encountered in the marketplace.

The narrow focus on energy efficiency implies that $u_i$ will reflect expected differences in energy consumption and associated financial savings. In particular, energy consumption directly affects exposure to variations in the price of heating fuels, so that risk aversion might act as a relevant source of heterogeneity in WTP for energy efficiency. In turn, a risk averse tenant may attribute a higher value to a given energy efficiency improvement, as lower energy expenditures reduce exposure to fuel price risk, so that $u_i$ includes a component associated with risk reduction. Similarly, heterogeneity in $u_i$ may be driven by differences in environmental preferences. In section 3.2, we lay out how we manipulate individual perceptions of heating cost savings, risk considerations, and $CO_2$ emissions, by means of various informational interventions.

[9] From the tenants' perspective, rents and energy costs are paid each month, so the decision problem is static. We therefore do not consider the role of time preferences. In our experimental setting, we further clarify that selecting the standard appliance as a replacement corresponds to usual maintenance of the property, so that choosing this option would not affect rents.

## 2.2 Identifying the effect of information

In order to quantify how financial and environmental information affect choices, we first elicit $u_i$ with a baseline MPL choice task, and then randomly assign tenants to one of several information treatments. As we describe in more detail in the next section, these conditions mainly focus on providing information about energy cost savings and $CO_2$ tax payments. Subsequently, we elicit $u_i$ with an endline MPL choice task.

Formally, we denote tenant $i$'s *baseline* utility as $u_i^0$, and utility *after* being subject to one of the interventions as $u_i^1$. We refer to the latter as *endline* utility. We exploit within- and between-subject variation in $u_i^s$, $s \in \{0, 1\}$ to identify the impact of information in WTP-space. This is achieved with a set of linear regressions in which the outcome variable is $u_i^s$ measured by respective MPL tasks:[10]

$$u_i^s = \alpha + \sum_k \beta_k T_{ik} + \epsilon_i \tag{1}$$

where $T_{ik}$ is a set of treatment indicators (i.e. one dummy variable for each treatment condition) and $\epsilon_i$ is an error term. The vector of coefficients in $\beta_k$ represents average treatment effects, and provides direct evidence on how information affects $u_i$ in monetary equivalent.

Similarly, we study how alternative treatment interventions affect the distribution of tenants' WTP. For this purpose, we employ a set of quantile regressions. Formally, we estimate the (unconditional) quantile function for quantile $\tau$, denoted $Q^\tau$, with the following quantile regression model:

$$Q^\tau(u_i^s) = \alpha^\tau + \sum_k \beta_k^\tau T_{ik} + \epsilon_i^\tau \tag{2}$$

where $Q^\tau(u_i^s)$ is the $\tau$th quantile of $u_i^s$ and the vector of coefficients in $\beta_k^\tau$ denotes quantile treatment effects. In other words, $\beta_k^\tau$ provides evidence on the effect of information on the $\tau$th quantile of the WTP distribution.

[10]Note that MPL tasks only provide bounds on $u_i^s$, as measured by the price intervals specified in the sequence of $t$ MPL choices. An alternative to linear regression using the mid-point of the interval is to apply an interval data model (e.g. Cameron, 1988). With our data, however, we find that OLS and interval data models yield very similar treatment effects, and therefore stick with OLS specifications.

# 3 Experimental design

In a nutshell, subjects go through the following sequence: (i) a baseline MPL choice task, (ii) random assignment to one of six information treatments plus a control group, and (iii) an endline MPL choice task. In the following, we provide details of the MPL elicitation tasks and informational interventions. We then provide some notes about how we administer the experimental survey. A full set of screenshots of the experimental material is provided in Appendix K.

## 3.1 Multiple price list procedures

The MPL exercise asks subjects to consider that the current appliance supplying heat to their dwelling needs replacement, and invites them to think about which option would be best suited for their household. We also make them aware that the choice of heating appliance could influence their rents. The owner of the property may choose a “standard” replacement option, which is considered normal maintenance of the property and would therefore not affect monthly rents. Alternatively, the owner may invest in a more energy efficient central heating appliance, and may therefore increase rents to cover higher upfront investment costs.[11]

The choice focuses explicitly on replacing the appliance that supplies heat to the dwelling through the heating system. The two options considered by the owner only differ by a standard energy efficiency label of the form mandated by the European Union, ranging from $A^{++}$ (most efficient) to G (least efficient). To keep it simple, we attribute label $A^{+}$ to the efficient appliance and label B to the standard appliance, which corresponds to an approximate 25% improvement in energy efficiency (Council of European Union, 2013).[12] The description of the choice makes clear that both appliances perform equally well, meet general requirements, and are expected to have the same operating life of 15 years. We also emphasize that the installation of the new appliance would necessarily take place

[11]The distribution of efficiency grades among tenants’ own heating equipment might influence the choice of acceptable rent increase. However, the impact of subjects’ initial endowment on choices is not the focus of this study (to the extent that there are no concerns with sampling, see section 3.3). Much rather, we direct our attention to the role of information in tenants’ decision-making by exploiting between- and within-subjects comparisons.

[12]In order to focus exclusively on energy efficiency, we do not mention specific energy technologies. Nevertheless, the standard option with label B corresponds to conventional and comparatively cheap oil boilers, whereas the option labeled $A^{+}$ corresponds to either a heat pump appliance or, alternatively, a “package” combining a standard oil boiler coupled with solar panels. Because the choice is framed as a replacement decision, one of the two options would be installed in any case.

in the year of the survey (to mitigate discounting issues), and that other elements of the heating system (such as radiators) would not be affected. As mentioned previously, this relatively narrow focus allows us to abstract from comfort considerations associated with energy efficiency improvements, so that WTP estimates exclusively relate to expected benefits associated with energy efficiency.[13]

As we focus on a single dimension of space heating (the efficiency of the appliance that supplies heat), standard MPL elicitation procedure is particularly well suited. Moreover, MPL choice tasks are easy to explain to respondents, and allow elicitation of robust and relatively precise valuations (see Andersen et al., 2006; Anderson et al., 2007). In order to mitigate possible biases associated with the MPL elicitation format, and foster incentives for truthful preference revelation in a stated preference context, we take the following steps. First, in order to eliminate the risk of subjects feeling inclined to pick a response in the middle of the MPL task (framing effect), we present the choice tasks sequentially, i.e. one MPL choice task per screen. Subjects therefore do not know, a priori, the upper bound used in the experimental survey. Second, to prevent multiple switching sometimes observed in MPLs, the sequence of choices stops whenever the respondent selects the standard appliance.[14] Third, to make sure that respondents fully understand the MPL task, we provide them with an example before they start each sequence. However, we do not display a specific price tag to avoid anchoring effects.

The last set of steps is more directly geared towards the hypothetical nature of the choice task.[15] On the one hand, we use a number of scripts in line with the literature on truthful preference revelation (e.g. Vossler et al., 2012; Newell

[13]The specific text we use is as follows: "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 central heating appliance, but the rest of your heating system, such as the radiators, would not need to be changed."

[14]Multiple switching behavior leads to inconsistent valuations and thus complicates inference, while preventing it imposes structure (strict monotonicity and transitivity) on the subject's responses that is not always justified (Anderson et al., 2007). However, while multiple switching behavior can be at least partly explained by subject's indifference between options (and therefore by weakly rather than strictly convex preferences), enforcing a single switching point has been shown to have no systematic effect on results (Andersen et al., 2006).

[15]We note that MPL choice tasks have similarities with two widely used stated preferences formats, namely dichotomous choice and payment card contingent valuation, although with costs presented sequentially. It follows from the literature (e.g. see Johnston et al., 2017) that the first MPL choice is incentive compatible, whereas subsequent choices are not. Another important result from the stated preference literature is that iterative bidding can potentially lead respondents to anchor their response to their first choice (see Bateman et al., 2001). Because we start with a price of zero, our approach would therefore tend to underestimate tenants' WTP.

and Siikamäki, 2014). More specifically, previous work on the topic has shown that a crucial element involves perceived consequentiality of stated choices. We therefore inform subjects that their answers will be used by academic research, and explain that it is in their best interest to answer the questions truthfully. On the other hand, following important insights from the stated preference literature (see Johnston et al., 2017), we use a number of budget constraint reminders.[16] The full text underlying MPL choices is reported in Appendix K, Figures K1 to K5.

Turning to the MPL choice task itself, shown in Figure 1, we ask subjects to consider a binary choice between a standard and an efficient appliance. At the beginning of the MPL task neither of the two alternatives is associated with a rent increase. Since both options have the same cost (zero) but one is more efficient, we would expect tenants to choose the efficient alternative. After that, the rent associated with the more efficient option increases gradually, with steps along the ladder shown in Table 1. Note that the price levels selected were piloted to ensure that they yield meaningful switch-points for respondents.

## 3.2 Informational interventions

The baseline MPL sequence ends either when respondents select the standard appliance or when they reach the maximum price level specified. Respondents are then randomly allocated to one of seven conditions, summarized in Table 2. Each condition consists of two consecutive information screens, all of which closely match each other in design, structure, complexity and length. Therefore, only the actual content of the screen should affect the MPL decision (see Figures K10 to K14).

Following Allcott and Taubinsky (2015) and Allcott and Knittel (2019), we take a number of steps to ensure that information is effectively conveyed to tenants. First, information is displayed both verbally and visually (in the form of a simple figure). Second, to incentivize attention, we announce upfront that each information screen will be followed by a one-question quiz (a simple question about the core information displayed on the screen). Respondents are required to answer the quiz question in order to move forward in the experimental survey (if they do not answer correctly, the correct answer is displayed). In our sample, 76%

[16]We include two different 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."

Figure 1: Baseline multiple price list choice task

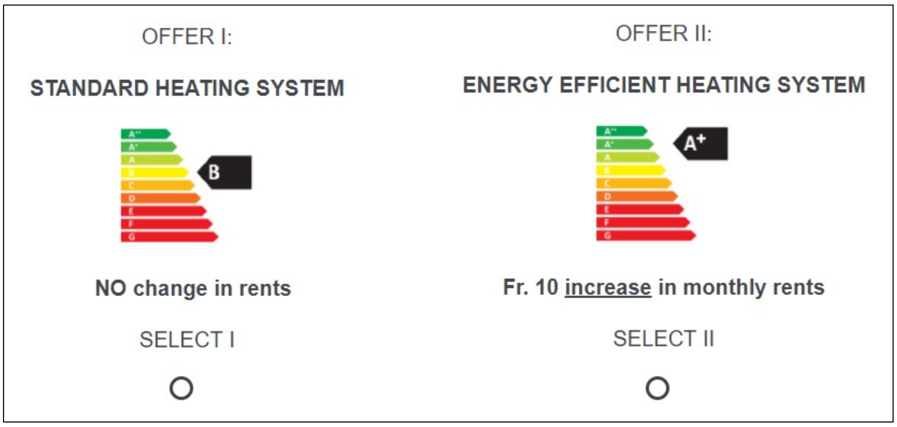



Table 1: Multiple price list payment ladder of rent increases

| Choice task | Rent increase standard heating appliance | Rent increase energy efficient heating appliance |
|---|---|---|
| No. 1 | 0 CHF | 0 CHF |
| No. 2 | 0 CHF | 10 CHF |
| No. 3 | 0 CHF | 20 CHF |
| No. 4 | 0 CHF | 30 CHF |
| No. 5 | 0 CHF | 40 CHF |
| No. 6 | 0 CHF | 50 CHF |
| No. 7 | 0 CHF | 75 CHF |
| No. 8 | 0 CHF | 100 CHF |
| No. 9 | 0 CHF | 150 CHF |
| No. 10 | 0 CHF | 200 CHF |

of respondents answered both quiz questions correctly on first attempt, and 89% gave at least one correct answer.

After being exposed to the two information screens and completing the quiz questions, subjects receive instructions for the second (endline) MPL task. As we discuss below, in some treatments the design of the MPL is modified to reinforce salience of the information provided. Thus, after being exposed to both information screens, respondents either repeat the same MPL task as in the baseline, or a slightly modified version of it. In the following subsections, we discuss our set of

Table 2: Overview of informational treatment interventions

| Treatment indicator | Treatment group name | $1^{st}$ information screen | $2^{nd}$ information screen | Endline choice task |
|---|---|---|---|---|
| $T_{iA}$ | Control | Neutral I | Neutral II | Rent increase (baseline) |
| $T_{iB}$ | Heating cost | Heating cost | Neutral I | Rent increase (baseline) |
| $T_{iC}$ | Heating cost salient | Heating cost | Neutral I | Rent increase + Heating cost |
| $T_{iD}$ | Heating cost variability | Heating cost | Heating cost variability | Rent increase + Heating cost |
| $T_{iE}$ | $CO_2$ tax | Heating cost | $CO_2$ tax | Rent increase (baseline) |
| $T_{iF}$ | $CO_2$ tax salient ($A^+$ lower tax) | Heating cost | $CO_2$ tax | Rent increase + Heating cost + $CO_2$ tax ($A^+$ lower tax) |
| $T_{iG}$ | $CO_2$ tax salient ($A^+$ no tax) | Heating cost | $CO_2$ tax | Rent increase + Heating cost + $CO_2$ tax ($A^+$ no tax) |

treatment conditions in more detail.

### Control group ($T_{iA}$)

Treatment group A represents the control intervention. It is designed to provide "placebo information" that should not affect the demand for efficient heating appliances, and thus tenants' acceptance of rent increases. Concretely, in this condition tenants are given information about the age of the Swiss building stock (information screen *Neutral I*, Figure K10) and the different energy sources used to heat buildings in Switzerland (information screen *Neutral II*, Figure K11). After the two information screens (and the associated quiz questions), respondents repeat the MPL choice task presented in the baseline.

### Information about heating costs ($T_{iB}$, $T_{iC}$, $T_{iD}$)

Treatments B and C both provide one information screen about average monthly heating costs associated with each option (information screen *Heating cost*, shown in Figure K12), and then the neutral information screen on the age of the Swiss building stock (information screen *Neutral I*, Figure K10). The information about heating costs aims at illustrating the importance of specific financial information for tenants' choices.[17] It is based on an average expenditure of CHF 170 per month

[17]Nonetheless, the empirical analysis relies on subjects perceiving the provided information as credible and trustworthy. Given the ambiguous findings in the literature regarding returns from energy efficiency investments (see e.g. Fowlie et al., 2018), it is conceivable that some subjects doubt the magnitude of the provided ex-post savings. This would render our informational inter-

(about USD 178) for a standard appliance and CHF 130 per month (about USD 136) for the energy efficient alternative. As a result, financial savings associated with the efficient alternative correspond to 3% of monthly net median rent[18] and represent an approximate 25% change, which is consistent with the energy efficiency labels discussed.[19]

Treatments B and C differ in how the endline MPL task is designed. In particular, tenants in treatment B complete the MPL presented in the baseline, just as those in the control group. Thus endline WTP from treatment B allows us to measure the effect of our information screen about heating costs on tenants' WTP. Conditional on respondents not having been fully aware of financial savings associated with energy efficiency, we expect treatment B to increase endline WTP as compared to baseline WTP. We label this treatment "*Heating cost*."

By contrast, tenants in treatment C face an endline MPL task which explicitly includes the estimate of heating costs associated with each option. This modified MPL task is shown in Figure 2. Reminding tenants about heating costs *during* MPL choices increases salience of financial implications of energy efficiency, and should therefore reinforce the informational intervention. Treatment C, labeled "*Heating cost salient*," therefore provides further evidence about the importance of heating cost information for the acceptability of rent increases in exchange for energy efficiency improvements. This format is close to U.S. energy labels for water heating appliances discussed in Newell and Siikamäki (2014), and if salience matters endline WTP is expected to be higher in treatment C than in treatment B ($T_{iB} < T_{iC}$).

