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MULTIPLE DISCRETE-CONTINUOUS CHOICE MODEL OF HOUSEHOLD ENERGY REDUCTION ACROSS MULTIPLE SECTORS USING PRIORITY EVALUATOR DATA

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ABSTRACT

This paper presents a multiple discrete-continuous extreme value model (MDCEV) of energy savings. The model predicts household decisions where to reduce CO_2 emissions if they were forced to do so. The model's approach is to include all sectors of energy consumption such as private transport, housing, meat consumption and air travel. The hypothesis is that if households view all energy consumption as part of one overall budget, trade-offs between energy sectors are possible and can be modeled. The data base for the model was established with a survey among Swiss homeowners who have at least one car. In the survey the Priority Evaluator method was implemented in a web application with which the participants interactively reduced their CO_2 output to a predefined goal. The MDCEV chooses multiple alternatives a household considers to reduce CO_2 output and allocates the percentage of the overall reduction of to the chosen alternative. Estimation results show that installing new heating systems are preferred over refurbishment of roof and façade, an effect that is even greater for higher income levels. Females and higher income households are more likely to buy a more efficient car. Households living in municipalities with better public transport accessibility are more likely to reduce annual mileage traveled. The paper also includes an assessment of the model performance analyzing the residuals. The conclusion of the paper is that the hypothesis of one overall energy budget could not be supported.

INTRODUCTION

Context

In the last two decades, governments and international organizations have been actively committed to reduce the concentration of greenhouse gases (GHG). GHG are composed of ozone, carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O) and water vapor, gases which exist naturally in order to maintain a global temperature suitable for living. However, the concentrations of these gases have increased beyond natural amounts due to human activity. For example, carbon dioxide is created by burning fossil fuels and waste and methane is released into the atmosphere through the production of coal and natural gas *(1)*. In particular, fluorinated gases, which are anthropogenic gases created through industrial processes, have a high global warming potential and can sometimes stay in the atmosphere for thousands of years. As a consequence, human activity is recognized as the leading contributor to climate change *(2)*. Climate change is caused by GHG trapping the heat of the Earth in the atmosphere. As a result of heat trapping, the Earth's surface temperature increases. According to Hansen *et al. (3)*, the global surface temperatures for 2010 tied with 2005 for the warmest year on record; this record reflects the continuing upward trend of increasing temperatures: since 1880, the average global temperature has increased 1.5°F.

The effects of climate change are diverse, and can be classified in environmental, economic and health effects. Environmental effects of climate change include increase in the global mean sea level, extensive melting of glaciers and snow, increase in heat waves, and changes in species' migration patterns *(2)*. Economic effects are associated with food and forestry production *(4)*, tourism *(5)* and transportation infrastructure needs *(6)*. Finally, health effects include changes to the quality of air, water and shelter, and spread of diseases *(7)*. These last consequences of climate change have a particular significance in developing countries, which are more at risk because of their lack of health care.

A reduction of such GHG as CH_4 (e.g. from cattle), N_2O (e.g. from fertilizer) and fluorinated gases (industrial processes) needs to be achieved by industrial and agricultural regularization and policy measures. However, these GHG make up only 17% *(1)* of total worldwide output, in Switzerland even less: 15.3% *(8)*. The majority of GHG worldwide is CO_2, which itself is emitted while burning fossil fuels (77%) or due to the reduction of biomass (23%, e.g. deforestation). In Switzerland, CO_2 emissions are almost entirely due to energy generation by fossil fuel, either for direct energy use like heating or industrial process heat (50.7%), airborne transportation (9.6%) or private transportation (39.7%) *(9)*.

Public transportation in Switzerland consists of a fully electrified rail and tram system and can be neglected in CO_2 consideration because electricity is either hydro power or nuclear power and considered officially as almost CO_2 neutral. As most Swiss houses have either oil or a natural gas furnace as a heating system, 50% of CO_2 from direct energy use is due to residential housing. That means that GHG emissions which are directly caused by the consumer consist mainly of heating, private transport by car and air traffic. Each of these sectors can be addressed by technological or policy measures separately because they show a huge potential for efficiency. However, assuming the consumer is aware of the threat of GHG and wants to reduce the overall CO_2 output of the household, he has a choice set that covers all three sectors. The purpose of this study is to model the trade-offs between sectors in the event of enforced CO_2 emission reduction, imaginable with either a heavy environmental taxation or a CO_2 cap for households. Such drastic measures might seem unrealistic today, but to maintain international commitment on GHG reduction in the coming decades, they will potentially be necessary. In Switzerland several studies about energy efficiency were conducted in the past years.

