


# Multiple discrete-continuous choice model of household energy reduction across multiple sectors using priority evaluator data

**Conference Paper****Author(s):**

Jäggi, Boris; Castro, Marisol; Schmitt, Laura; [Axhausen, Kay W.](#) ; Bhat, Chandra R.

**Publication date:**

2012-01

**Permanent link:**

<https://doi.org/10.3929/ethz-a-006567732>

**Rights / license:**

[In Copyright - Non-Commercial Use Permitted](#)

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

3 Date of submission: 2011-07-30

4 Boris Jäggi  
IVT, ETH Zurich, CH-8093 Zurich  
phone: +41-44-633 67 37  
fax: +41-44-633 10 57  
boris.jaeggi@ivt.baug.ethz.ch

5 Marisol Castro  
The University of Texas at Austin, Dept of Civil, Architectural & Environmental Engineering, 1  
University Station C1761, Austin, TX 78712-0278  
phone: 512-471-4535  
fax: 512-475-8744  
mcastro@mail.utexas.edu

6 Laura Schmitt  
The University of Texas at Austin, Dept of Civil, Architectural & Environmental Engineering, 1  
University Station C1761, Austin, TX 78712-0278  
phone: 512-471-4535  
fax: 512-475-8744  
lschmitt3@gatech.edu

7 Kay W. Axhausen  
IVT, ETH Zurich, CH-8093 Zurich  
phone: +41-44-633 39 43  
fax: +41-44-633 10 57  
axhausen@ivt.baug.ethz.ch

8 Chandra R. Bhat  
The University of Texas at Austin, Dept of Civil, Architectural & Environmental Engineering, 1  
University Station C1761, Austin, TX 78712-0278  
phone: 512-471-4535  
fax: 512-475-8744  
bhat@mail.utexas.edu

9 Words: 6612 words + 1 figure + 5 tables = 8112 word equivalents

**ABSTRACT**

1 This paper presents a multiple discrete-continuous extreme value model (MDCEV) of energy  
2 savings. The model predicts household decisions where to reduce CO<sub>2</sub> emissions if they were  
3 forced to do so. The model's approach is to include all sectors of energy consumption such as  
4 private transport, housing, meat consumption and air travel. The hypothesis is that if households  
5 view all energy consumption as part of one overall budget, trade-offs between energy sectors  
6 are possible and can be modeled. The data base for the model was established with a survey  
7 among Swiss homeowners who have at least one car. In the survey the Priority Evaluator  
8 method was implemented in a web application with which the participants interactively reduced  
9 their CO<sub>2</sub> output to a predefined goal. The MDCEV chooses multiple alternatives a household  
10 considers to reduce CO<sub>2</sub> output and allocates the percentage of the overall reduction of to the  
11 chosen alternative. Estimation results show that installing new heating systems are preferred  
12 over refurbishment of roof and façade, an effect that is even greater for higher income levels.  
13 Females and higher income households are more likely to buy a more efficient car. Households  
14 living in municipalities with better public transport accessibility are more likely to reduce annual  
15 mileage traveled. The paper also includes an assessment of the model performance analyzing  
16 the residuals. The conclusion of the paper is that the hypothesis of one overall energy budget  
17 could not be supported.

## INTRODUCTION

### 1 Context

2 In the last two decades, governments and international organizations have been actively com-  
3 mitted to reduce the concentration of greenhouse gases (GHG). GHG are composed of ozone,  
4 carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) and water vapor, gases which exist  
5 naturally in order to maintain a global temperature suitable for living. However, the concentra-  
6 tions of these gases have increased beyond natural amounts due to human activity. For example,  
7 carbon dioxide is created by burning fossil fuels and waste and methane is released into the  
8 atmosphere through the production of coal and natural gas (1). In particular, fluorinated gases,  
9 which are anthropogenic gases created through industrial processes, have a high global warming  
10 potential and can sometimes stay in the atmosphere for thousands of years. As a consequence,  
11 human activity is recognized as the leading contributor to climate change (2). Climate change is  
12 caused by GHG trapping the heat of the Earth in the atmosphere. As a result of heat trapping,  
13 the Earth's surface temperature increases. According to Hansen *et al.* (3), the global surface  
14 temperatures for 2010 tied with 2005 for the warmest year on record; this record reflects the  
15 continuing upward trend of increasing temperatures: since 1880, the average global temperature  
16 has increased 1.5°F.