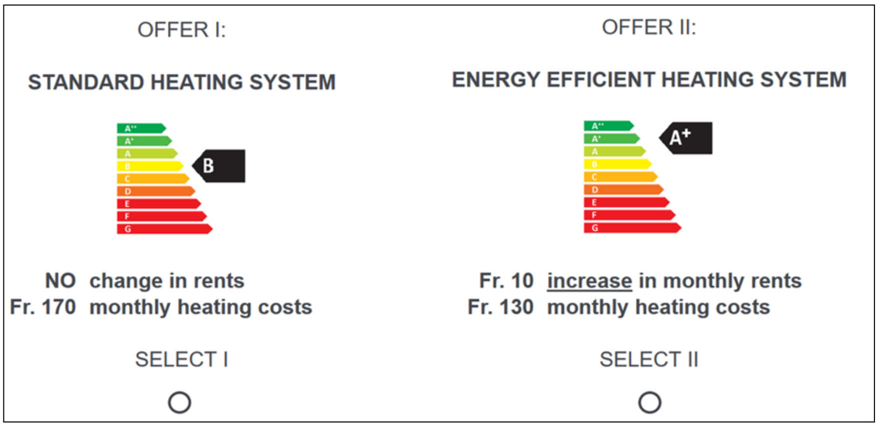
In treatment D, respondents first get to see the information screen *Heating cost*, and in the second screen we provide information about heating cost variability (information screen *Heating cost variability*, Figure K13). This second screen illustrates how heating costs may vary over time for reasons unrelated to technology choice, and we therefore label treatment D as "*Heating cost variability*." This

ventions ineffective in correcting imperfect information bias (the intervention would, however, still raise subjects' attention to the matter). As a result, we potentially underestimate the effect of (more credible) information on tenants' WTP.

[18]In 2016, monthly net median rent in Switzerland amounted to CHF 1322 per household. By comparison, a CHF 40 saving is not irrelevant for tenants, but informing them about higher energy savings might have a stronger effect on WTP. However, the information about heating costs mainly aims at illustrating the effect of specific financial information on tenants' choices, and emphasis was put on subjects perceiving the provided information as credible and trustworthy.

[19]Naturally, energy bills are expected to vary across households and over time. The specific numbers we use mainly support our objective of quantifying how information on financial savings affects tenants' decisions. We come back to the issue of cost variability when we discuss treatment D below.

Figure 2: Endline multiple price list choice task with heating costs




sequence of information screens, while maintaining the cost advantage of the energy efficient option, provides historical evidence that heating cost savings are in fact uncertain. We explain this to subjects by means of past energy costs associated with an oil based heating appliance (a comparatively inexpensive heating source with visible price volatility).[20] After the second information screen, respondents complete a second MPL task in which energy cost differentials are also reported (Figure 2). Comparing treatments D and C provides evidence about the incremental effect of information on energy cost variability, and we expect that this treatment should generally decrease attractiveness of the more efficient option ($T_{iC} > T_{iD}$).

### Information about carbon tax payments ($T_{iE}$, $T_{iF}$, $T_{iG}$)

Treatments E, F and G all focus on environmental impacts of energy efficiency choices, which we achieve by providing information about tax-inclusive prices. In particular, we measure subjects' behavioral response to increased salience of the carbon tax levied on heating fuels in Switzerland.[21] Subjects in these treatments first face the information screen *Heating cost*, and the second screen provides in-

[20]We frame the information as a risk that energy bills may not decline as much as expected, mainly because growing evidence suggests engineering projections tend to be overoptimistic (e.g. Fowlie et al., 2015).

[21]More precisely, the Swiss carbon tax is imposed on all fossil heating and process fuels (heating oil, natural gas, coal, petroleum coke, etc., see The Federal Council, 2012). At the time of the survey, the tax amounts to CHF 84 (about USD 87) per ton of $CO_2$, and carbon tax payments are indicated on fossil heating fuels invoices (in addition to the VAT amount). Importantly, the tax is set to increase over time, so that the cost associated with fossil-based central heating appliances can be expected to increase as well (The Federal Council, 2016).

formation about the $CO_2$ tax in Switzerland and its implications on fossil-based heating costs (information screen *$CO_2$ tax* is shown in Figure K14). Note that in Switzerland, the tax is paid when heating oil is delivered, so that most tenants receive no details about $CO_2$ tax payments when they pay their heating bills.

The difference between treatments E, F and G is again driven by whether and how the $CO_2$ tax information is included in the MPL task. In treatment E, we repeat the baseline MPL design reported in Figure 1, so that comparing treatments B and E provides evidence about whether the $CO_2$ information screen affects WTP. If environmental motives affect choices, one would expect WTP in treatment E to be higher than in treatment B ($T_{iE} > T_{iD}$). However, if respondents oppose government interventions in the form of taxes, they may react negatively to this information (Perino et al., 2014; Lanz et al., 2018).

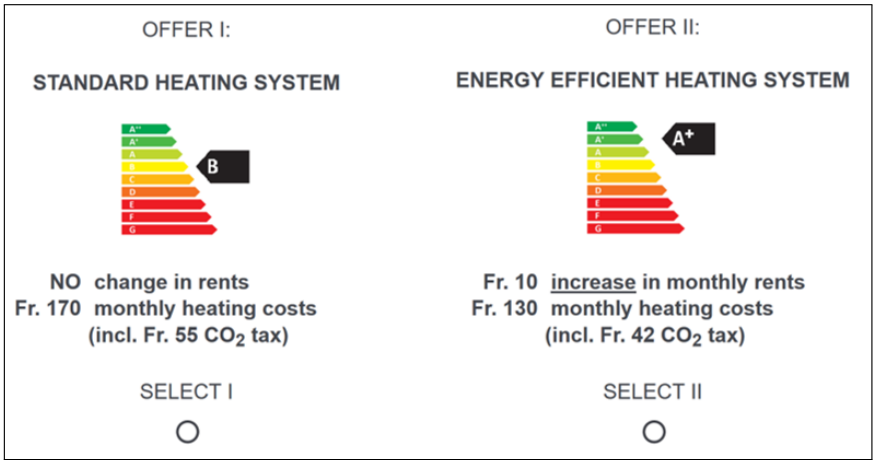
In treatments F and G, respondents see the same information screens *Heating cost* and *$CO_2$ tax* and, in addition, the endline MPL task integrates financial information about both energy expenditures and $CO_2$ tax payments. In treatment F we consider a situation in which the more efficient option still uses oil (e.g. an oil boiler coupled with solar panels), so that $CO_2$ tax payments are positive for both options (they are of course proportionally lower for the efficient appliance). An example of the ensuing MPL task is shown in Figure 3. In treatment G, we instead consider an efficient option with no $CO_2$ tax payments, signaling that it implies no (direct) $CO_2$ emissions. This alternative corresponds, for example, to a heat pump appliance. The ensuing MPL task is displayed in Figure 4. Because the efficient option in treatment G is free of $CO_2$ emissions, WTP of respondents with pro-environmental motives is expected to be higher than in treatments F ($T_{iF} > T_{iG}$).

## 3.3 Implementation

Our survey experiment is fielded as an online survey scripted with Qualtrics and administered in April and May 2017 as part of a wider study on energy behavior in Switzerland (Weber et al., 2017). Survey participants are drawn from an online subject pool managed by the private marketing company Intervista, which holds over 90,000 self-subscribers. As per other projects managed by the company, participants are invited via email and they are compensated for their time with vouchers (the equivalent of CHF 6 for completion of the present survey).[22]

[22]The e-mail invitation is neutral and reads as follows: "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

Figure 3: Endline multiple price list choice task with heating costs and $CO_2$ tax ($A^+$ lower tax)



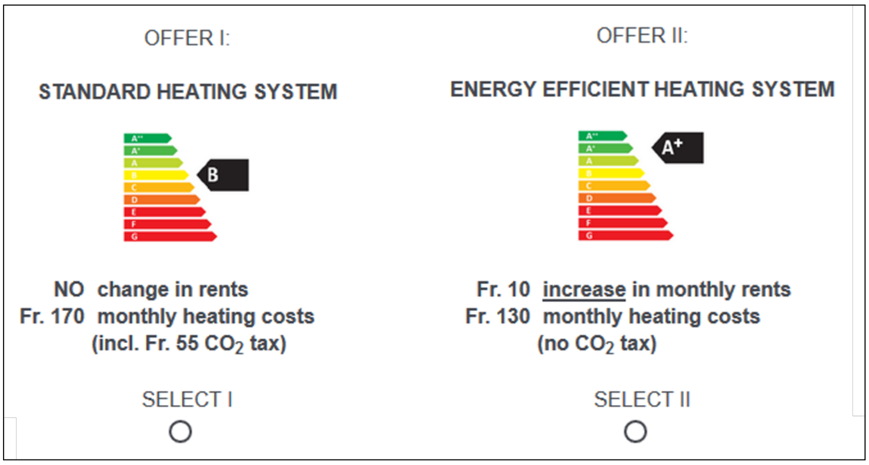

Among a sample of 5,535 participants to the study, a subsample of 406 tenants is randomly selected and completes our survey.

Relying on a panel of self-subscribers implies that our sample is not random. However, in terms of observable characteristics of participating tenants (see Table L1 of Appendix L), our sample is in line with figures from the Federal Statistical Office on the Swiss population for gender (53% women in our sample compared to 50% in Switzerland, FSO 2017a), high-education groups (47% of our sample completed tertiary education against 43% in the general population, FSO 2019a), average age (43 years in our sample compared to 42 years in Switzerland, FSO 2018b), income (CHF 6,000-8,999 compared to CHF 7,566 in Switzerland, FSO 2018c), and dwelling size (92m$^2$ compared to 99m$^2$ in Switzerland, FSO 2019e). The proportion of households living in multifamily houses and using oil as a heating fuel are also close to population figures (respectively 84% vs. 77%, FSO 2019e, and 37% vs. 39%, FSO 2019e).[23] In Table L2, Appendix L, we further summarize randomized treatment assignment across conditions. The average number of participant per condition is 58, and differences across subsamples are due to the fact

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 30min 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.

[23]The second most prevalent heating source in our sample as well as in the general population is natural gas (with 19% vs. 21% respectively, FSO 2019e). Our sample also covers households heating with district heat (7%), electricity (7%), wood (6%), and heat pump (5%). 17% of tenants do not know the source.

Figure 4: Endline multiple price list choice task with heating costs and $CO_2$ tax ($A^+$ no tax)




that a small number of tenants dropped out of the experimental survey. Note that we find some small differences in baseline WTP across treatment groups, although Wald tests indicate that the differences are statistically insignificant.[24]

# 4 Experimental results

This section reports the main results from the survey experiment. We first provide evidence on tenants' WTP for efficient heating appliances based on baseline MPL choices. Second, we exploit within- and between-subjects variations to identify the impact of information about energy costs and $CO_2$ tax payments on subjects' WTP. Third, we employ a set of quantile regressions to discuss the effect of information on the distribution of tenants' WTP.

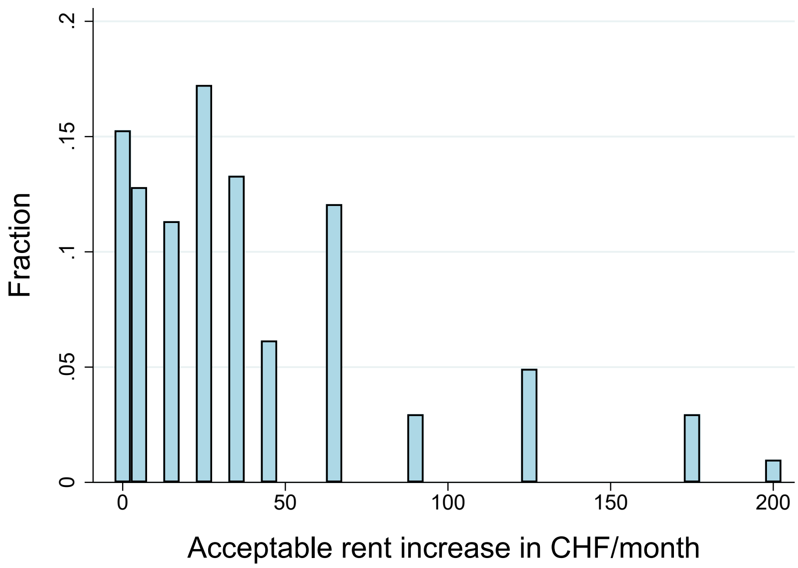
## 4.1 Tenants' WTP estimates from baseline choices

Figure 5 shows the distribution of baseline WTP estimates for our sample of 406 tenants, as measured by the mid-point intervals reported in Table 1.[25] Average WTP associated with a central heating appliance of grade $A^+$ rather than B is $u_i^0 =$ CHF 37.51 per month. This corresponds to 3.07% of net median rents in Switzer-

[24]In particular, we fail to reject the hypothesis that $T_{iA} = T_{iC}$, the largest difference in baseline WTP across groups, with a p-value of 0.2.

[25]To be conservative, WTP for the highest value on the list is set at its lower bound, which is CHF 200.

Figure 5: Distribution of baseline WTP ($u_i^0$)




land (per household) and 2.76% of net average rents.[26] Since in the baseline MPL task tenants have not received information about heating bills reductions and rely exclusively on labels (as they would in the marketplace), our estimate of $u_i^0$ includes both expectations about reductions in energy bills as well as other expected impacts (such as environmental benefits). We come back to this below.

Baseline MPL results also show that around 15% of respondents select the standard heating appliance in the first choice (i.e. no increase in rents). In other words, these tenants choose the inefficient appliance even though the more efficient option is provided at no additional cost.[27] Another 12.8% of respondents switch from the more efficient option to the standard one in the second MPL question.[28] One interpretation is that these tenants value energy efficiency in principle, but refuse to pay (much) for it in the form of an increase in rents.[29] The remaining

[26]In 2016, monthly net median rent in Switzerland amounted to CHF 1322 per household, while net average rents were CHF 1220 (FSO, 2018a).

[27]It is conceivable that these respondents did not understand the choice task and should be excluded from the analysis. However, the careful set-up of the contextual framework and the relatively simple design of the baseline choice tasks instead suggest that these respondents exhibit some unexplained preference for the standard technology that is not to be neglected. In any case, we note that dropping these respondents does not affect inference.

[28]By construction, these respondents are attributed a WTP of $u_i^0$ = CHF 5 per month, or CHF 60 per year.

[29]An alternative interpretation is that tenants value energy efficiency but simply do not trust the accuracy of the official energy efficiency labels. See also footnote 17.

72% of our sample accept an increase in rents for improved energy efficiency. Both median and mode WTP correspond to the fourth step in the MPL ladder, translating to a WTP of CHF 25 per month for the energy efficient option relative to the standard one.

## 4.2 The impact of information on tenants' WTP

Table 3 tabulates average WTP estimates across baseline MPL choices (before treatment, $u_i^0$) and endline MPL choices (after treatment, $u_i^1$). For endline MPL choices, we break down average WTP across treatment conditions. This provides both within- and between-tenant information about the impact of information on WTP.