Literature

Banfi *et al.* *(10)* estimated the willingness to pay for different refurbishment measures using stated choice experiments for home owners as well as apartment tenants. The study showed a significant willingness to pay (WTP). In a similar survey by Achtnicht *(11)* home owners were asked to choose between insulation or a modern heating system in a series of stated choice experiments. Younger respondents showed higher preferences towards alternative heating instead of insulation. A similar preference of heating replacement over insulation (façade and roof) in Germany was found by Grösche and Vance *(12)*. A survey among 509 Korean households conducted by Kwak *et al.* *(13)* showed significant WTP for energy efficiency measures in the case of a new purchase of a house. An early study about acceptance of alternative-fuel vehicles was done by *(14)* and found that younger and high income participants are the most concerned about energy efficiency and in the case of equal performance alternative-fuel vehicles are generally preferred over gasoline cars. Similar results come from Germany where Achtnicht *(15)* found that emissions have a negative influence on car choice in general and particularly for younger and female individuals. Müller and de Haan *(16)* established a sophisticated consumer choice model to asses how incentives on more efficient cars affect car purchase. With this model, de Haan *et al.* *(17)* state abatement costs through incentives to be between 6 and 13 EUR per ton CO_2.

These previous studies neglected a trade off or a relationship between energy consumption of both sectors, housing and private transport. Our study does not aim at estimating WTP for different energy efficiency measures, but to find out how an overall energy consumption approach in behavioral modeling could look like. The goal was to survey and model that includes all possible alternatives of reducing energy consumption a household has, including all sectors. Such a model can give information about if and how households view their energy consumption: as one combined budget for energy or separate independent budget for each sector. If a combined budget is the reality, more flexible and specific policy measures can be thought of for different regions, purposes or economies. Such an overall approach that explicitly focuses on trade-offs between sectors has not been reported in the literature so far. The rest of the paper is structured as follows. The next section presents the survey characteristics. The following sections presents the model structure and estimation procedure, illustrate the application of the proposed model for analyzing CO_2 reductions at the household level and show the estimation results and a residual analysis. The final section offers concluding thoughts and directions for further research.

SURVEY CHARACTERISTICS

Survey Design

The data source used for this analysis is a survey of energy efficiency in housing and transportation, conducted in the canton of Zurich, Switzerland in year 2010 *(18)*. The main objective of this survey is to compare household preference on energy savings between housing and transport. For this purpose, a constraint experiment was designed in the form of a Priority Evaluator (PE) method. The PE method is based on the simulation of choices in a market place, where respondents are allocated a hypothetical budget and are offered a set of items they could consume, each with a hypothetical price. The key advantage of constrained experiments as the PE method is that they introduce an element of feasibility where, given the budget constraint and prices, the choice of any option requires a trade-off. The method was pioneered by Hoinville *(19)* who used it to value travel time, road safety, vehicle pollution and vehicle congestion in London. Recent applications of the PE method include automotive fuel economy *(20)*, valuations of aircraft noise *(21)* and estimations of benefits of biodiversity protection *(22)*.

To accomplish the objective of this survey, the use of the PE method is inverted: in the survey, households are forced to reduce their CO_2 emissions to meet a target. Therefore, individuals must fill a giving budget by choosing negative quantities, instead of using the available budget to consume positive quantities. To accomplish the objective of the survey, households were eligible if they fulfil the following requirements: 1) households must live in a single-family house and own the house where they live in, 2) they must have at least one car, and 3) the household must be able to make decisions about house refurbishment and bear the potential costs of these refurbishments. Households fulfilling the previous conditions were randomly selected in the canton of Zurich, and were asked to provide data about energy consumption, socioeconomic background, house characteristics and car information. Then, energy consumption was converted in CO_2 output, assuming that it is easier to allocate CO_2 reductions instead of energy reductions, which is more abstract than CO_2 emissions. Based on this information, the PE was designed for each household, allowing personalized alternatives based on their CO_2 output; the CO_2 target is 50% of their current output (excluding the emission embedded in consumer goods, which is on average 4.5 tons of CO_2 per year per person). Finally, each household filled the PE on an Internet application. The rate of response was 56.2%, showing the high interest among householders on the survey. The PE included 12 alternatives among which households could reduce their CO_2 emissions to reach the target. These alternatives are associated with changes in lifestyle or house refurbishment, and some of them have an associated implementation cost (lump sum) or running costs (or savings, depending on the case). When completing the PE, households were asked to consider the costs shown in the PE as if they were real costs and thus are assumed to remain within their monetary budget, based on the cost of each alternative, and only available alternatives were presented.