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

25 A reduction of such GHG as CH<sub>4</sub> (e.g. from cattle), N<sub>2</sub>O (e.g. from fertilizer) and fluorinated  
26 gases (industrial processes) needs to be achieved by industrial and agricultural regularization  
27 and policy measures. However, these GHG make up only 17% (1) of total worldwide output,  
28 in Switzerland even less: 15.3% (8). The majority of GHG worldwide is CO<sub>2</sub>, which itself  
29 is emitted while burning fossil fuels (77%) or due to the reduction of biomass (23%, e.g.  
30 deforestation). In Switzerland, CO<sub>2</sub> emissions are almost entirely due to energy generation by  
31 fossil fuel, either for direct energy use like heating or industrial process heat (50.7%), airborne  
32 transportation (9.6%) or private transportation (39.7%) (9).

33 Public transportation in Switzerland consists of a fully electrified rail and tram system and  
34 can be neglected in CO<sub>2</sub> consideration because electricity is either hydro power or nuclear power  
35 and considered officially as almost CO<sub>2</sub> neutral. As most Swiss houses have either oil or a  
36 natural gas furnace as a heating system, 50% of CO<sub>2</sub> from direct energy use is due to residential  
37 housing. That means that GHG emissions which are directly caused by the consumer consist  
38 mainly of heating, private transport by car and air traffic. Each of these sectors can be addressed  
39 by technological or policy measures separately because they show a huge potential for efficiency.  
40 However, assuming the consumer is aware of the threat of GHG and wants to reduce the overall  
41 CO<sub>2</sub> output of the household, he has a choice set that covers all three sectors. The purpose of  
42 this study is to model the trade-offs between sectors in the event of enforced CO<sub>2</sub> emission  
43 reduction, imaginable with either a heavy environmental taxation or a CO<sub>2</sub> cap for households.  
44 Such drastic measures might seem unrealistic today, but to maintain international commitment  
45 on GHG reduction in the coming decades, they will potentially be necessary. In Switzerland

1 several studies about energy efficiency were conducted in the past years.

## 2 **Literature**

3 Banfi *et al.* (10) estimated the willingness to pay for different refurbishment measures using  
4 stated choice experiments for home owners as well as apartment tenants. The study showed  
5 a significant willingness to pay (WTP). In a similar survey by Achtnicht (11) home owners  
6 were asked to choose between insulation or a modern heating system in a series of stated choice  
7 experiments. Younger respondents showed higher preferences towards alternative heating instead  
8 of insulation. A similar preference of heating replacement over insulation (façade and roof)  
9 in Germany was found by Grösche and Vance (12). A survey among 509 Korean households  
10 conducted by Kwak *et al.* (13) showed significant WTP for energy efficiency measures in  
11 the case of a new purchase of a house. An early study about acceptance of alternative-fuel  
12 vehicles was done by (14) and found that younger and high income participants are the most  
13 concerned about energy efficiency and in the case of equal performance alternative-fuel vehicles  
14 are generally preferred over gasoline cars. Similar results come from Germany where Achtnicht  
15 (15) found that emissions have a negative influence on car choice in general and particularly for  
16 younger and female individuals. Müller and de Haan (16) established a sophisticated consumer  
17 choice model to asses how incentives on more efficient cars affect car purchase. With this model,  
18 de Haan *et al.* (17) state abatement costs through incentives to be between 6 and 13 EUR per  
19 ton CO<sub>2</sub>.