As average WTP from baseline MPL choices is discussed above, here we focus on endline choices for each treatment group. Starting with the control intervention ($T_{iA}$), as expected we find a very modest difference compared to average baseline WTP. Individual-level distribution of WTP changes ($\Delta$WTP$= u_i^1 - u_i^0$), reported in Figure 6 panel (a), further shows that almost 80% of respondents switched at the same MPL payment level, while only a small number increased WTP (for one respondent, WTP declined from around CHF 90 per month to zero). This is an indication that the placebo information screens worked as intended, as they have very little effect on WTP for energy efficiency. We will get back to this below.

Turning to the set of informational interventions $T_{iB}$ to $T_{iG}$, we find clear evidence that all of them lead to an increase in the average valuation of energy efficiency. The largest increase is observed for treatments that provide information about financial implications of both options *and* also make the impact on energy bills salient in the endline MPL task (i.e. $T_{iC}$, $T_{iD}$, $T_{iF}$ and $T_{iG}$). By contrast, in treatments that provide expected financial savings through an information screen but not in the endline MPL task ($T_{iB}$ and $T_{iE}$), the change in average WTP is smaller. This is confirmed by looking at individual changes in WTP (Figure 6, panels b-f),[30] as we find that treatments $T_{iB}$ and $T_{iE}$ feature the largest proportion of respondents with no change in WTP.

Inference on these results is reported in Table 4. In column 1, we report OLS regression results for equation (1), which models baseline and endline individual

[30]Note that we find almost no difference between the distributions of treatment groups F and G, and therefore report observations for these two treatments together in panel (f) of Figure 6. For completeness, for group F endline WTP is CHF 60.14 on average, CHF 58.15 for group G, and the median for both groups is CHF 45.

Table 3: Descriptive results of WTP across baseline/endline choices and treatments

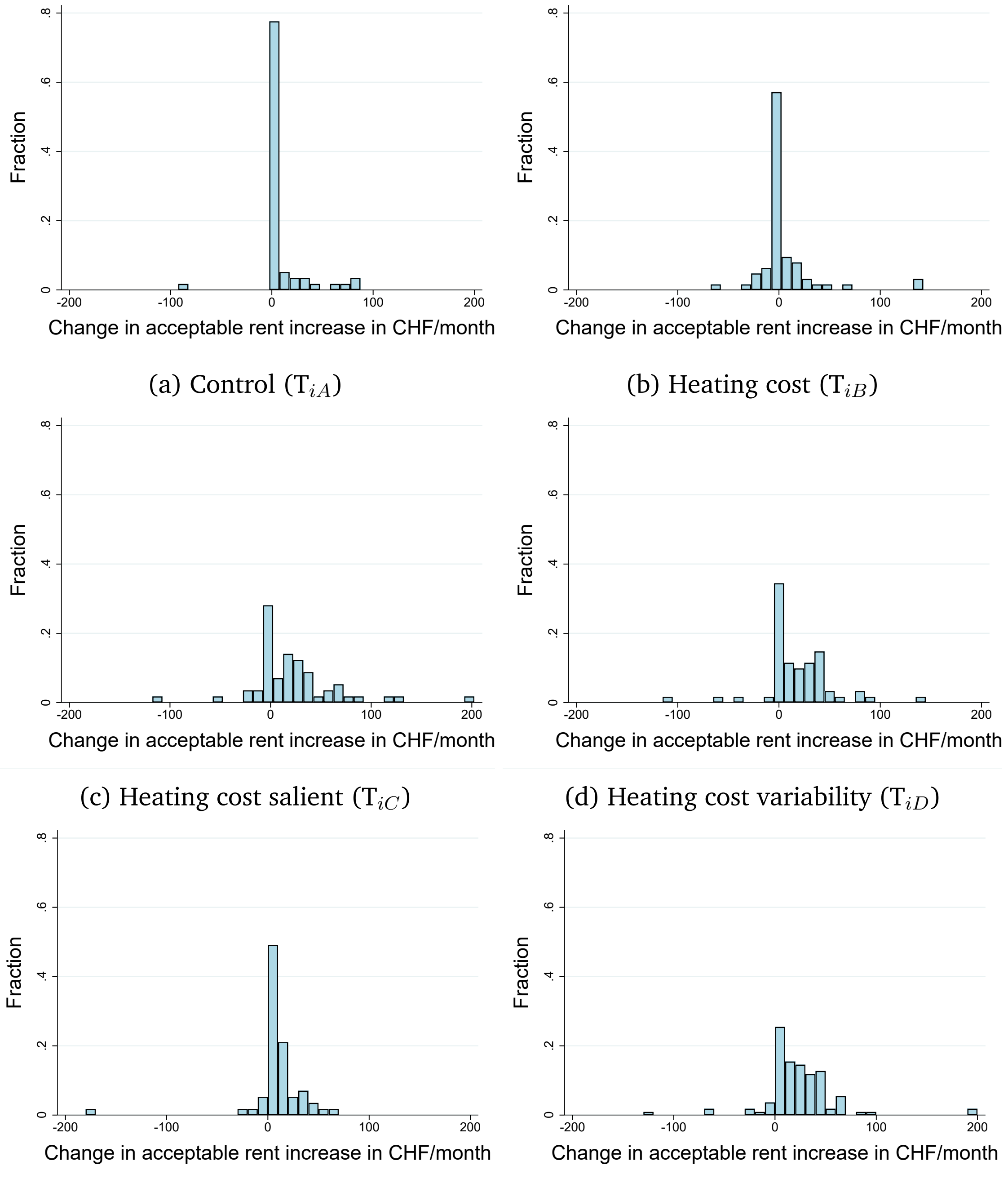
| Treatment | N | Mean | Std.-dev. |
|---|---|---|---|
| Baseline choices ($u_i^0$) | 406 | 37.51 | 42.29 |
| Endline choices ($u_i^1$): | | | |
| Control ($T_{iA}$) | 58 | 38.71 | 43.55 |
| Heating cost ($T_{iB}$) | 63 | 44.96 | 48.99 |
| Heating cost salient ($T_{iC}$) | 57 | 64.87 | 51.74 |
| Heating cost variability ($T_{iD}$) | 61 | 53.32 | 41.59 |
| $CO_2$ tax ($T_{iE}$) | 57 | 43.95 | 38.72 |
| $CO_2$ tax salient ($T_{iF}$, $A^+$ lower tax) | 52 | 60.14 | 48.92 |
| $CO_2$ tax salient ($T_{iG}$, $A^+$ no tax) | 58 | 58.15 | 42.54 |

*Notes*: All WTP estimates are measured in CHF per month (2017 exchange rate: CHF 1 = USD 1.04).

WTP values ($u_i^0$ and $u_i^1$, respectively) as a function of treatment dummies and a constant term (the latter captures average baseline WTP). We therefore have two observations per respondent, and cluster standard-errors at the respondent level. Column 2 reports OLS results for the *change* in individual WTP, so that the dependent variable is $\Delta\text{WTP}_i = u_i^1 - u_i^0$. Finally, column 3 reports OLS results for a model of endline WTP $u_i^1$ as a function of treatment dummies, controlling for baseline WTP $u_i^0$. Note that regressions in columns 2 and 3 only feature one observation per subject, and inference for these models is based on heteroskedasticity-robust standard errors.

Estimation results in column 1 confirm that salience of financial information significantly affect the valuation of energy efficiency. More specifically, treatments B and E that do not include financial information in the MPL task show comparatively small treatment effects. For these conditions, the difference in WTP between baseline and endline choices is around CHF 7 and not statistically significantly different from zero. By contrast, when energy costs are displayed in endline MPL tasks, information has a positive and highly statistically significant impact on WTP. Treatment C, which informs tenants about financial savings *and* introduces this information in the MPL task, shows an increase of WTP of about CHF 27 per month, a 73% increase compared to baseline WTP. This result parallels earlier

Figure 6: Distributions of the change in acceptable rent increases ($\Delta$WTP= $u_i^1 - u_i^0$)




(a) Control ($T_{iA}$)

(b) Heating cost ($T_{iB}$)

(c) Heating cost salient ($T_{iC}$)

(d) Heating cost variability ($T_{iD}$)

(e) $CO_2$ tax ($T_{iE}$)

(f) $CO_2$ tax salient ($T_{iF}$ and $T_{iG}$)

findings on the role of financial information for choices reported by Newell and Siikamäki (2014) and Allcott and Taubinsky (2015). Moreover, because financial savings information provided to respondents is set to CHF 40 per month, whereas endline WTP in treatment C is higher at CHF 64.87 per month on average (CHF

780 per year, see also Table 3), financial considerations of energy efficiency only partly determine tenants' WTP.

Results for treatment D shows that information about energy cost variability dampens the impact of information on financial savings. Uncertainty about future energy savings thus reduces WTP.[31] We also find little evidence that additional information on $CO_2$ tax payments affects decisions by tenants, and in turn WTP. Specifically, $T_{iB}$ and $T_{iE}$ provide very similar average treatment effect estimates (both treatments do not include financial savings in the MPL task), and treatment effects for $T_{iF}$ and $T_{iG}$ are close in magnitude to $T_{iC}$.[32] Given our previous interpretation that tenants hold more than financial motives when choosing energy efficient appliances, insensitivity to $CO_2$ tax information may reflect a negative perception of environmental taxes, as already discussed in Perino et al. (2014) and Lanz et al. (2018).

Alternative models reported in columns 2 and 3 show similar results, with a few exceptions. First, OLS regression on $\Delta$WTP (column 2) shows that within treatment changes in WTP are around CHF 15 for treatments C, F, and G. This number is lower as compared to column 1 because within-subject change in WTP for treatment group A (as represented by the constant in column 2) amounts to CHF 7.16. This is due to the fact that average baseline WTP differs slightly across treatment groups (see Table L2), and focusing on within-subject WTP estimation allows us to control for this discrepancy.[33] Second, OLS regression on endline WTP controlling for baseline WTP (column 3) shows that the coefficient for baseline WTP ($u_i^0$) is statistically significant, positive, and smaller than one as one would expect. This illustrates the fact that baseline WTP plays a large though not the sole role in determining endline WTP. Coefficient estimates for treatments B and E again provide sharp evidence that simply providing tenants with information on heating cost savings and $CO_2$ tax payments prior to investment decisions has a limited impact on WTP, highlighting the importance of making information salient for decisions.

[31] Interestingly, this information screen has the lowest rate of correct answers to the quiz question (63.93%, N=61), suggesting that this information is also more difficult to comprehend for respondents.

[32] Wald tests fail to reject equality of coefficients for $T_{iB}$ and $T_{iE}$ (p-value=0.84), and the same is true for the coefficients of $T_{iC}$, $T_{iF}$ and $T_{iG}$ (p-value=0.87 for $T_{iC}$=$T_{iF}$; p-value=0.99 for $T_{iF}$=$T_{iG}$; p-value=0.86 for $T_{iC}$=$T_{iG}$).

[33] Wald tests for column 2 again fail to reject equality for the coefficients of $T_{iB}$ and $T_{iE}$ (p-value=0.90), as well as for the coefficients of $T_{iC}$, $T_{iF}$ and $T_{iG}$ (p-value=0.62 for $T_{iC}$=$T_{iF}$; p-value=0.82 for $T_{iF}$=$T_{iG}$; p-value=0.45 for $T_{iC}$=$T_{iG}$).

Table 4: Average treatment effect of information on tenants' WTP

| | (1)<br>WTP (panel)<br>$u_i^s$ | (2)<br>$\Delta$ WTP<br>$u_i^1 - u_i^0$ | (3)<br>Endline WTP<br>$u_i^1$ |
|---|---|---|---|
| Control ($T_{iA}$) | 1.20 | – | – |
| | (5.40) | | |
| Heating cost ($T_{iB}$) | 7.45 | -0.53 | 1.19 |
| | (5.89) | (4.93) | (5.03) |
| Heating cost salient ($T_{iC}$) | 27.36*** | 15.34** | 18.08*** |
| | (6.62) | (6.54) | (6.28) |
| Heating cost variability ($T_{iD}$) | 15.81*** | 9.94* | 11.12** |
| | (5.22) | (5.44) | (5.14) |
| $CO_2$ tax ($T_{iE}$) | 6.44 | -1.63 | 0.11 |
| | (4.98) | (5.09) | (4.65) |
| $CO_2$ tax salient ($A^+$ lower tax, $T_{iF}$) | 22.64*** | 14.09** | 15.95*** |
| | (6.47) | (6.21) | (5.85) |
| $CO_2$ tax salient ($A^+$ no tax, $T_{iG}$) | 20.64*** | 14.01** | 15.38*** |
| | (5.58) | (5.84) | (5.64) |
| Baseline WTP ($u_i^0$) | – | – | 0.75*** |
| | | | (0.06) |
| Constant | 37.51*** | 7.16** | 15.14*** |
| | (2.11) | (3.23) | (3.41) |
| Observations | 812 | 406 | 406 |
| Adjusted $R^2$ | 0.04 | 0.03 | 0.50 |

*Notes*: Column (1) reports OLS estimates for a model with two observations per subject (baseline WTP $u_i^0$ and endline WTP $u_i^1$). Standard errors are clustered at the respondent-level and reported in parentheses. Column (2) reports OLS estimates for a model of $\Delta WTP_i = u_i^1 - u_i^0$. Column (3) reports OLS results for a model of endline WTP $u_i^1$. For models reported in columns (2) and (3), we report heteroskedasticity-robust standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

## 4.3 Heterogeneous treatment effects: Quantile regressions

In this section we study the treatment effect of information across all deciles of the WTP distribution (equation 2). In order to isolate the marginal impact of information on WTP, we code our treatment dummies according to their information content: (i) *Heating cost screen* equals one if the treatment includes the information screen *Heating cost* (i.e. all treatments except $T_{iA}$); (ii) *Cost MPL task* equals one if the endline MPL task includes heating costs (i.e. $T_{iC}$, $T_{iD}$, $T_{iF}$, and $T_{iG}$); (iii) *Cost variability screen* equals one if the treatment includes the information screen *Heating cost variability* (i.e. $T_{iD}$); (iv) *$CO_2$ tax screen* equals one if the treatment includes the $CO_2$ tax screen (i.e. $T_{iE}$, $T_{iF}$, and $T_{iG}$); and (v) *$CO_2$ tax MPL* *task* equals one if the endline MPL task includes $CO_2$ tax payments (i.e. $T_{iF}$ and $T_{iG}$).[34] This allows us to decompose treatment effects into specific informational components, and thereby identify key drivers of WTP changes.

Estimation results are reported in Table 5. For comparison purposes, column 1 reports OLS estimates of average treatment effects for our dummy-coded specification. Columns 2-10 then report regression results for each decile of the WTP distribution. The dependent variable is individual WTP measured in baseline and endline MPL tasks ($u_i^0$, $u_i^1$, see Table 4, column 1), which allows us to exploit both within- and between-subject variations. Because we observe two outcomes for each tenant, we cluster standard errors at the subject level.

OLS results in column 1 confirm that the key element of our informational intervention is salience of heating cost differentials between efficient and standard appliances (*Cost MPL task*). Quantitatively, we find that this feature alone increases tenants' WTP by CHF 19.91 per month on average. This corresponds to a 53% increase compared to baseline estimates. Importantly, *Heating cost screen* also has a positive impact on WTP, although the average treatment effect is smaller (around CHF 7) and not statistically significantly different from zero.