Table 1 presents the 12 alternatives. The first six alternatives are related to house refurbishment, all of them associated with a reduction of the energy needed for heating the house.[1] The implementation costs vary across alternatives, while the running costs are all the same, and equal to 300 CHF per year. The next six alternatives correspond to changes in lifestyle. We differentiate these alternatives between transportation and non-transportation related. Alternative 7, buy new/more efficient car, entails replacing or acquiring more efficient car models (the

[1] Survey designers were particularly interested in alternative 6, install a heat pump. Heat pumps use renewable energy sources found in the environment such as thermal energy from the air, water, and ground to heat and cool homes. Heat pumps reduce CO_2 emissions because they move heat rather than generate it.

experiment did not specified the car technology)[2]. When respondents have more than one car, options for each vehicle are provided separately. Alternative 8 is reducing the traveled distance, which includes preferring transit, car-pooling, driving less, or abstaining from taking trips. Alternative 9 corresponds to reduce the number of air trips, which means reducing the frequency of flying or canceling flights. Air trips were distinguished between short (less than 1000 Km), middle (less than 5000 Km) and long (more than 5000 Km) distance; household could chose to reduce air trips between these options, which were only available in the quantity that the respondents previously stated. Reduce house temperature is alternative 10, and households can choose to reduce between 1 and 5 Celsius degrees their home temperature. Alternative 11 is buying a CO_2 certificate. These emission certificates allow for the emission of one ton of CO_2 each. The last alternative is to reduce meat consumption. The CO_2 reduction depends on the percentage reduced from current consumption (0%, 25%, 50%, 75% and 100%). Although the task is clearly hypothetical, the survey can be understood as a middle point in between stated and revealed preferences, given that every household only does one experiment and this experiment is as realistic and personalized as possible in regard to costs and CO_2 reduction. There is no variance in costs or efficiency of the measures and the same realistic configurations have been applied to all participants. None of the participants actually faced this kind of task as a whole but were perhaps familiar with the separate options and their consequences.

Sample Characteristics

In the canton of Zurich, 112,644 households live in single-family homes. Out of these households a sample of 491 households were recruited by telephone. The first part of the survey consisting of a paper and pen questionnaire for the socioeconomic, house and car information was completed by 333 respondents who were provided with the PE internet application. Out of that, 197 household completed all parts in a reasonable manner, including the PE and all necessary financial questions. This gives a final completion rate for the PE of 40%. Socioeconomic characteristics are shown in Table 1 . The Head of Household is the person who filled in the questionnaire and is assumed to be the same person that also did the PE experiment. The sample shows high shares of older respondents. Although shares of higher age groups are relatively big among home owners because it is relatively expensive to own a house in Switzerland, the sample over (under) represents persons that are older than 65 (younger than 46) years old by about 12%. The share of 46 to 65 years matches the national and cantonal share quite well. Most of the decision makers in the household are male although the distribution over all household members is equal. Driver license ownership and car availability are high due to the selection bias. The distribution of heating systems and drive-trains match the national statistics well. Also the average vehicle miles traveled per car is very close to the national average of about 12,000 km/year. In our view the most important characteristic of the household is the income and assets level. The monthly gross household income was asked using eight classes. To derive the assets level for a household we asked for the value of assets that are liquefiable within one year offering seven classes. We believe that this represents best the budget constraint a home owner faces when considering a major refurbishment of his home. In the case of investing in a house an increase of the mortgage is a common option. For this reason we also asked for the insurance value of the house (housing insurance is mandatory in Switzerland) and the mortgage. We are aware of the fact that the value of a property is mainly driven by land prices rather than the house itself, but is still the best proxy given that determining real estate prices is impossible

[2]If households decide to sell their cars, the CO_2 output does not change, as it is assumed that annual distance driven are made through car sharing

in the current economic situation in Zurich (real estate boom). Table 2 shows the distribution of income and wealth of the sample. The numbers show that a large part of the homeowners participating in the survey have adequate assets for refurbishment or would be able to further increase the mortgage, given that property values are greater than house values in most parts of the canton. As an explanatory variable for the model, the accessibility of the home location municipality was taken from Fröhlich *et al. (23)* where it is defined as:

$$A_i = \ln\left(\sum_{j=1} x_j \cdot e^{-\beta c_{ij}}\right) \tag{1}$$

where x_j is the number of activity points, such as workplaces, shops, leisure activity facilities, schools, etc., in zone j, c_{ij} are the generalized costs between zones i and j, and $\beta = 0.2$ is the parameter associate to the generalized costs.

METHODOLOGY

Behavioral Framework

To understand the choices and preferences regarding CO_2 reduction within a restricted budget, the household is the basic decision-making unit where these decisions can be explicitly observed. The choice made by each household consists of a discrete and a continuous component. The discrete component relates to the alternatives selected to reduce either heating costs or variable mobility costs, whereas the continuous component relates to the amount of CO_2 the households choose to reduce. Further, given the nature of the survey, households can choose one or more alternatives. The MDCEV relies on satiation as a force to explain multiple-discreteness, where satiation refers to diminishing marginal utility as the level of consumption of any particular alternative increases. In our application, satiation plays a strong role on the choice process, because households face increasing marginal costs and marginal utility losses when reducing CO_2 output. The first 1,000 km a household chooses not to drive are much easier to endure, compared to having reduced vehicle miles traveled (VMT) already by 50% and still considering a reduction. The model structure used in the research effort is based on the MDCEV approach *(24)*, based on the traditional random utility maximizing theory of consumer behavior. The MDCEV, being a discrete-continuous model, enables the seamless integration of the discrete and continuous components, besides capturing multiple discreteness. Additionally, this model provides an elegant closed probability form and a clear interpretation of the estimated parameters. This approach is superior to mutinomial models as it enables exploiting quantity information for inference (the continuous component), and facilitates policy analysis by being based on a utility function. The model is also superior to approaches that treat each alternative-quantity combination as a choice alternative, as does not introduce new random utility errors terms into consumer preferences for each potential combination.