20 These previous studies neglected a trade off or a relationship between energy consumption  
21 of both sectors, housing and private transport. Our study does not aim at estimating WTP for  
22 different energy efficiency measures, but to find out how an overall energy consumption approach  
23 in behavioral modeling could look like. The goal was to survey and model that includes all  
24 possible alternatives of reducing energy consumption a household has, including all sectors.  
25 Such a model can give information about if and how households view their energy consumption:  
26 as one combined budget for energy or separate independent budget for each sector. If a combined  
27 budget is the reality, more flexible and specific policy measures can be thought of for different  
28 regions, purposes or economies. Such an overall approach that explicitly focuses on trade-offs  
29 between sectors has not been reported in the literature so far. The rest of the paper is structured  
30 as follows. The next section presents the survey characteristics. The following sections presents  
31 the model structure and estimation procedure, illustrate the application of the proposed model for  
32 analyzing CO<sub>2</sub> reductions at the household level and show the estimation results and a residual  
33 analysis. The final section offers concluding thoughts and directions for further research.

## SURVEY CHARACTERISTICS

### 1 Survey Design

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

14 To accomplish the objective of this survey, the use of the PE method is inverted: in the survey,  
15 households are forced to reduce their CO<sub>2</sub> emissions to meet a target. Therefore, individuals  
16 must fill a giving budget by choosing negative quantities, instead of using the available budget to  
17 consume positive quantities. To accomplish the objective of the survey, households were eligible  
18 if they fulfil the following requirements: 1) households must live in a single-family house and  
19 own the house where they live in, 2) they must have at least one car, and 3) the household  
20 must be able to make decisions about house refurbishment and bear the potential costs of these  
21 refurbishments. Households fulfilling the previous conditions were randomly selected in the  
22 canton of Zurich, and were asked to provide data about energy consumption, socioeconomic  
23 background, house characteristics and car information. Then, energy consumption was converted  
24 in CO<sub>2</sub> output, assuming that it is easier to allocate CO<sub>2</sub> reductions instead of energy reductions,  
25 which is more abstract than CO<sub>2</sub> emissions. Based on this information, the PE was designed for  
26 each household, allowing personalized alternatives based on their CO<sub>2</sub> output; the CO<sub>2</sub> target is  
27 50% of their current output (excluding the emission embedded in consumer goods, which is on  
28 average 4.5 tons of CO<sub>2</sub> per year per person). Finally, each household filled the PE on an Internet  
29 application. The rate of response was 56.2%, showing the high interest among householders  
30 on the survey. The PE included 12 alternatives among which households could reduce their  
31 CO<sub>2</sub> emissions to reach the target. These alternatives are associated with changes in lifestyle or  
32 house refurbishment, and some of them have an associated implementation cost (lump sum) or  
33 running costs (or savings, depending on the case). When completing the PE, households were  
34 asked to consider the costs shown in the PE as if they were real costs and thus are assumed to  
35 remain within their monetary budget, based on the cost of each alternative, and only available  
36 alternatives were presented.

37 Table 1 presents the 12 alternatives. The first six alternatives are related to house refurbish-  
38 ment, all of them associated with a reduction of the energy needed for heating the house.<sup>1</sup> The  
39 implementation costs vary across alternatives, while the running costs are all the same, and  
40 equal to 300 CHF per year. The next six alternatives correspond to changes in lifestyle. We  
41 differentiate these alternatives between transportation and non-transportation related. Alternative  
42 7, buy new/more efficient car, entails replacing or acquiring more efficient car models (the

---

<sup>1</sup>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<sub>2</sub> emissions because they move heat rather than generate it.