Quantile regression results for individual deciles reveal that the average treatment effect associated with salience of financial savings (*Cost MPL task*) is driven by heterogeneous effects along the entire WTP distribution. In particular, results reported in columns 2 and 3 show that treatment interventions are ineffective in shifting the lower tail of the WTP distribution. This part of the distribution does not respond to information. Moreover, we find statistically significant treatment effects in five out of nine decile regressions. The third, fourth and fifth decile (columns 4, 5 and 6) adjust WTP with reference to the provided information about financial cost savings. The treatment effect of financial information *declines* across these deciles, and implies that endline WTP for these respondents bunches around CHF 45. This is very close to expected financial cost savings highlighted in the experimental intervention (these respondents select the energy efficient option for a level of CHF 40, and the standard option at CHF 50). Finally, the upper tail increases WTP substantially.[35]

[34]As mentioned in footnote 30, results for treatment groups F and G are very similar, and we therefore lump these together without affecting our results.

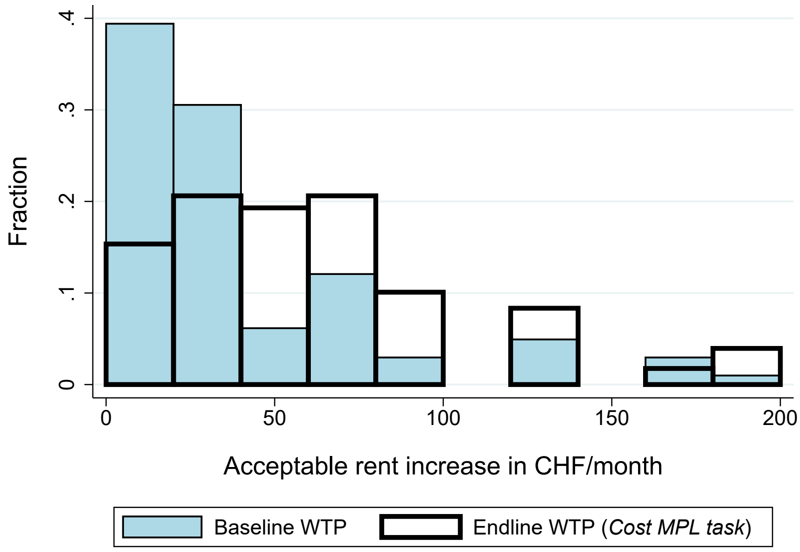
[35]Quantile coefficients provide information about effects on distributions, not individuals. In Appendix M, we document correlations between observable tenant characteristics and WTP, and also seek to identify heterogeneous treatment effects using a set of interaction terms. OLS regression results show that interaction terms have the expected signs, but are statistically insignificant except for the effect of having a university degree, which has a positive impact on baseline WTP but influences the treatment effect negatively. Nevertheless, these results suggest

Table 5: Quantile treatment effect of information on tenants' WTP

| | (1) WTP (panel) $u_i^s$ | (2) WTP (panel) (10th quantile) | (3) WTP (panel) (20th quantile) | (4) WTP (panel) (30th quantile) | (5) WTP (panel) (40th quantile) | (6) WTP (panel) (50th quantile) | (7) WTP (panel) (60th quantile) | (8) WTP (panel) (70th quantile) | (9) WTP (panel) (80th quantile) | (10) WTP (panel) (90th quantile) |
|---|---|---|---|---|---|---|---|---|---|---|
| Control | 1.20 | 0 | 0 | 0 | -10$^{***}$ | 0 | 0 | -10 | 0 | 37.50$^{***}$ |
| | (5.34) | (3.02) | (4.19) | (6.60) | (2.98) | (2.61) | (3.14) | (7.96) | (15.91) | (11.86) |
| Heating cost screen | 7.45 | 5 | 10 | 0 | 0 | 0 | 0 | 17.50$^{**}$ | 0 | 37.50$^{**}$ |
| | (5.89) | (4.92) | (6.77) | (7.09) | (2.62) | (2.59) | (3.19) | (7.58) | (4.49) | (16.89) |
| Cost MPL task | 19.91$^{**}$ | 0 | 10 | 30$^{***}$ | 20$^{***}$ | 20$^{***}$ | 27.50$^{**}$ | 0 | 62.50$^{***}$ | 0 |
| | (9.19) | (7.90) | (28.37) | (8.84) | (4.74) | (4.66) | (10.91) | (10.79) | (6.15) | (16.38) |
| Cost variability screen | -11.55 | 0 | 0 | -10 | -10$^{**}$ | 0 | 0 | 0 | -37.50$^{***}$ | 0 |
| | (8.65) | (8.79) | (28.44) | (8.85) | (4.97) | (6.16) | (11.77) | (10.62) | (8.79) | (8.03) |
| $CO_2$ tax screen | -1.01 | 0 | 0 | 10 | 10$^{**}$ | 10$^{**}$ | 10$^{*}$ | 0 | 0 | -37.50$^{**}$ |
| | (8.00) | (7.08) | (11.38) | (19.04) | (4.58) | (4.52) | (5.28) | (7.59) | (6.48) | (18.94) |
| $CO_2$ tax MPL task | -4.77 | 10 | 0 | -20 | -10 | -10 | -10 | 0 | -37.50$^{***}$ | 37.50$^{*}$ |
| | (11.37) | (14.38) | (31.03) | (21.51) | (6.88) | (6.79) | (12.19) | (12.54) | (9.07) | (22.56) |
| Constant | 37.51$^{***}$ | 0 | 5$^{***}$ | 15$^{***}$ | 25$^{***}$ | 25$^{***}$ | 35$^{***}$ | 45$^{***}$ | 62.50$^{***}$ | 87.50$^{***}$ |
| | (2.11) | (1.12) | (1.44) | (4.18) | (1.27) | (1.25) | (1.30) | (6.66) | (2.45) | (10.44) |
| Observations | 812 | 812 | 812 | 812 | 812 | 812 | 812 | 812 | 812 | 812 |
| (Pseudo) $R^2$ | 0.04 | 0.01 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.03 | 0.03 |

*Notes*: Dependent variable is baseline WTP $u_i^0$ and endline WTP $u_i^1$. Column 1 reports OLS estimates. Column 2-10 report regression results for each decile of the WTP distribution. Standard errors are clustered at the respondent-level and reported in parentheses. $^{*}$, $^{**}$ and $^{***}$ denote statistical significance at 10%, 5% and 1% levels respectively.

Figure 7: Distribution of tenants' WTP before and after treatment




In a nutshell, salient information on financial savings leads to an upward shift in WTP of the middle and upper part of the distribution, without an accompanying shift of the lowest quantiles. These conclusions are further illustrated in Figure 7, which plots the distribution of baseline WTP and endline WTP for subjects exposed to treatment component *Cost MPL task*. The graph confirms that the treatment leads to a large majority of tenants adjusting their WTP in response to the CHF 40 information provided. It also shows that part of the distribution remains in place.

Taken together, our results suggest that financial information affects WTP for a large majority of our sample, and that the estimated average treatment effect is not driven by the tails of the distribution. Moreover, the treatment effect on median WTP is very close to the treatment effect on average WTP. However, providing information does not push the full distribution of tenants above the illustrative CHF 40 threshold, possibly on account of individual social and environmental motives. Finally, we note that the lack of average treatment effect for other interventions appears across deciles, with no clear-cut impact.

## 5 Discussion and conclusion

In this paper, we have applied a MPL procedure on a sample of 406 Swiss tenants in order to estimate their valuation of improved energy efficiency of their space

that heterogeneity in the impact of information is mostly driven by unobserved characteristics.

heating system. We find that tenants' WTP for an efficiency upgrade from B to $A^+$ is statistically and economically significant, and that information about financial implications plays a crucial role in the acceptability of such measure. We also find that financial information has to be made salient, clearly associating it with the decision at hand, whereas providing information on $CO_2$ tax payments has virtually no impact on tenants' valuation of energy efficiency improvements.

From a policy perspective, our results have important implications. The fact that tenants are willing to support part of the additional investment cost imposed on property owners by paying higher rents could be leveraged to promote energy efficiency investments in rented properties.[36] Importantly, our work suggests that providing tenants with realistic and credible information about financial implications of energy efficiency investments is a necessary first step to make rent increase acceptable. Empirical research on the realizations of energy savings, which requires a credible counterfactual, is only burgeoning (see Chapter I; Fowlie et al., 2018; Burlig et al., 2017; Liang et al., 2018).

In this sense, our results also confirm the more conventional view that informational interventions can substantially improve attitudes towards energy efficiency. Our results show that even in a country where the majority of tenants lives in multifamily housing without separate meters, salience of financial savings associated with energy efficiency is critical, and this has implications for the design of energy efficiency labels (see also Newell and Siikamäki, 2014). Moreover, we show that the average treatment effect of information reflects heterogeneous changes along the entire distribution of acceptable rent increases. Identifying the specific drivers of the observed heterogeneity is left for future research.

[36]Similar to Chapter II, we cannot rule out a potential sample selection bias affecting tenants' baseline WTP for energy efficiency (respondents were drawn from a subject pool that consists of self-subscribers, and the experiment was implemented as part of the second wave of a repeated survey on energy behavior in general). Therefore, our attention is mainly directed towards between- and within-subjects comparisons quantifying the role of information provision for tenants' choices.

# Conclusion

This PhD thesis discusses the potential contribution of energy efficiency investments to the achievement of rising $CO_2$ emissions targets in the real estate sector. In particular, I provide empirical estimates of different energy efficiency investments' cost-effectiveness in reducing $CO_2$ emissions (Chapter I), and investigate common behavioral explanations for the slower-than-socially-optimal diffusion of these investments (Chapters II and III). To achieve this, I focus on three players in the residential market for energy efficiency: large institutional property owners (Chapter I), private owner-occupiers (Chapter II), and tenants (Chapter III).

The main findings provide important insights for current climate policy in the buildings sector, and subsidies targeting energy efficiency investments in particular. In a nutshell, the results imply that in the absence of a uniform carbon price, targeting the right interventions and market players is key to reaching Switzerland's $CO_2$ emissions targets in the least-cost way to society. In particular, I shed light on the large heterogeneity in cost-effectiveness associated with different energy efficiency improvements, and show that increasing salience of financial savings has virtually no impact on homeowners' choices. Instead, this information could be used to trigger tenants' acceptability of these investments.

In Chapter I, I provide empirical evidence on building-level energy savings, $CO_2$ abatement, and heating expenditure reductions. In addition, I document estimates for the implicit price of carbon, a simple metric to compare alternative investment strategies. Results show that the range of implicit carbon prices in the narrow domain of building energy retrofits is large. In particular, estimates span from around CHF -200 per tonne of $CO_2$ for the installation of smart thermostats to over CHF 1,000 for facade insulation, which exceeds available estimates of avoided damages (around USD 40/t$CO_2$, see Greenstone et al., 2013). By contrast, emerging technologies such as smart thermostats can achieve significant energy savings at a relatively low cost. Policy-makers' natural tendency to favor established abatement strategies will fail to incentivize these abatement opportunities.

Chapter II shows that homeowners value energy efficiency beyond simply financial returns on average, and that information programs on financial energy savings have virtually no impact on choices. This contrasts with conventional views that information market failure and attentional biases are to blame for low energy efficiency adoption rates. By contrast, fossil fuel users appear to hold persistent preferences towards the familiar technology that go beyond comfort considerations and expectations about financial implications of choices. Accordingly, promoting specific low-carbon technologies (such as wood pellets or heat pumps) might be a more effective emissions reduction strategy than subsidizing higher energy efficiency, and policies are likely to benefit from targeting (e.g., based on the currently installed heating system).

On a similar note, Chapter III shows that tenants are willing to support a substantial part of the additional investment cost associated with energy efficiency investments by means of higher monthly rents. This could be leveraged to promote energy efficiency investments in rented properties. However, my results show further that even in a country where the majority of tenants lives in multi-unit housing without separate meters, salience of financial savings is critical for the acceptability of energy efficiency investments. This has implications for the design of energy labels (see also Newell and Siikamäki, 2014). Accordingly, the first step to make post-investment rent increase acceptable is to provide tenants with realistic and credible information about financial implications of energy efficiency investments.

The results presented in Chapters II and III of this thesis allow drawing three additional conclusions that are relevant from a policy perspective. First, both homeowners and tenants are willing to pay more for increased energy efficiency than can be expected to save with future energy savings. In particular, tenants' average WTP for energy label A+ relative to B is CHF 37.51 per month, which translates to about CHF 6,750 for the entire lifetime of a heating system (15-year undiscounted, 2017 energy prices). As a result, tenants' valuation of energy efficiency goes beyond expected energy savings (about CHF 5,850 for 15-year undiscounted, 2017 energy prices). By comparison, homeowners' baseline WTP for energy label A+ relative to B amounts to CHF 13,540, which is more than twice the expected gains from energy savings.[37] In theory, the substantial WTP for energy

[37]Note that the average household income of my sample of tenants ranges from CHF 4,500 to CHF 8,999, while it ranges from CHF 6,000 to CHF 12,000 for homeowners. Moreover, average annual heating costs reported by my sample of tenants amount to CHF 1,175, and CHF 1,920 for homeowners.

efficiency elicited for both parties could be leveraged to promote energy efficiency investments in residential properties. However, note that a potential sample selection bias inflating participants' baseline WTP cannot be ruled out for either study. As a next step, estimates elicited in this thesis should be complemented with either a study of revealed preferences (i.e., choices observed in real market transactions) or a carefully designed, incentivized choice experiment.

Second, I find that homeowners' continued investment in fossil fuel-based technologies can at least partly be explained with a persistent familiarity bias that goes beyond mere inertia and imperfect information market failure. As a result, subsidies promoting energy efficiency and renewable technologies risk being taken-up by *infra-marginal* consumers (i.e., consumers whose WTP for a particular good is higher than the purchase price under a particular incentive scheme). In an attempt to avoid such inefficient climate policy, market interventions should consider targeting current fossil fuel users in particular. While this could have implications for the Swiss federal and cantonal Buildings Programme, the Swiss $CO_2$ levy on thermal fuels (which provides a substantial part of the funding for this programme) precisely fulfills this requirement.

Third, results show that there is potential to correct imperfect information market failure and attentional biases with information programs targeting private benefits of energy efficiency improvements among tenants, but not among homeowners. More precisely, informing subjects about expected financial savings increases tenants' WTP for energy efficiency by 53% on average, but has no statistically significant effect on homeowners' choices. Note that homeowners' WTP was elicited with multi-attribute choice tasks, while tenants were presented with one-dimensional choices. Consequently, it is conceivable that homeowners are *rationally* inattentive to energy efficiency as discussed by Sallee (2014). Alternatively, they might be better informed than tenants at the baseline about financial implications of choices, a phenomenon for which I find support in the data. This would suggest that the residential market for energy efficiency is subject to asymmetric information (rather than imperfect information affecting both tenants and homeowners), a result that matches the findings of Myers (2018) and has implications for landlord-tenant split incentives. In particular, providing tenants with realistic and credible information about financial implications of energy efficiency investments could help overcome split incentives with more rent increases.

Overall, the results presented in the three chapters of this thesis shed light to multiple avenues for future research. First, the declining trend in pre-treatment heating energy use observed in Chapter I, which could be partly caused by rising temperatures and fossil fuel prices, warrants further research. If the trend continues and extends to the entire building stock, then the implicit price of carbon associated with energy efficiency interventions is bound to increase even more in the future. On the other hand, future estimations of the implicit price of carbon should consider the rising demand for cooling in Switzerland, which could *increase* the cost-effectiveness of weatherization measures relative to interventions solely related to heating demand.