Model Specification

The MDCEV model *(24)* is based on the utility maximization theory, assuming that each household tries to maximize their utility, which is a measure of satisfaction, by selecting various quantities of CO_2 reduction among the available alternatives. The utility function U for each household is:

$$U(x) = \sum_{k=1}^{K} \frac{\gamma_k}{\alpha_k} \psi_k \left(\left(\frac{x_k}{\gamma_k} + 1 \right)^{\alpha_k} - 1 \right) \tag{2}$$

where x ≥ 0 is the amount of CO_2 reduced associated with alternative k (vector of dimension $(Kx1)$), measured in tons per year, α_k and γ_k are parameters and ψ_k is the baseline utility associated with alternative k. The utility function belongs to the family of translated utility functions. α_k is the satiation parameter, reducing the marginal utility with increasing CO_2 reduction of alternative k. The utility function in equation (1) is valid for $\alpha \leq 1$: the limit case when $\alpha = 1$ for all alternatives represents absence of satiation effects, and when α moves downward from the value of 1, the satiation effect for alternative k increases ($\alpha \to -\infty$ represents the case of immediate full-satiation). The primary role of the γ_k, called location parameter, is to allow for corner solutions (i.e., zero CO_2 reduction for some alternatives) and it is also related with satiation effects. The location parameter is defined $\gamma_k \geq 0$, such that when its value increases, there is a stronger preference (or lower satiation) for alternative k. Finally, ψ_k is named baseline utility function, and it represents the marginal utility of one ton of CO_2 reduction of alternative k at the point of zero consumption for the alternative. To guarantee the positivity of the baseline utility, we parameterize $\psi(z_k, \epsilon_k) = \exp(\beta' z_k + \epsilon_k)$, where z_k is a set of attributes that characterize alternative k and the households (including a constant), β is a vector of parameters influencing baseline utility, and ϵ_k captures the idiosyncratic (unobserved) characteristics that impact the baseline utility of good k.

The utility function is maximized by each household, subject to the reduction target imposed by the survey design, $\sum_{k=1}^{K} \mathrm{x}_k = CO_2^{target}$. To find the optimal CO_2 reduction allocation x_k^*, we construct the Lagrangian assuming that alternative 1 is always chosen [3], and derive the Khun-Tucker (KT) conditions presented in equation (2) (see Bhat *(24)*).

$$\begin{aligned} V_k + \epsilon_k &= V_1 + \epsilon_1, if x_k^* > 0, k = 2, 3, ..., K \\ V_k + \epsilon_k &< V_1 + \epsilon_1, if x_k^* = 0, k = 2, 3, ..., K \end{aligned} \tag{3}$$

where $V_k = \beta' z - k + (\alpha - 1)\ln\left(\frac{x_k^*}{\gamma_k} + 1\right)$. These stochastic KT conditions can be used to write the joint probability expression of consumption patterns if the density function of the stochastic terms is known. Following Bhat *(24)*, we assume that the error terms are assumed to follow an independent and identically distributed (iid) and standard Gumbel distribution. The probability that the household choose M of the K alternatives is given by an elegant and compact closed form structure:

$$P(x_2^*, x_3^*, ..., x_M^*, 0, 0, ..., 0) = \left[\prod_{i=1}^{M} c_i\right]\left[\prod_{i=1}^{M} \frac{1}{c_j}\right]\left[\frac{\prod_{i=1}^{M} e^{V_i}}{(\sum_{j=1}^{K} e^{V_i})^M}\right](M-1)! \tag{4}$$

where $c_i = \frac{1-\alpha_i}{x_i^* + \gamma_i}$. In the case when $M = 1$ for a particular household, the model in equation (3) collapses to the standard multinomial logit structure. The model can be estimated using standard maximum likelihood procedures.

[3] Alternative 1 is selected without loss of generality; this alternative is used as the based to compare with the other alternatives (similar to introducing a constant in the utility function), and it has no effect on the estimates

ESTIMATION RESULTS

This section presents detailed description of the model estimation results. A variety of explanatory variables were considered in the model specification including head of the household and household socio-demographics, house characteristics, accessibility of the house and alternatives costs. The final specification was based on a systematic process of removing statistically insignificant variables and combining variables when their effects were not significantly different. A number of alternative model forms were explored and it was found that the data fit was superior for the gamma profile *(24)*, a specification in which the values of α_k are set to zero for all alternatives. The final specification obtained after this procedure is presented in table 4 (Refurbishment Alternatives) and table 5 (Lifestyle Changes); in general, the model is found to offer plausible behavioral interpretations across a wide range of explanatory variables. In the next section, the estimation results are discussed in detail, and in the following section, the model performance is analyzed. Most Parameters are Dummy Variables, unless its mentioned explicitly as linear or the unit is specified. ASC means alternative specific constant.

Model Estimation Results

In the context of head of the household characteristics, it is found that households with older individuals are less inclined install solar panels, automated ventilation and heat pumps. In particular, individuals aged over 75 years are less likely to reduce their CO_2 emissions via house refurbishment. This result is consistent with comments made by the interviews, who stated they were "too old to make major changes to the house" *(18)*; in fact, Poortinga *et al.* *(25)* also concluded that younger participants find home alternatives more acceptable than older participants. Also, households with older individuals are likely to buy CO_2 certificates and more likely to reduce their meat consumption. Households where the head is a female, compared to men, are inclined to reach the CO_2 target by installing automated ventilation systems. The highest education level of the head of the household impacts the household choices. Households where the head has a Master degree are less likely to replace windows, but more likely to buy a certificate (because CO_2 certificates are an "abstract" option, people with higher levels of education may be more inclined to choose that alternative), and when the head of the household has a Bachelor degree, households are more likely to replace windows; this result is consistent with the finding of Achtnicht *(15)*, who concluded that individuals, that are better educated are more likely to choose insulation alternatives than heating technologies (in our case, heat pumps). When the head of the household is a worker, they have a smaller probability to install a heat pump, but are more likely to reduce their air trips. This last finding is consistent with the notion that workers have less available time than non-workers, because they are constrained by their work schedule, and therefore prefer to keep their current number of flights per year in order to save time. As expected, people who declared have the household car always available, are less likely to reduce their mileage compared to people whose cars are not always accessible. Finally, workers whose workplace is located far from home (more than 50 Km and between 35 and 50 Km away) tend to choose more often the reduction of traveled distance. A plausible explanation of these results is that individuals who have to travel every day long distances to work spend a considerable amount of time traveling; thus, they are willing to travel less. Among household characteristics, income has important consequences for the choice and amount of CO_2 reductions undertaken by the households. If the income is larger than 16,000 CHF/month, households are more likely to install automated ventilation systems and heat pumps (which, among house refurbishment alternatives, are two of the most expensive ones), to buy new/more efficient car (which also is an expensive alternative), to reduce air trips and meat consumption. Poortinga *et al. (25)* concluded too that, when asked about energy-saving scenarios, participants with a high or average income find alternatives more acceptable than participants with low incomes. When the household earns between 10,000 and 16,000 CHF/month its more likely to reduce their CO_2 output by installing a heat pump, although the effect is smaller than for households whose income is larger than 16,000 CHF/month. Regarding household composition, when the number of adults increases, the household is more likely to refurbish roof and facades, reduce the number of air trips and the meat consumption. The number of children in the house (defined as people aged less than 19 years old) decreases the chances to install a heat pump, but increases the probability of reducing meat consumption. This last result was unexpected, as we anticipated that households would not limit the amount of meat given to the children base on nutritional concerns. More research on the relationship between meat consumption and households-with-children based preferences might shed more light on this issue. It was also found that when the head of the household is a female and there are children in the house, the preferences change: these households are inclined to buy new/more efficient cars (similarly, Achtnicht *(15)* confirmed that women assess the emission variable more negatively than men do) and to reduce the house temperature. Regarding the number of persons in the household (without distinguish between adults and children), it was found that when the household consists of less than three persons is more likely to travel less Kenny and Gray *(26)*, surveying households emissions, found that single and two person households travel the most; therefore, we can think that these households performed more non-mandatory trips, allowing them to easily reduce their traveled distance). Also, single-individual's households are less likely to install solar panels. Poortinga *et al. (25)*, had a similar conclusion, as single participants found home alternatives less acceptable than couples and families), while households with two persons are less inclined to reduce their meat consumption. Several preference differences were found regarding the house characteristics. Among the characteristics that have a significant effect on the households CO_2 reductions are found age and size of the house, type of the house (row house compared to detached, attached to only one house and end-of-the-row houses), heating fuel, large insurance value (more than 90,000 CHF) and mortgage, reason for renovation (seven ordinal levels, from only comfort to only energy savings) and condition of the roof and facades (good or bad, according to the respondent's perception). The accessibility of the municipality the house is located in has the expected effects on the transportation-related alternatives. Accessibility measures, defined in Section "Sample Characteristics", were standardized between 0 and 1 to reduce its variance. As result, the estimations show that people living in houses with good public transportation are less likely to reduce their traveled distance or flight trips. We believe that this effect is produced by the perception of high mobility, which discourages individuals to reduce the CO_2 emission via traveling less. On the other hand, people living in houses with good private transportation are more likely to reduce their traveled distance or flight trips, effect which is reversed when the accessibility is too high (more than 0.8, which correspond to the houses with accessibility equal or larger than 80% of the highest accessibility in the sample).