Second, my analysis on the implicit price of carbon abstracts from important welfare impacts of building retrofits such as improved comfort for tenants, lower maintenance costs for property owners, or distributional implications through increased rents. The timing of renovations (or rather, the age of the building element at the time of replacement) is also not considered in the thesis, despite the fact that it has a direct impact on cost-effectiveness of interventions. These considerations all have implications for investment decisions and for the design of public policies, and warrant exploration. Beyond that, I emphasize that evidence on the implicit price of carbon is by construction context-dependent (Gillingham and Stock, 2018),[38] which implies that further work on the impact of specific abatement investments is critical.

Third, more research is necessary to identify the mechanisms explaining why both tenants and homeowners are unresponsive to salience of $CO_2$ tax payments imposed on fossil fuel-based choices.[39] One possible explanation is that displayed tax levels derived from the Swiss context might be too low to trigger a reaction from respondents. Alternatively, it is possible that subjects were already well informed about $CO_2$ tax payments (and associated environmental consequences of choices) at the baseline, which would limit the need to correct imperfect information market failure in this context. This would raise the question whether high environmental awareness is a feature of the sample or the population. Another possible explanation is that subjects did not perceive the provided information as credible and trustworthy.[40] However, the intervention would still have raised

[38]In particular, variation in annual pre-treatment energy use in my sample (mean: 175 kWh/$m^2$; standard deviation: 47 kWh/$m^2$) could be too low to allow extrapolation of the results to other regions of the world. The same is true for buildings' pre-treatment energy efficiency levels (such as the baseline quality and thickness of exterior walls).

[39]Note that this conclusion does not extend to the main functionality of the $CO_2$ tax, which is to increase the price of fossil fuels.

[40]Given the ambiguous findings in the literature regarding the returns from energy efficiency investments (see e.g. Fowlie et al., 2018), subjects might have doubted the magnitude of the provided ex-post savings.

subjects' attention to the matter. Finally, it is conceivable that tax-inclusive prices failed to signal environmental consequences of choices to consumers because these did either not understand (see Blasch et al., 2019; Brent and Ward, 2018) or intentionally ignore (see Sallee, 2014) the information provided. Further research in this area is required to improve the design of information programs in general and energy labels in particular.

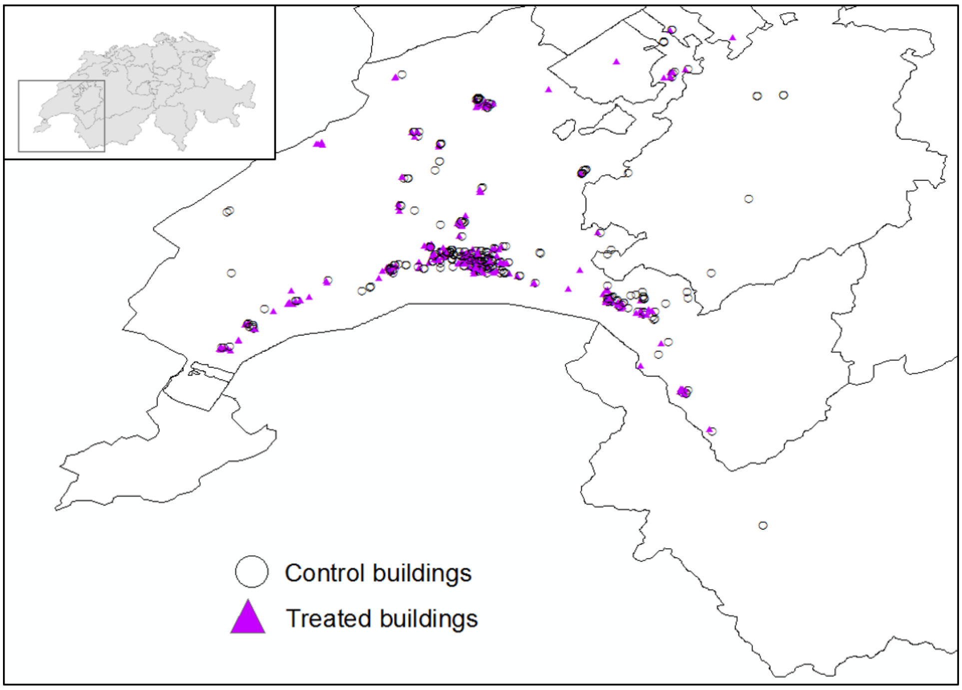
Importantly, the differences in results between homeowners and tenants are likely to be at least partly driven by the respective elicitation methods. For instance, while the MPL elicitation procedure applied in Chapter 3 allows tenants to concentrate on one single product attribute (i.e., energy efficiency), the DCE employed in Chapter 2 is associated with a higher cognitive effort because homeowners have to make multi-dimensional choices. By contrast, within-between interventions provided to homeowners in Chapter 2 consist of only one information screen, while treatment conditions showed to tenants in Chapter 3 consist of two information screens per subject, which increases complexity on the part of tenants. While the two methods proved adequate in estimating within-between variations in information disclosure in each context, a single method would need to be applied to both samples in order to draw more detailed comparisons between homeowners' and tenants' valuations of energy efficiency.

# Appendix

The Appendix contains supplementary information for Chapters I, II, and III.

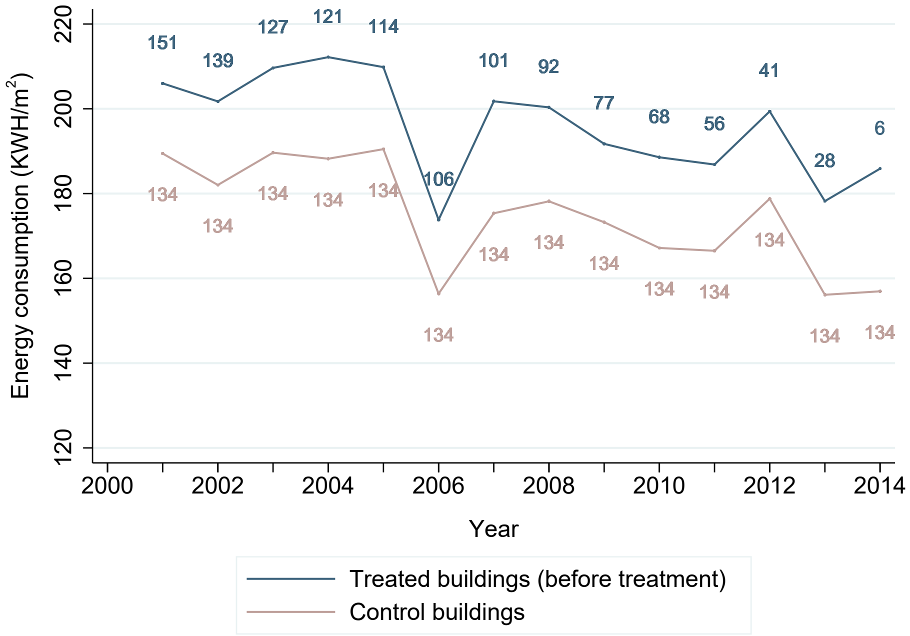
## A Location of buildings (Chapter I)

Figure A1: Geographical distribution of buildings across treatment and control groups



# B Pre-treatment trends in the balanced sample (Chapter I)

Figure B1: Trends in pre-treatment energy use for treated and control buildings (balanced sample)




*Notes:* This figure reports pre-treatment average energy use (in kWh/$m^2$) for treated and control buildings over time, together with the number of buildings used to calculate group-specific averages (i.e., the number of observations per group per year). In the treatment group, the number of pre-treatment observations decreases with time as buildings enter the during-treatment period. From 2015 onwards, all buildings in the treatment group have entered the during-treatment period.

# C Estimation of the implicit price of carbon (Chapter I)

This appendix provides the details for the estimation of the implicit price of carbon associated with alternative interventions. First, we compute total $CO_2$ abatement associated with a unit investment in each energy efficiency intervention, denoted by $\overline{CO2}_k$. This is mainly based on our estimate for annual $CO_2$ abatement (in kg / CHF invested), $\theta_k$, scaled to obtain tonnes of $CO_2$. In addition, we make an assumption about the lifetime of each building element (denoted $\omega_k$, in years), which is derived from engineering sources and reported in Table C1. The total change in $tCO_2$ per CHF invested is then given by: $\overline{CO2}_k = -\omega_k \cdot \theta_k/1000$. The inverse of this quantity gives the financial cost associated with a 1 $tCO_2$ reduction of emissions.

Table C1: Assumptions about the lifetime of building elements

| Treatment | Lifetime (in years) under | | Based on |
|---|---|---|---|
| | Average use | Heavy use | |
| Exterior walls | 80 | 70 | SIA (2004) and CRB (2012) |
| Roof or attic | 40 | 30 | SIA (2004) |
| Windows | 50 | 30 | SIA (2004) |
| Smart thermostats | 15 | 10 | CRB (2012) |
| Boiler appliance | 40 | 30 | SIA (2004) |

Second, the interventions we consider also reduce expenditures on heating fuels, and we compute total financial savings associated with a unit investment in each energy efficiency intervention, denoted $\overline{cost_k}$. Given our notation, we have that investing CHF 1 in retrofit $k$ saves, each year, $\lambda_k$ on average in terms of heating expenditures. Using an assumption about the discount rate $\delta$, we can write total financial savings over the lifetime of the building element as: $\overline{cost_k} = -\sum_{t=0}^{\omega_k}(1+\delta)^{-t} \cdot \lambda_k$. Note that this also involves an assumption that fuel prices remain consistent with the values observed over the estimation period.

Finally, we combine the two measures and write the implicit price of carbon as: $P_k = \frac{1}{\overline{CO2}_k}(1 - \overline{cost_k})$. Intuitively, reducing $CO_2$ emissions by one tonne requires an investment of CHF $\frac{1}{\overline{CO2}_k}$, and this investment in turn saves a total of $\frac{1}{\overline{CO2}_k} \cdot \overline{cost_k}$ in terms of fuel expenditures. Given estimated standard errors for $\theta_k$ and $\lambda_k$, we use the delta method to carry out statistical inference on $P_k$.

# D Results for panel fixed effects event-study regressions (Chapter I)

Table D1: Event study regression results for pooled energy efficiency investments

| | Energy use | | $CO_2$ emissions | | Heating cost | |
|---|---|---|---|---|---|---|
| | ln(kWh/m$^2$) | kWh/m$^2$ | ln(kg/m$^2$) | kg/m$^2$ | ln(CHF/m$^2$) | CHF/m$^2$ |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| 5+ years before ($t_{-5}$): | -0.02 | -3.06 | -0.01 | -0.34 | -0.02 | -0.67*** |
| | (0.02) | (2.36) | (0.02) | (0.60) | (0.01) | (0.21) |
| 4 years before ($t_{-4}$): | -0.01 | -0.89 | -0.01 | -0.20 | -0.01 | -0.35 |
| | (0.01) | (2.43) | (0.01) | (0.58) | (0.01) | (0.23) |
| 3 years before ($t_{-3}$): | -0.02 | -2.74 | -0.02 | -0.63 | -0.01 | -0.28 |
| | (0.02) | (2.27) | (0.02) | (0.56) | (0.01) | (0.20) |
| 2 years before ($t_{-2}$): | -0.003 | -1.00 | -0.001 | -0.16 | 0.002 | -0.06 |
| | (0.01) | (1.79) | (0.01) | (0.46) | (0.01) | (0.16) |
| 1 year after ($t_{+1}$): | -0.12*** | -19.86*** | -0.18*** | -6.78*** | -0.07*** | -1.05*** |
| | (0.01) | (2.34) | (0.02) | (0.65) | (0.02) | (0.24) |
| 2 years after ($t_{+2}$): | -0.13*** | -20.92*** | -0.17*** | -6.66*** | -0.09*** | -1.41*** |
| | (0.02) | (2.57) | (0.02) | (0.69) | (0.02) | (0.28) |
| 3 years after ($t_{+3}$): | -0.13*** | -21.01*** | -0.17*** | -6.61*** | -0.10*** | -1.36*** |
| | (0.02) | (2.84) | (0.02) | (0.75) | (0.02) | (0.31) |
| 4 years after ($t_{+4}$): | -0.14*** | -22.78*** | -0.18*** | -6.83*** | -0.11*** | -1.66*** |
| | (0.02) | (2.78) | (0.02) | (0.73) | (0.02) | (0.29) |
| 5+ years after ($t_{+5}$): | -0.13*** | -19.56*** | -0.16*** | -6.31*** | -0.07*** | -0.97*** |
| | (0.02) | (3.47) | (0.02) | (0.85) | (0.02) | (0.35) |
| Observations | 7,047 | 7,047 | 7,047 | 7,047 | 7,047 | 7,047 |
| Buildings (clusters) | 548 | 548 | 548 | 548 | 548 | 548 |
| Adj. R-squared | 0.18 | 0.31 | 0.24 | 0.37 | 0.71 | 0.64 |

*Notes*: OLS coefficients reported. Column (1) reports a regression of the log of buildings' annual energy use in kWh/m$^2$ on a pooled intervention dummy (=1 if any energy efficiency investment is applied), where each pre-treatment and post-treatment year represents a separate category ($t_{+1}$, $t_{+2}$, etc.). The last pre-treatment period $t_{-1}$ is the reference category, with the associated coefficient normalized to zero. In column (2), the dependent variable is annual energy use in levels. Corresponding results are reported in column (3) and (4) for $CO_2$ emissions in kg $CO_2$/m$^2$ (logs and levels, respectively), while column (5) and (6) report results for annual heating expenditures in CHF/m$^2$ (logs and levels, respectively). Prices refer to a 2015 baseline; exchange rate approx. CHF 1 = USD 1. All regressions include control variables, year and buildings fixed effects, and during-treatment dummies. Standard errors are clustered at the building-level and reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

# E Robustness: Summary statistics for subsamples (Chapter I)

Table E1: Building characteristics across subgroups

| | Heating oil buildings | | | Purely residential buildings | | | Balanced panel | | |
|---|---|---|---|---|---|---|---|---|---|
| | All | Treated | Control | All | Treated | Control | All | Treated | Control |
| Annual energy use (kWh/$m^2$) | 185.18 | 198.48 | 171.71 | 174.43 | 195.54 | 159.96 | 188.00 | 201.45 | 172.85 |
| Total surface area ($m^2$) | 1588.23 | 1725.98 | 1448.81 | 1353.42 | 1403.06 | 1319.37 | 1561.5 | 1721.75 | 1380.92 |
| Construction year[a] | 1962.22 | 1963.57 | 1960.87 | 1972.89 | 1967.14 | 1976.84 | 1960.49 | 1961.96 | 1958.84 |
| Number of units[b] | 22.27 | 24.12 | 20.4 | 18.48 | 19.88 | 17.52 | 21.98 | 24.38 | 19.27 |
| Avg. unit size[c] | 3.11 | 3.09 | 3.13 | 3.25 | 3.09 | 3.36 | 3.09 | 3.08 | 3.10 |
| Monthly rent[d] (CHF/$m^2$) | 15.29 | 14.82 | 15.76 | 15.97 | 15.20 | 16.52 | 15.17 | 14.70 | 15.70 |
| Heating degree days[e] | 2882.21 | 2888.41 | 2875.48 | 2883.47 | 2892.75 | 2876.61 | 2881.09 | 2884.93 | 2876.76 |
| Commercial units (%) | 0.05 | 0.05 | 0.04 | 0.00 | 0.00 | 0.00 | 0.04 | 0.04 | 0.04 |
| Observations | 334 | 168 | 166 | 322 | 131 | 191 | 285 | 151 | 134 |

*Notes*: This table reports summary statistics for subsamples used in the robustness section. For treated buildings pre-treatment averages are reported. [a]Average construction year of buildings in Switzerland: 1963.3 (FSO, 2019d). [b]Total number of residential and/or commercial leases; average for Switzerland: 4.9 (FSO, 2019d). [c]Average number of rooms per unit; average for Switzerland: 3.3 (FSO, 2019d). [d]Average monthly rent for Switzerland: 13.7 CHF/m$^2$ (FSO, 2019d). Prices refer to a 2015 baseline; exchange rate approx. CHF 1 = USD 1. [e]Heating degree days measure the difference between the local average outdoor temperature in a given day and 20$°C$, cumulated over a given heating season (see footnote 11).