Finally, it was found that the relative costs of house renovation (excluding the alternative install a heat pump) and the potential carbon cost of new/more efficient vehicles affects the probability of choosing the corresponding alternatives. In particular, when the potential carbon cost increases in one unit, households are less likely to buy new/more efficient vehicles, and when the relatives costs of house renovation are greater than 0.8 (that is, the cost of the renovation is very close to the household assets), households are less inclined to make any type of house refurbishment.

Model Simulation and Performance

To test the model on its forecasting performance, the model was simulated using the same data set used for the estimation. We applied the forecasting procedure developed by Pinjari and Bhat *(27)*. The algorithm sorts all alternatives according to their baseline utility and defines iteratively the number of alternatives with the highest utility that get chosen. Then, the optimal consumption, in this case CO_2 reduction, for the chosen alternatives is calculated. Every observation was simulated 50 times and averaged. The absolute differences between the simulated and the observed CO_2 reductions are calculated and summed up over all alternatives to compute the absolute residuals, R_{abs}. Relative residuals $R_{rel} = R_{abs} / (2 \cdot BCO_2)$, with BCO_2 as the overall target of CO_2 reduction. R_{rel} gives the percentage of the overall budget that is allocated wrongly by the simulation. For the presented model, the average R_{rel} over all observations is 52.8%. To assess the performance of a model specification it needs to be compared to the performance of the random model, which is defined as a simulation with all parameters set to zero. R_{rel} of the random model is 67.1%, meaning that the model specification brings an improvement that is visible but not excellent. Comparing the distributions of the models, as shown in figure 2, indicates that because of the explanatory variables, many households could be predicted reasonably well, with $R_{rel} < 0.4$, result not obtained by the random model. Also, the number of very wrong predictions decreased. However, R_{rel} of the specified model is still high and too many predictions are inadequate despite the high number of estimated parameters.

CONCLUSIONS

The present work studied household preferences for different energy saving alternatives, based on priority evaluator data. Alternatives included house refurbishment options and life-style changes. Specific information regarding socioeconomic characteristics of the household, house characteristics and accessibility measures were part of the survey. Because households were asked to reach a energy reduction target, measured in CO_2 emissions per year, and they could chose several alternatives simultaneously, the multiple-discrete continuous extreme value model MDCEV *(24)* was selected to model the household preferences. This model provides a number of advantages over other models. First, it is based on the random utility maximization framework, using the Khun-Tucker conditions to obtain the optimal allocation of goods. Second, it has a simple closed form for the probability expression, being a practical method for handling multiple choices of a large number of discrete consumption alternatives. Further, the model collapses to the conventional multinomial logit when consumers choose only one alternative. Third, the parameters have a clear interpretation related to the concept of satiation (that is, diminishing marginal returns), allowing for corner and interior solutions.

The model presented is based on a very unique data set. The tasks of the survey were not only fairly complex, but contained unusual questions. In the survey respondents had to treat all different kinds of CO_2 output together as one budget silo and make trade-offs between very different sectors. People or households have in most (if not all) cases have no experience at all such choices. This explains partly the relatively poor model fit. People are very used to be forced to distribute a fixed budget of for example time (24h) into predefined activities. CO_2 output reduction however most households don't regard as something they make decisions about and is therefore an externality. And the concept of a fixed budget of CO_2 is even less habitual. A second problem for the model arises from the PE survey design, which was optimized to reproduce reality through extended personalization: in reality a household cannot choose the amount of CO_2 emissions it wants to reduce with each measure, because that is determined by technology. The survey was not designed to get an optimal model fit or to estimate a precise willingness-to-pay for investments in energy efficiency but to test whether households consider their energy consumption as one budget silo or distinct between separate silos. The more general question was if and how this can be tested and what a good approach would look like.

The conclusions from this work are basically that it is very hard to get information about the decision process in a situation as it is presented in the paper. The choices we tried to model have proven to be very emotional and personal. As costs did not change in the experiments and comfort levels are given by reality, the real underlying relevant attributes could hardly be observed as they are personally and individually different. The emotional costs and implications of a major refurbishment can differ a lot and be dependent on inheritance, location, family issues, other renovation plans, individual conditions, etc. Not to forget that the house itself has an emotional value for many home owners. The same is true for a reduction of miles traveled (air and road) which has specific ramifications for specific situations. Just the replacement of the car with a more efficient one can be viewed as half-decent emotionally neutral. But until today a more efficient car still implicates a loss of status or comfort in many cases. The combination of emotionally individual sectors gives even more unobservable preferences in this case. The conclusion is that a household's choice, on which lifestyle is to change to save energy, is largely dependent of socioeconomic and other observable variables. Also, a quantification of trade-off behavior could not be achieved. A design that focuses more on the influence of specific attributes would probably give more significant parameters and a better model fit, but would have to rely on more hypothetical questions and we would not know how important these parameters are compared to unobservable attributes.