# F Experimental script (Chapter II)

Figure F1: Introductory screen 1

*odce_intro1.* 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.

Figure F2: Introductory screen 2

*odce_intro2*. 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:

Figure F3: Introductory screen 3

*odce_intro3*. 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** |   |   |   |

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

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.

Figure F4: Introductory screen 4

*odce_intro4*. 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.

Figure F5: Example baseline choice task

*odce_ce1_1_1.*

| | Offer I | Offer II | Offer III |
|---|---|---|---|
| **Heating technology** | Heat pump using electricity | Boiler with natural gas | Boiler with heating oil |
| **Investment cost** | Fr. 10'160 | Fr. 30'140 | Fr. 17'030 |
| **Energy label** | B | A+ | A |
| | I | II | III |
| Which offer do you prefer? | ○ | ○ | ○ |

Figure F6: Instructions for information screens ($C$)

*odce_ta1.* 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.

Figure F7: Instructions for information screens ($T_A$ and $T_B$)

*odce_tc1.* 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.

Figure F8: Instructions for information screens ($T_C$ and $T_D$)

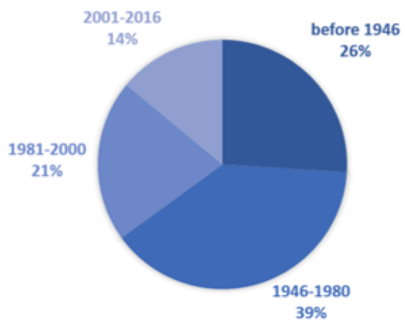
*odce_td1.* In the next part of the study, you will have the opportunity to learn more about the $CO_2$ tax on heating oil and natural gas.

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.

Figure F9: Information screen - Neutral ($C$)

*odce_ta2*. 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.

---

*odce_ta3*. How many % of Swiss apartments were built between 2001 and 2016?

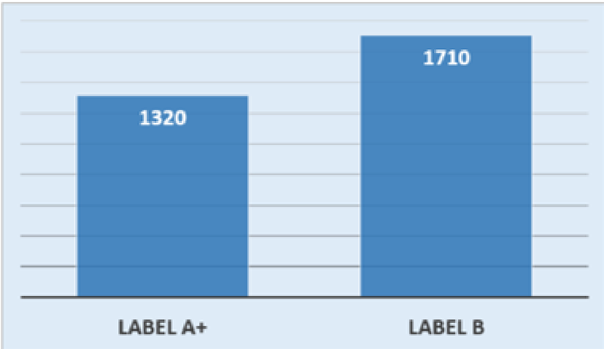
*To answer this question, you can only enter integers between 0 and 100. Type your answer below:*

[ ] %

Figure F10: Information screen - Heating costs ($T_A$ and $T_B$)

*odce_tb2*. 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.

**HEATING COSTS IN SWISS FRANCS PER YEAR**




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.

---

*odce_tb3*. Typically, and all else being equal, 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?

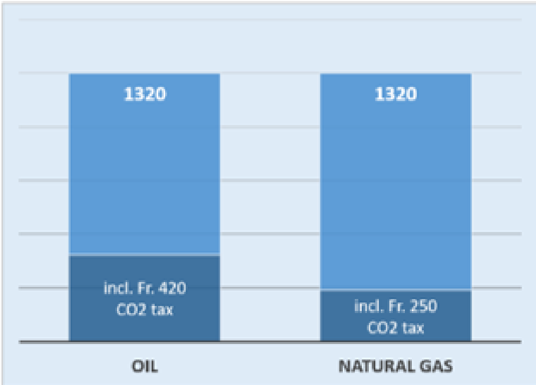
*To answer this question, you can only enter integers. Type your answer below:*

CHF

Figure F11: Information screen - $CO_2$ tax ($T_C$ and $T_D$)

*odce_td2*. 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.

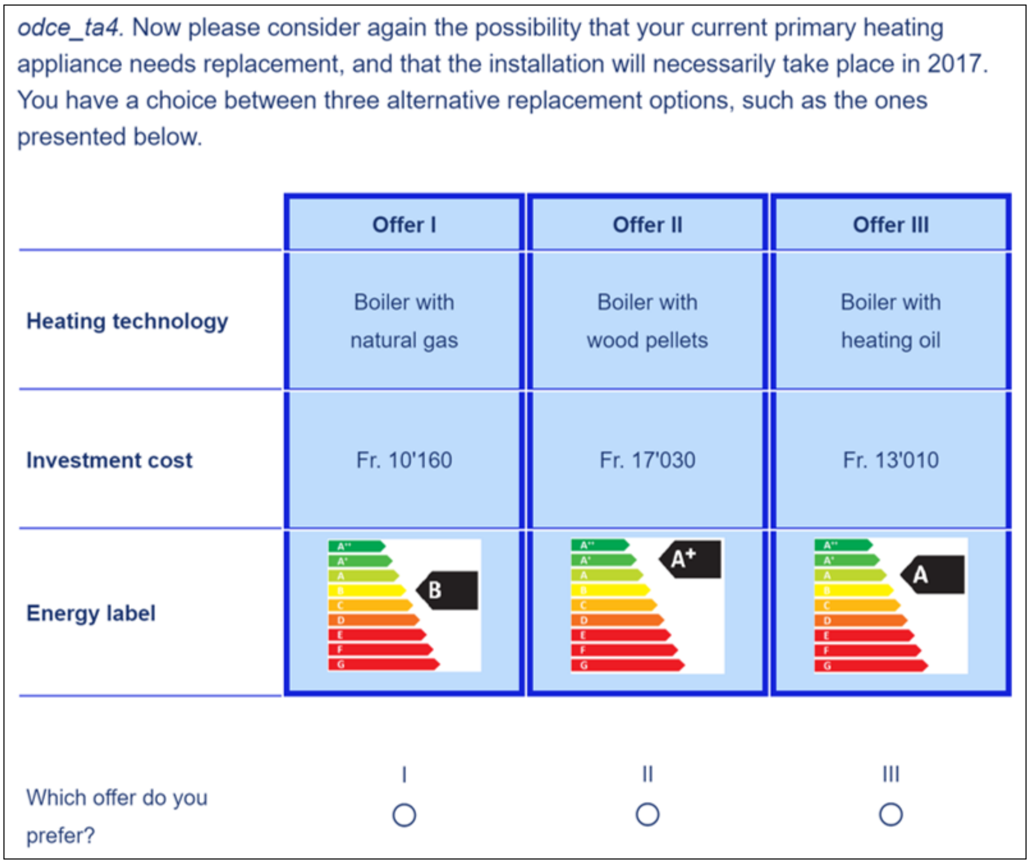
---

*odce_td3*. If your heating system is operating on heating oil and your annual heating bill amounts to Fr. 1'320, how high is the associated $CO_2$ tax payment?

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

[ ] CHF

Figure F12: Instructions for endline choice task ($C$, $T_A$ and $T_C$)

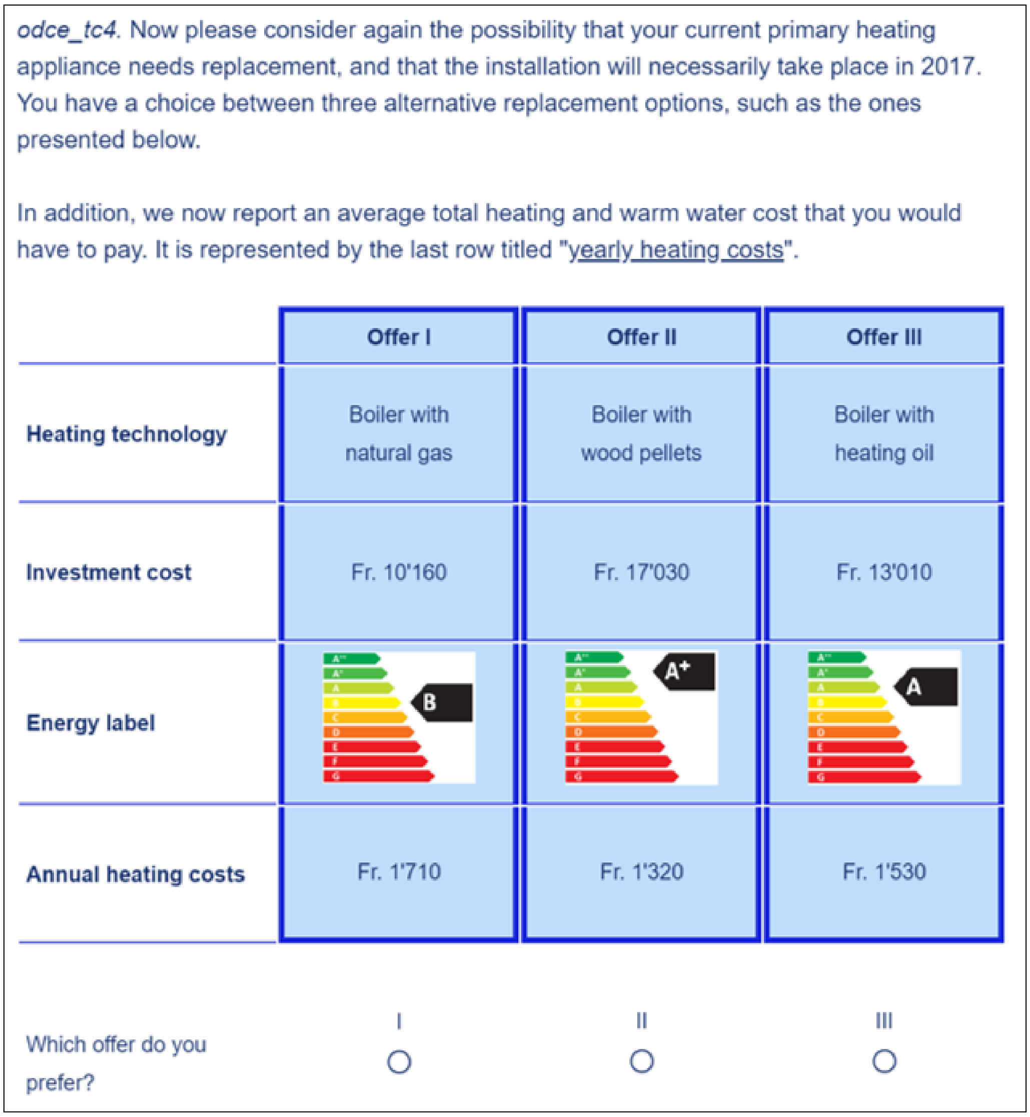


*odce_ta4.* Now please consider again the possibility that your current primary heating appliance needs replacement, and that the installation will necessarily take place in 2017. You have a choice between three alternative replacement options, such as the ones presented below.

| | 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** | B | A+ | A |

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

Figure F13: Instructions for endline choice task with heating costs ($T_B$)



*odce_tc4*. 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** | B | A+ | A |
| **Annual heating costs** | Fr. 1'710 | Fr. 1'320 | Fr. 1'530 |

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

Figure F14: Instructions for endline choice task with heating costs and $CO_2$ tax ($T_D$)

*odce_te4*. 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) |

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

Figure F15: Instructions for endline choice task ($C$-$T_D$)

*odce_ta5*. 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.

Figure F16: Example endline choice task - Heating cost ($T_B$)

*odce_ce2C_2_9.*

| | Offer I | Offer II | Offer III |
|---|---|---|---|
| **Heating technology** | Boiler with heating oil | Heat pump using electricity | Boiler with natural gas |
| **Investment cost** | Fr. 17'030 | Fr. 10'160 | Fr. 30'140 |
| **Energy label** | A+ | A | B |
| **Annual heating costs** | CHF 1'320 | CHF 1'530 | CHF 1'710 |

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

Figure F17: Example endline choice task - Heating cost and $CO_2$ tax ($T_D$)

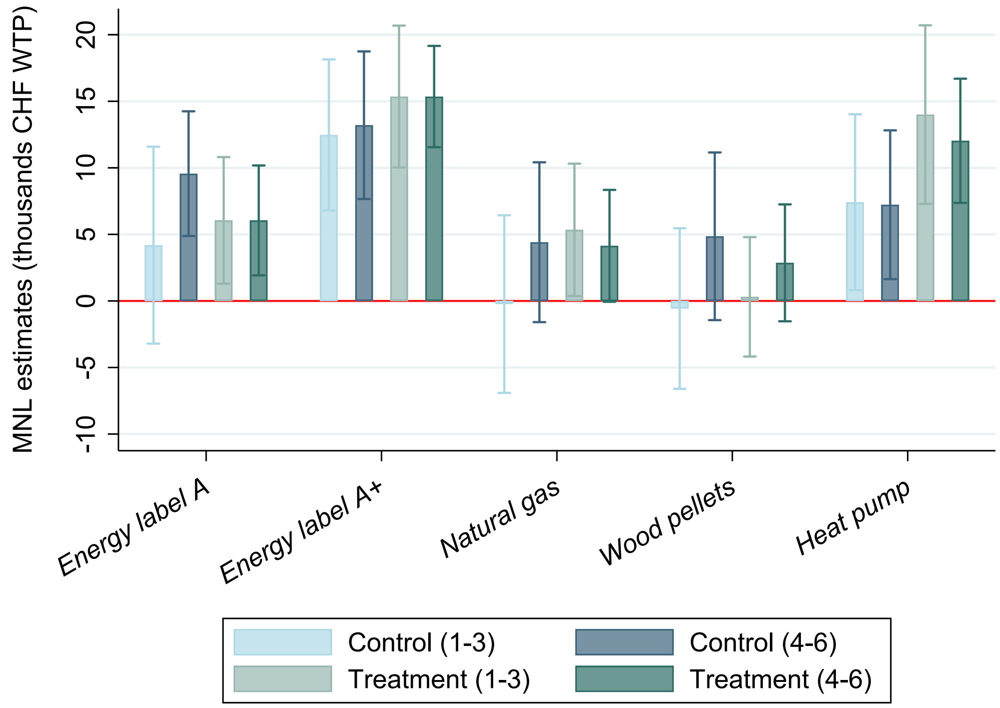
*odce_ce2E_3_17.*

| | Offer I | Offer II | Offer III |
|---|---|---|---|
| **Heating technology** | Boiler with natural gas | Boiler with heating oil | Boiler with wood pellets |
| **Investment cost** | Fr. 17'030 | Fr. 10'160 | Fr. 30'140 |
| **Energy label** | A+ | B | A |
| **Annual heating costs** | CHF 1'320 (incl. Fr. 250 $CO_2$ tax) | CHF 1'710 (incl. Fr. 550 $CO_2$ tax) | CHF 1'530 (no $CO_2$ tax) |

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

# G Pre-treatment trends (Chapter II)

Figure G1: Trends in pre-treatment WTP for treatment and control group




*Notes:* This figure reports pre-treatment WTP (in thousands CHF) associated with various attributes for (pooled) treatment and control group over time. Displayed coefficients were estimated by means of a MNL model in WTP space involving only the subsample of choices before treatment, and choices were grouped into two categories in order to accommodate the reduced sample size (i.e., choice tasks 1-3 and 4-6 were grouped together).