The difficulty to establish a model with highly significant parameters and a good simulation performance from the data set shows us that the hypothesis of one overall energy budget can be rejected. Despite sophisticated modeling efforts consistent trade-off behavior could not be found with using the available explanatory variables. If trade-offs exist in this field they are either determined by attributes we were not able to quantify or they are negligible compared to other influences regarding house refurbishment and lifestyle changes.

Further research includes the used of more sophisticated multiple-discrete continuous models, such as the mixed-MDCEV and the nested MDCEV or a survey methodology that would focus more on the emotional aspects of lifestyle, car ownership and housing.

TABLE 1 Priority Evaluator Alternatives and Statistics of CO2 reductions

Alternatives	CO_2 reductions Statistics [ton/year]				
	Mean	**Chosen**	**Std.Dev.**	**Max.**	**Min**
House Refurbishment					
1. Replace windows	0.84	62	0.38	2.21	0.1
2. Refurbish roof	1.27	64	0.5	2.95	0.47
3. Install solar panels	0.77	92	0.33	2.49	0.08
4. Refurbish facades	1.92	43	0.81	3.82	0.7
5. Install automated ventilation system	0.73	22	0.32	1.3	0.32
6. Install heat pump	2.83	110	1.58	10.3	0.19
Lifestyle change					
Transportation					
7. Buy new/more efficient car	1.67	88	1.38	7.36	0.1
8. Reduce travelled distance	1.64	117	1.47	6.87	0.04
9. Reduce air trips	2.15	81	2.01	14	0.5
Non-Transportation					
10. Reduce house temperature	0.29	110	0.2	1.33	0.02
11. Buy a CO_2 certificate	2.31	39	1.94	10	1
12. Reduce meat consumption	0.64	46	0.35	1.88	0.13

FIGURE 1 Relative Residual R_{rel} of Simulation Results

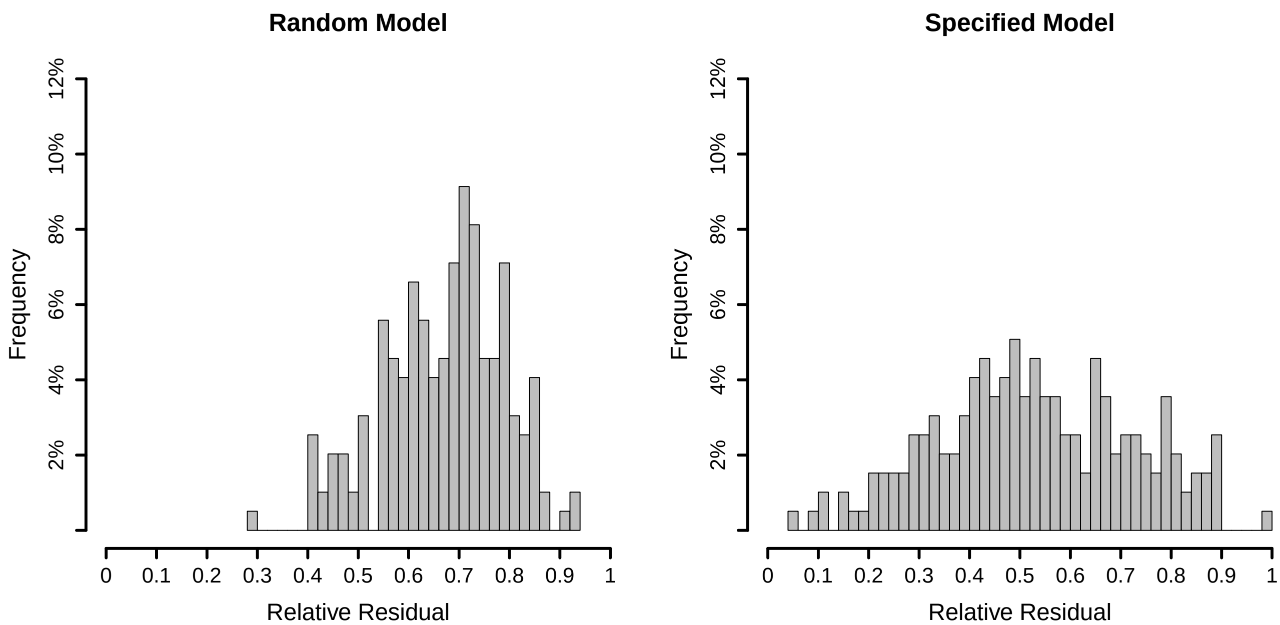

TABLE 2 Characteristics of Respondents, House and Cars

Variable	All Household members	Heads of Households
	[%]	[%]
Adults	80.1	100.0
Males	51.3	81.4
Age Groups		
Younger than 26	29.6	0.0
26 to 45	16.8	18.6
46 to 65	33.1	48.9
Older than 65 years		
Highest Education		
Up to Apprenticeship	56.6	40.3
Matura (first 2 years of college)	6.6	4.7
Bachelor equivalent	24.3	41.7
Master	8.9	12.8
Drivers License Ownership	71.7	98.3
Commute by Car	25.6	39.2
Mean Distance to Workplace	8.8 km	10.3 km
Car Availability		
never/seldom/often	37.0	15.7
always	63.0	84.3
Heating System of House		**Houses**
Oil furnace		58.1
Natural gas furnace		23.6
Electricity		7.9
Wood stove		7.9
District heating		2.3
Drive-train technology		**Cars**
Gasoline		81.1
Diesel		17.7
Natural gas		4.2
Hybrid or Electric		1.0
Mean annual mileage per car		11’635 km/year