# H Sample composition (Chapter II)

Table H1: 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 | 1,919.54 | (963.75) | 250.00 | 5,500.00 |

*Notes*: [a]Monthly gross household income is coded as: 1 – CHF 3,000 or less; 2 – CHF 3,000-4,459; 3 – CHF 4,500-5,999; 4 – CHF 6,000-8,999; 5 – CHF 9,000-12,000; 6 – CHF 12,000 or more. [b]Annual household expenditures for heating, as per the latest energy bill available.

Table H2: Summary statistics across treatment conditions

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 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] | 1,688.63 | 1,883.52 | 1,881.04 | 2,082.16 | 2,038.55 |
| Observations | 103 | 100 | 104 | 97 | 106 |

*Notes*: [a]Monthly gross household income is coded as: 1 – CHF 3,000 or less; 2 – CHF 3,000-4,459; 3 – CHF 4,500-5,999; 4 – CHF 6,000-8,999; 5 – CHF 9,000-12,000; 6 – CHF 12,000 or more. [b]Annual household expenditures for heating, as per the latest energy bill available.

# I Multinomial logit model results (Chapter II)

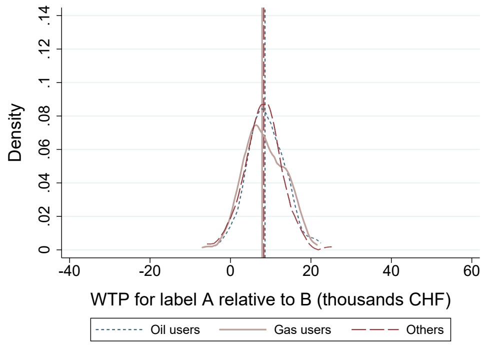
Table I1: Multinomial logit model estimates in WTP space (thousands CHF)

| | Before treatment | After treatment |
|---|---|---|
| | (1) | (2) |
| Energy label A | 6.55*** | 7.90*** |
| | (1.23) | (0.92) |
| Energy label $A^+$ | 14.31*** | 14.35*** |
| | (1.30) | (1.08) |
| Natural gas | 4.18*** | 4.87*** |
| | (1.60) | (1.27) |
| Wood pellets | 1.78 | 4.05*** |
| | (1.58) | (1.20) |
| Heat pump | 11.40*** | 11.74*** |
| | (1.72) | (1.42) |
| Investment cost | -2.83*** | -2.59*** |
| | (0.11) | (0.09) |
| Observations | 9,108 | 9,096 |
| Subjects (clusters) | 510 | 510 |
| Log-Pseudolikelihood | -2,997.48 | -2,863.49 |
| AIC | 6,006.96 | 5,738.98 |
| BIC | 6,049.66 | 5,781.68 |
| Pseudo $R^2$ | 0.10 | 0.14 |

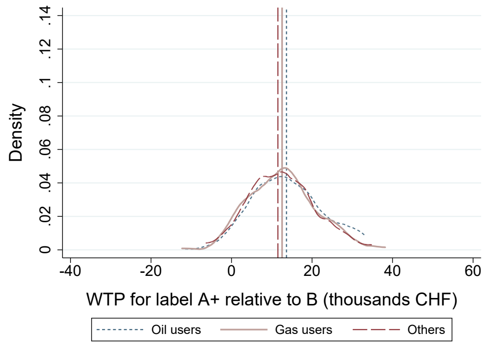
*Notes*: Column (1) reports multinomial logit WTP estimates (in thousands CHF) before treatment. Column (2) reports multinomial logit WTP estimates after treatment. Reference categories for the energy labels (A, $A^+$) and the technology variables (natural gas, wood pellets, heat pump) are energy label B and heating oil, respectively. Estimates refer to the mean of an attribute underlying the cost coefficient, as well as the cost coefficient itself. Standard errors are clustered at the respondent-level and reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

# J Density distributions of individual-specific WTP (Chapter II)

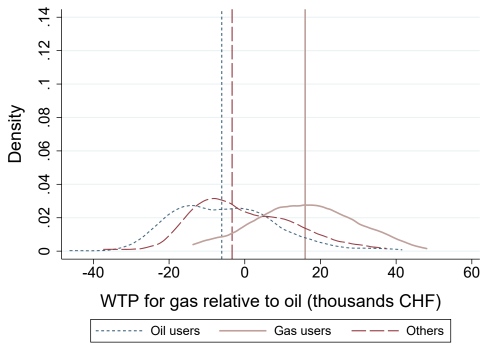
Figure J1: Density distributions of individual-specific WTP by status quo heating technology (after treatment)



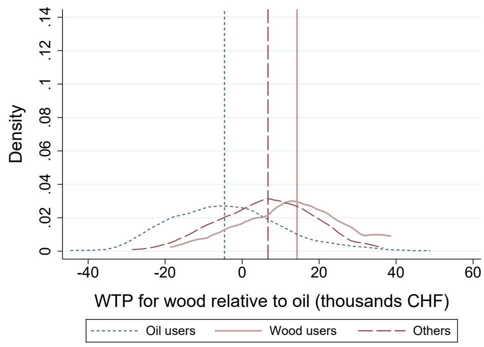

(a) Energy label A



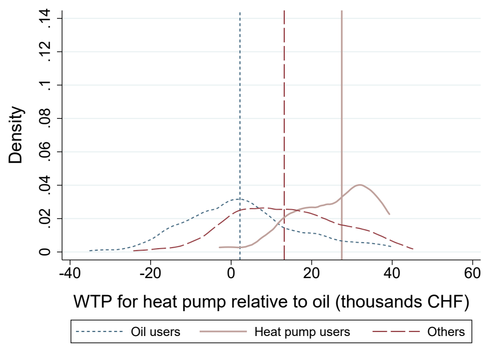

(b) Energy label $A^+$




(c) Natural gas




(d) Wood pellets




(e) Heat pump

*Notes:* Each kernel density estimate uses Epanechnikov kernel function with an optimal bandwidth. The vertical lines represent the corresponding estimates for the median.

# K Experimental script (Chapter III)

Figure K1: Introductory screen 1

*tmpl_i1*. In this part of the survey, we now 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 rent 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.

Figure K2: Introductory screen 2

*tmpl_i2.* For the next set of questions, please imagine that your landlord plans to replace your building's current heating system. Note that this choice could influence your rent, and we will imagine different scenarios about such a choice and seek to understand which alternative would be best for your household.

We will consider a choice between two alternative replacement options, and these options are described by 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:

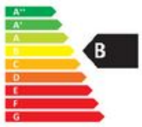

Imagine that your landlord may choose a standard heating appliance, graded B, or alternatively a more energy efficient option, graded A+. Selecting the appliance graded B is considered standard maintenance, so as a tenant your rents would not change. However, if your landlord decides to install a more costly and highly energy efficient (A+) appliance, she/he may ask for an increase in rents to cover some of the additional costs.

Figure K3: Introductory screen 3

*tmpl_i3*. Here is an example of the choice we want you to consider. Each offer (I and II) describes an alternative central heating appliance that would fully replace your current one. Offer I has an energy efficiency label "B", and therefore this offer has no impact on the monthly rent you pay. Offer II is graded "A+", and this could mean that your rent would increase by a particular amount Fr. xx to cover the higher investment costs.

OFFER I:

**STANDARD HEATING SYSTEM**

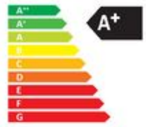



**NO change in rents**

SELECT I

OFFER II:

**ENERGY EFFICIENT HEATING SYSTEM**




**Fr. xx increase in monthly rents**

SELECT II

Besides the different energy efficiency grades, these two appliances are exactly similar. 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 be changed.

Figure K4: Instructions for baseline MPL choice task

*tmpl_bc_i*. You will now be asked to make a number of decisions such as the example displayed before. All decisions have the same format. In making your choices, please remember that any money spent on your dwelling will not be available for other expenses by your household.

There is no right or wrong answer. It is important that your choices reflect your preferred situation, as this research will contribute to inform energy policy in Switzerland.

Figure K5: First baseline MPL choice task

*tmpl_bc1*. Please make your choice below.

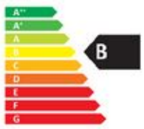
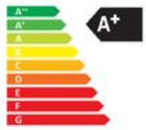
| OFFER I: | OFFER II: |
|---|---|
| **STANDARD HEATING SYSTEM** | **ENERGY EFFICIENT HEATING SYSTEM** |
|  |  |
| **NO change in rents** | **NO change in rents** |
| SELECT I | SELECT II |
| ○ | ○ |

Figure K6: Instructions for information screens ($T_{iA}$)

*tmpl_ta1*. For the next part of the study, you will have the opportunity to learn more about Swiss residential buildings and energy. We will show you information about:

- The construction year of residential buildings
- Heating technologies and energy sources

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

Figure K7: Instructions for information screens ($T_{iB}$ and $T_{iC}$)

*tmpl_tb1*. For the next part of the study, you will have the opportunity to learn more about Swiss residential buildings and energy. We will show you information about:

- Energy efficiency and heating costs
- The construction year of residential buildings

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

Figure K8: Instructions for information screens ($T_{iD}$)

*tmpl_td1.* For the next part of the study, you will have the opportunity to learn more about Swiss residential buildings and energy. We will show you information about:

- Energy efficiency and heating costs
- How heating costs can vary from year to year

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

Figure K9: Instructions for information screens ($T_{iE}$, $T_{iF}$ and $T_{iG}$)

*tmpl_tg1.* For the next part of the study, you will have the opportunity to learn more about Swiss residential buildings and energy. We will show you information about:

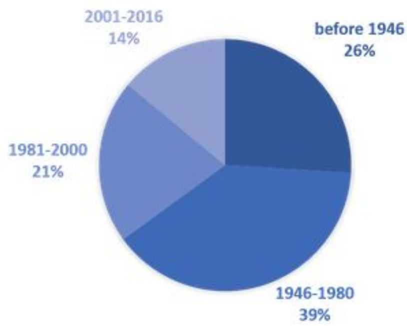
- Energy efficiency and heating costs
- The $CO_2$ tax on heating oil and natural gas

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

Figure K10: Information screen - Neutral I ($T_{iA}$, $T_{iB}$ and $T_{iC}$)

*tmpl_ta2*. 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.

---

*tmpl_ta3*. How many % of Swiss apartments were built between 2001 and 2016?

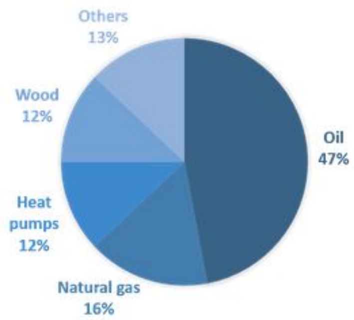
*To answer this question, you can only enter integers between 0 and 100. Type your answer below:*

[ ] %

Figure K11: Information screen - Neutral II ($T_{iA}$)

*tmpl_ta4.* Swiss households use a variety of different heating technologies and energy sources to enjoy temperate dwellings and warm water. Official records show that heating oil is the most prevalent source of energy to produce residential heat (47%), followed by natural gas (16%).

**HEATING SYSTEMS AND ENERGY SOURCES IN SWISS RESIDENTIAL BUILDINGS**




Compared to 2009, there has been a 5% decline in the use of oil-based heating, and a 4% increase in the number of heat pumps installed.

---

*tmpl_ta5.* How many % of Swiss residential buildings are heated with natural gas today?

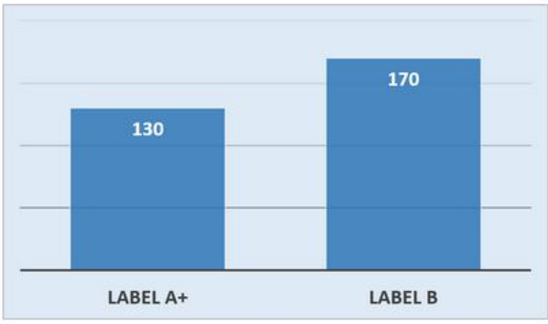
*To answer this question, you can only enter integers between 0 and 100. Type your answer below:*

[ ] %

Figure K12: Information screen - Heating costs ($T_{iB}$-$T_{iG}$)

*tmpl_te2.* 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. 170 per month with an appliance graded B could decline to Fr. 130 per month with an A+ appliance.

**HEATING COST IN SWISS FRANCS PER MONTH**




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.

---

*tmpl_te3.* Typically, if heating expenditures with an appliance graded A+ amount to Fr. 130 per month, how much would heating cost be with an appliance graded B?

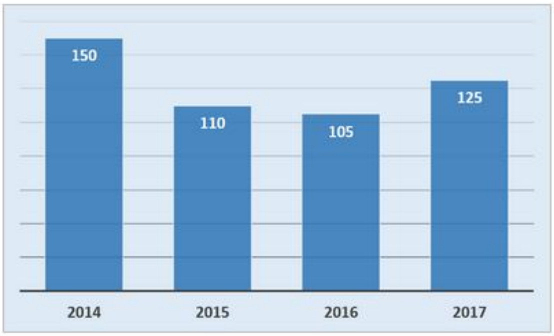
*To answer this question, you can only enter integers. Type your answer below:*

Fr.

Figure K13: Information screen - Heating cost variability ($T_{iD}$)

*tmpl_td4*. Heating costs depend in great part on the cost of fuel. Yearly energy costs for a boiler operated with heating oil, for instance, vary from year to year with the price of oil: while average monthly heating costs were at Fr. 150 per household in 2014, they only amounted to Fr. 105 per household in 2016.

HEATING COST IN SWISS FRANCS PER MONTH




Therefore, because of varying energy prices, heating costs of households who select an energy efficient heating system may not necessarily decline as much as expected.

---

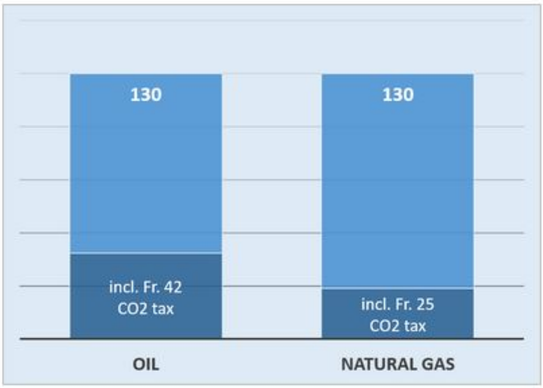
*tmpl_td5*. Does the purchase of energy efficient heating appliances always result in lower heating costs?

- ○ Yes
- ○ No

Figure K14: Information screen - $CO_2$ tax ($T_{iE}$, $T_{iF}$ and $T_{iG}$)

*tmpl_te4*. Switzerland participates in international efforts to reduce the risk of climate change, and the government has enacted laws that require a reduction in $CO_2$ emissions by 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 MONTH




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. 42 for a monthly heating bill of Fr. 130, while the tax on natural gas amounts to Fr. 25 for a monthly heating bill of Fr. 130. For other fuels, including wood and electricity, the $CO_2$ tax is nil.

---

*tmpl_te5*. If your heating system is operating on heating oil and your monthly heating bill amounts to CHF 130, how high is the associated $CO_2$ tax payment?