TABLE 3 Financial Characteristics of Households

Variable	**Households**
	[%]
Income	
1,000 - 4,900 CHF	5.1
5,000 - 9,900 CHF	48.7
10,000 -15,900 CHF	34.0
> 16,000 CHF	12.2
Wealth	
< 30,000 CHF	16.5
30,000 - 69,900 CHF	28.2
70,000 - 149,900 CHF	19.7
> 150,000 CHF	35.6
No Mortgage	15.7
Mortgage smaller than Insurance Value	72.1

TABLE 4 Estimation Results, House Refurbishment Alternatives

Variable	Repl. Windows		Refurb. Roof		Inst. Solar Panels		Refurb. Fac.		Aut. Ventilation		Heat Pump	
	β-par	t-stat.	β-par	t-stat.	β-par	t-stat.	β-par	t-stat.	β-par	t-stat.	β-par	t-stat.
ASC			-2.26	-3.07	0.16	0.21	-1.78	-2.14	-0.62	-0.49	-0.09	-0.08
Satiation γ	0.09	4.75	0.13	4.67	0.08	5.80	0.30	3.62	0.12	2.92	0.34	5.05
Household (Head)												
Age [years]					-0.02	-2.22			-0.03	-1.38	-0.03	-2.31
Aged > 75 y	-0.46	-1.48	-0.46	-1.48	-0.46	-1.48	-0.46	-1.48	-0.46	-1.48	-0.46	-1.48
Female									-1.09	-1.41		
Masters degree	0.57	1.51										
Bachelor	-0.81	-2.10										
Worker											-0.88	-2.82
Inc. > 16k CHF									0.75	1.54	0.81	2.16
Inc. 10k-16k CHF											0.65	2.23
Number of adults			0.30	1.81			0.52	2.75				
Number of children											-0.40	-2.51
1 Person HH					-1.97	-1.91						
House												
Age House [years]			0.01	2.98					-0.02	-1.98		
House > 200 old			-4.61	-2.61							-1.22	-1.93
Size [m^2]							-0.01	-2.27				
House > 250 m^2									1.21	1.72		
Row house							-0.56	-1.21				
Heating fuel												
Oil	-0.89	-1.73			0.39	1.62					1.06	3.82
Nat. Gas	-1.42	-2.51										
Electric	-1.13	-1.69									1.26	3.13
Ins. value > 90k CHF					-0.64	-1.69	0.74	1.62				
Reason for renovation												
Only energy savings									-2.05	-1.96	0.57	2.23
Current condition												
Good roof			-0.69	-2.21								
Good facade							-0.81	-2.22				
Costs												
Rel. Ren. Costs > 0.8	-0.21	-1.33	-0.21	-1.33	-0.21	-1.33	-0.21	-1.33	-0.21	-1.33		

TABLE 5 Estimation Results, Lifestyle Changes, Transportation & non Transportation

Variable	**More efficient Car**		**Reduce VMT**		**Reduce air trips**		**Reduce Temp.**		**Buy Certificate**		**Reduce meat cons.**	
	β-par	**t-stat.**	**β-par**	**t-stat.**	**β-par**	**t-stat.**	**β-par**	**t-stat.**	**β-par**	**t-stat.**	**β-par**	**t-stat.**
ASC	-1.6541	-3.249	-1.3862	-2.287	-2.1485	-2.951	-1.7712	-3.198	0.4084	0.432	-5.8191	-3.652
Satiation γ	0.1849	5.274	0.1189	5.809	0.1678	5.039	0.0229	6.275	0.2963	3.455	0.0644	4.283
Household (Head)												
Age [years]									-0.0569	-3.615	0.048	2.233
Masters degree									0.9119	2.265		
Inc. > 16k CHF	0.5239	1.94			0.7143	2.38					0.8021	2.221
Number of adults					0.3574	2.224					0.3249	1.759
Number of children											0.3861	1.7
Head is female + child	1.2668	3.385					1.2525	3.514				
1 Person HH			0.7998	1.792								
2 Persons HH			0.5746	2.477							-1.4163	-2.885
Heating Fuel												
Oil							0.6207	1.841				
Nat. Gas							0.7585	2.119				
Public Transp. Acc.												
linear			-0.7525	-1.646	-0.975	-1.897						
Private Transp Acc.												
linear			2.4834	2.152	3.3764	2.479						
Acc. > 0.8			-1.2733	-1.489	-2.3283	-2.108						
Costs												
Carbon Costs New Car	-0.0569	-1.523										

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