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

[ ] Fr.

Figure K15: Introductory screen 4 - Endline MPL

*tmpl_ta_ec_i1*. Now please consider again the possibility that the current primary heating appliance of your dwelling needs replacement. Imagine once again that your landlord may choose a standard heating appliance, graded B, or alternatively a more energy efficient option, graded A+.

Figure K16: Instructions for endline MPL with rent increase (i.e. $T_{iA}$, $T_{iB}$ and $T_{iE}$)

*tmpl_tb_ec_i2.* You will now be asked to make further choices between pairs of offers. Here is an example of the choice we want you to consider:

OFFER I:

**STANDARD HEATING SYSTEM**


**NO change in rents**

SELECT I

OFFER II:

**ENERGY EFFICIENT HEATING SYSTEM**


**Fr. xx increase in monthly rents**

SELECT II

Besides the the attributes described, these two appliances are again exactly similar and the change of appliance will again take place in 2017. All decisions have the same format.

Please consider your choices carefully, and remember that expenses for your dwelling will not be available for other things. It is important that your choices reflect your preferred situation, as this research will contribute to inform energy policy in Switzerland. The only right answer is what you would choose in reality.

Figure K17: Instructions for endline MPL with heating costs ($T_{iC}$ and $T_{iD}$)

*tmpl_tc_ec_i2*. You will now be asked to make further choices between pairs of offers. In addition, for each offer we now report approximate total heating and warm water cost for an average Swiss household:

OFFER I:

**STANDARD HEATING SYSTEM**


**NO change in rents**

**Fr. 170 monthly heating costs**

SELECT I

OFFER II:

**ENERGY EFFICIENT HEATING SYSTEM**


**Fr. xx increase in monthly rents**

**Fr. 130 monthly heating costs**

SELECT II

Besides the the attributes described, these two appliances are again exactly similar and the change of appliance will again take place in 2017. All decisions have the same format.

Please consider your choices carefully, and remember that expenses for your dwelling will not be available for other things. It is important that your choices reflect your preferred situation, as this research will contribute to inform energy policy in Switzerland. The only right answer is what you would choose in reality.

Figure K18: Instructions for endline MPL with heating costs and $CO_2$ tax, $A^+$ lower tax ($T_{iF}$)

*tmpl_tf_ec_i2.* You will now be asked to make further choices between pairs of offers. In addition, for each offer we now report approximate total heating and warm water cost, as well as the associated $CO_2$ tax for an average Swiss household:

| OFFER I: | OFFER II: |
|---|---|
| **STANDARD HEATING SYSTEM** | **ENERGY EFFICIENT HEATING SYSTEM** |
|   |   |
| **NO change in rents** | **Fr. xx increase in monthly rents** |
| **Fr. 170 monthly heating costs** | **Fr. 130 monthly heating costs** |
| **(incl. Fr. 55 $CO_2$ tax)** | **(incl. Fr. 42 $CO_2$ tax)** |
| SELECT I | SELECT II |

Besides the the attributes described, these two appliances are again exactly similar and the change of appliance will again take place in 2017. All decisions have the same format.

Please consider your choices carefully, and remember that expenses for your dwelling will not be available for other things. It is important that your choices reflect your preferred situation, as this research will contribute to inform energy policy in Switzerland. The only right answer is what you would choose in reality.

Figure K19: Instructions for endline MPL with heating cost and $CO_2$ tax, $A^+$ no tax ($T_{iG}$)

*tmpl_tg_ec_i2*. You will now be asked to make further choices between pairs of offers. In addition, for each offer we now report approximate total heating and warm water cost, as well as the associated $CO_2$ tax for an average Swiss household:

| OFFER I: | OFFER II: |
|---|---|
| **STANDARD HEATING SYSTEM** | **ENERGY EFFICIENT HEATING SYSTEM** |
|  |  |
| **NO change in rents** | **Fr. xx increase in monthly rents** |
| **Fr. 170 monthly heating costs** | **Fr. 130 monthly heating costs** |
| **(incl. Fr. 55 $CO_2$ tax)** | **(no $CO_2$ tax)** |
| SELECT I | SELECT II |

Besides the the attributes described, these two appliances are again exactly similar and the change of appliance will again take place in 2017. All decisions have the same format.

Please consider your choices carefully, and remember that expenses for your dwelling will not be available for other things. It is important that your choices reflect your preferred situation, as this research will contribute to inform energy policy in Switzerland. The only right answer is what you would choose in reality.

Figure K20: First endline MPL choice task - Heating cost ($T_{iC}$ and $T_{iD}$)

*tmpl_tc_ec1*. Please make your choice below.

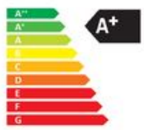
| OFFER I: | OFFER II: |
|---|---|
| **STANDARD HEATING SYSTEM** | **ENERGY EFFICIENT HEATING SYSTEM** |
|  |  |
| **NO change in rents** | **NO change in rents** |
| **Fr. 170 monthly heating costs** | **Fr. 130 monthly heating costs** |
| SELECT I | SELECT II |
| ○ | ○ |

Figure K21: First endline MPL choice task - Heating cost and $CO_2$ tax ($A^+$ lower tax, $T_{iF}$)

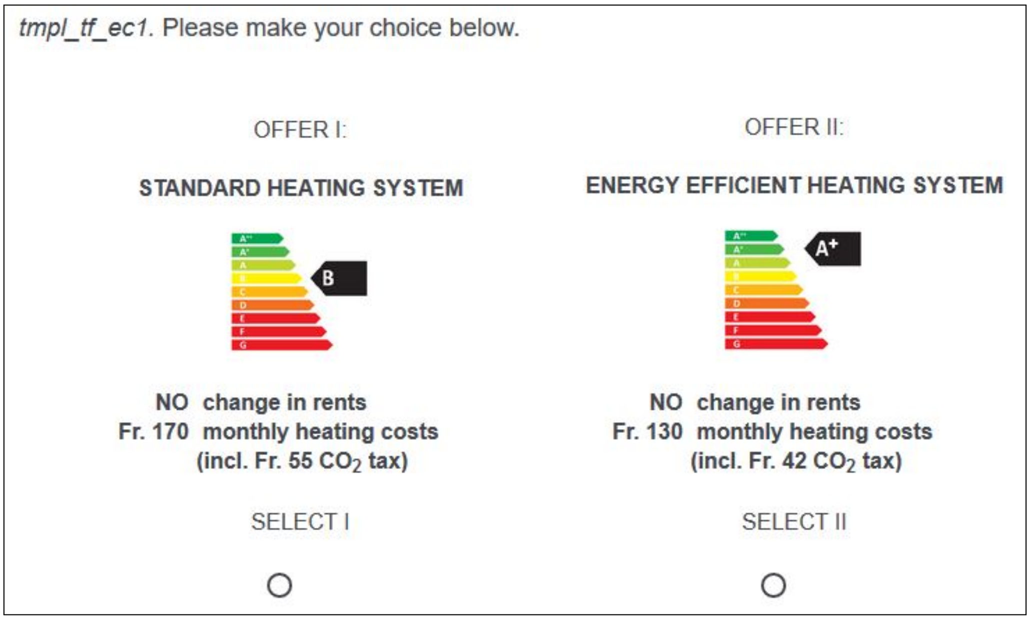
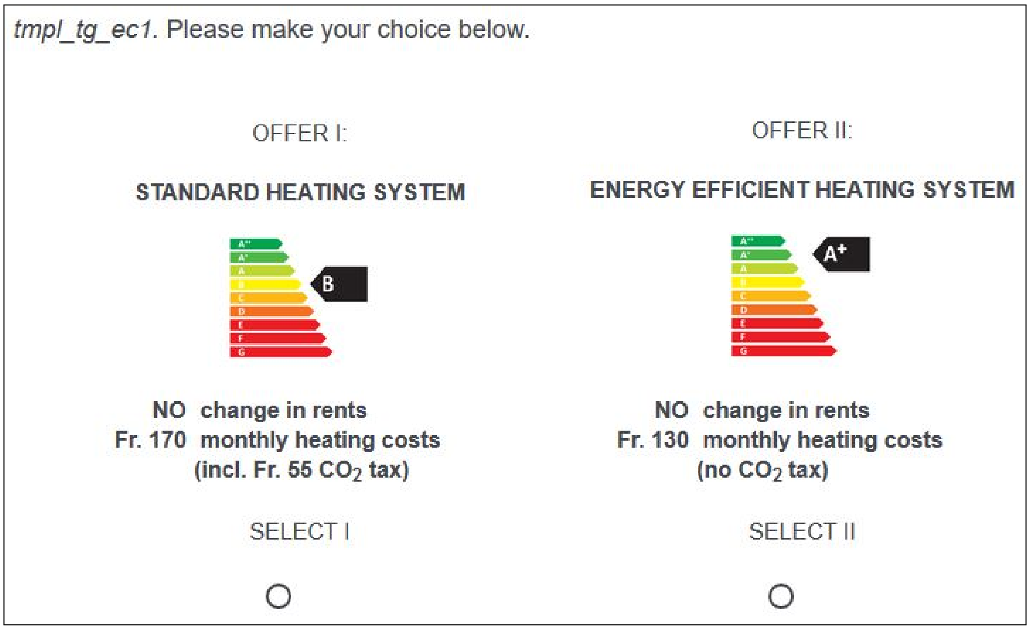



Figure K22: First endline MPL choice task - Heating cost and $CO_2$ tax ($A^+$ no tax, $T_{iG}$)



# L Sample composition (Chapter III)

Table L1: Summary statistics for the sample of tenants

| | N | Mean | Std.-dev. | Min | Max |
|---|---|---|---|---|---|
| Female indicator | 406 | 0.53 | 0.50 | 0 | 1 |
| Age (in years) | 406 | 43.38 | 15.01 | 20 | 85 |
| University indicator | 406 | 0.47 | 0.50 | 0 | 1 |
| Household income[a] | 340 | 3.74 | 1.41 | 1 | 6 |
| Dwelling size (in $m^2$) | 406 | 92.00 | 45.16 | 2 | 500 |
| Multifamily house indicator | 406 | 0.84 | 0.37 | 0 | 1 |
| Oil heating indicator | 406 | 0.37 | 0.48 | 0 | 1 |
| Individual meter for heating | 406 | 0.40 | 0.49 | 0 | 1 |
| Annual heating costs (in CHF)[b] | 124 | 1174.62 | 888.69 | 20 | 4692 |

*Notes*: [a]Monthly gross household income is coded as: 1 – CHF 3,000 or less; 2 – CHF 3,000-4,459; 3 – CHF 4,500-5,999; 4 – CHF 6,000-8,999; 5 – CHF 9,000-12,000; 6 – CHF 12,000 or more. [b]Annual household expenditures for heating, as per the latest energy bill available.

Table L2: Treatment randomization and observable characteristics

| Treatment condition | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Baseline WTP ($u_i^0$)[a] | 31.55 | 38.33 | 42.37 | 36.23 | 38.42 | 38.89 | 36.98 |
| Female indicator | 0.50 | 0.41 | 0.51 | 0.51 | 0.60 | 0.65 | 0.55 |
| Age (in years) | 43.76 | 42.79 | 43.42 | 44.57 | 44.39 | 43.62 | 41.14 |
| University indicator | 0.48 | 0.56 | 0.51 | 0.44 | 0.49 | 0.42 | 0.38 |
| Household income[b] | 3.48 | 3.63 | 3.92 | 4.08 | 3.85 | 3.70 | 3.50 |
| Dwelling size (in $m^2$) | 81.71 | 89.90 | 88.79 | 96.54 | 96.91 | 96.19 | 94.36 |
| Multifamily house indicator | 0.90 | 0.83 | 0.91 | 0.77 | 0.88 | 0.87 | 0.74 |
| Oil heating indicator | 0.34 | 0.38 | 0.33 | 0.44 | 0.33 | 0.44 | 0.33 |
| Individual meter for heating | 0.38 | 0.38 | 0.37 | 0.39 | 0.42 | 0.37 | 0.48 |
| Observations | 58 | 63 | 57 | 61 | 57 | 52 | 58 |

*Notes*: [a]Acceptable rent increases as measured in the MPL *before* treatment, in CHF per month. [b]Monthly gross household income is coded as: 1 – CHF 3,000 or less; 2 – CHF 3,000-4,459; 3 – CHF 4,500-5,999; 4 – CHF 6,000-8,999; 5 – CHF 9,000-12,000; 6 – CHF 12,000 or more.

# M Additional regression results (Chapter III)

Table M1: Regressions with control variables and interaction terms

| | (1) Endline WTP $u_i^1$ | (2) Endline WTP (Control set a) | (3) Endline WTP (Control set b) | (4) Endline WTP (Interactions) |
|---|---|---|---|---|
| Heating cost screen | 1.19 | 1.35 | 1.04 | 2.11 |
| | (5.02) | (5.00) | (5.02) | (5.18) |
| Cost MPL task | 16.89** | 15.61** | 15.53** | 33.86** |
| | (6.66) | (6.62) | (6.72) | (13.69) |
| Cost variability screen | -6.96 | -5.84 | -5.65 | -5.68 |
| | (6.76) | (6.61) | (6.74) | (6.85) |
| $CO_2$ tax screen | -1.08 | -1.79 | -1.36 | -3.59 |
| | (5.25) | (5.23) | (5.24) | (5.36) |
| $CO_2$ tax MPL task | -1.35 | -1.27 | -0.95 | 0.39 |
| | (8.19) | (8.17) | (8.30) | (8.52) |
| Baseline WTP ($u_i^0$) | 0.75*** | 0.75*** | 0.75*** | 0.72*** |
| | (0.06) | (0.05) | (0.05) | (0.06) |
| Female indicator | – | 6.59** | 6.93** | 4.71 |
| | | (3.27) | (3.27) | (3.96) |
| Age (in years)[a] | – | -0.19 | -0.19 | 0.04 |
| | | (0.12) | (0.12) | (0.15) |
| University indicator | – | 4.69 | 4.25 | 10.53** |
| | | (3.15) | (3.10) | (4.26) |
| High income indicator[b] | – | – | -0.06 | 13.89** |
| | | | (0.05) | (6.65) |
| Dwelling size (in $m^2$)[a] | – | – | – | 0.05 |
| | | | | (0.04) |
| Multifamily house indicator | – | – | – | 1.13 |
| | | | | (5.07) |
| Cost MPL task X Female indicator | – | – | – | 2.90 |
| | | | | (6.30) |
| Cost MPL task X Age (in years)[a] | – | – | – | -0.32 |
| | | | | (0.22) |
| Cost MPL task X University indicator | – | – | – | -11.13* |
| | | | | (6.30) |
| Cost MPL task X High income indicator[b] | – | – | – | -8.18 |
| | | | | (9.17) |
| Cost MPL task X Dwelling size (in $m^2$)[a] | – | – | – | -0.09 |
| | | | | (0.06) |
| Cost MPL task X Multifamily house indicator | – | – | – | -5.67 |
| | | | | (9.36) |
| Constant | 15.14*** | 11.93*** | 12.90*** | 1.41 |
| | (3.41) | (4.38) | (4.23) | (6.34) |
| Observations | 406 | 403 | 403 | 403 |
| Adjusted $R^2$ | 0.50 | 0.51 | 0.51 | 0.52 |

*Notes*: [a]Normalized to mean zero for ease of interpretation. [b]Monthly gross household income of CHF 9,000 or more (above sample median). Robust standard errors are reported in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% respectively.

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