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

## 19 **Sample Characteristics**

20 In the canton of Zurich, 112,644 households live in single-family homes. Out of these households  
21 a sample of 491 households were recruited by telephone. The first part of the survey consisting of  
22 a paper and pen questionnaire for the socioeconomic, house and car information was completed  
23 by 333 respondents who were provided with the PE internet application. Out of that, 197  
24 household completed all parts in a reasonable manner, including the PE and all necessary  
25 financial questions. This gives a final completion rate for the PE of 40%. Socioeconomic  
26 characteristics are shown in Table 1 . The Head of Household is the person who filled in the  
27 questionnaire and is assumed to be the same person that also did the PE experiment. The sample  
28 shows high shares of older respondents. Although shares of higher age groups are relatively  
29 big among home owners because it is relatively expensive to own a house in Switzerland, the  
30 sample over (under) represents persons that are older than 65 (younger than 46) years old by  
31 about 12%. The share of 46 to 65 years matches the national and cantonal share quite well. Most  
32 of the decision makers in the household are male although the distribution over all household  
33 members is equal. Driver license ownership and car availability are high due to the selection  
34 bias. The distribution of heating systems and drive-trains match the national statistics well.  
35 Also the average vehicle miles traveled per car is very close to the national average of about  
36 12,000 km/year. In our view the most important characteristic of the household is the income  
37 and assets level. The monthly gross household income was asked using eight classes. To derive  
38 the assets level for a household we asked for the value of assets that are liquefiable within one  
39 year offering seven classes. We believe that this represents best the budget constraint a home  
40 owner faces when considering a major refurbishment of his home. In the case of investing in a  
41 house an increase of the mortgage is a common option. For this reason we also asked for the  
42 insurance value of the house (housing insurance is mandatory in Switzerland) and the mortgage.  
43 We are aware of the fact that the value of a property is mainly driven by land prices rather than  
44 the house itself, but is still the best proxy given that determining real estate prices is impossible

---

<sup>2</sup>If households decide to sell their cars, the CO<sub>2</sub> output does not change, as it is assumed that annual distance driven are made through car sharing

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

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

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



## METHODOLOGY

### 1 Behavioral Framework

2 To understand the choices and preferences regarding CO<sub>2</sub> reduction within a restricted budget,  
 3 the household is the basic decision-making unit where these decisions can be explicitly observed.  
 4 The choice made by each household consists of a discrete and a continuous component. The  
 5 discrete component relates to the alternatives selected to reduce either heating costs or variable  
 6 mobility costs, whereas the continuous component relates to the amount of CO<sub>2</sub> the households  
 7 choose to reduce. Further, given the nature of the survey, households can choose one or more  
 8 alternatives. The MDCEV relies on satiation as a force to explain multiple-discreteness, where  
 9 satiation refers to diminishing marginal utility as the level of consumption of any particular  
 10 alternative increases. In our application, satiation plays a strong role on the choice process,  
 11 because households face increasing marginal costs and marginal utility losses when reducing  
 12 CO<sub>2</sub> output. The first 1,000 km a household chooses not to drive are much easier to endure,  
 13 compared to having reduced vehicle miles traveled (VMT) already by 50% and still considering  
 14 a reduction. The model structure used in the research effort is based on the MDCEV approach  
 15 (24), based on the traditional random utility maximizing theory of consumer behavior. The  
 16 MDCEV, being a discrete-continuous model, enables the seamless integration of the discrete  
 17 and continuous components, besides capturing multiple discreteness. Additionally, this model  
 18 provides an elegant closed probability form and a clear interpretation of the estimated parameters.  
 19 This approach is superior to multinomial models as it enables exploiting quantity information  
 20 for inference (the continuous component), and facilitates policy analysis by being based on a  
 21 utility function. The model is also superior to approaches that treat each alternative-quantity  
 22 combination as a choice alternative, as does not introduce new random utility errors terms into  
 23 consumer preferences for each potential combination.

### 24 Model Specification

25 The MDCEV model (24) is based on the utility maximization theory, assuming that each  
 26 household tries to maximize their utility, which is a measure of satisfaction, by selecting various  
 27 quantities of CO<sub>2</sub> reduction among the available alternatives. The utility function U for each  
 28 household is:

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

29 where  $x \geq 0$  is the amount of CO<sub>2</sub> reduced associated with alternative  $k$  (vector of dimension  
 30  $(K \times 1)$ ), measured in tons per year,  $\alpha_k$  and  $\gamma_k$  are parameters and  $\psi_k$  is the baseline utility  
 31 associated with alternative  $k$ . The utility function belongs to the family of translated utility  
 32 functions.  $\alpha_k$  is the satiation parameter, reducing the marginal utility with increasing CO<sub>2</sub>  
 33 reduction of alternative  $k$ . The utility function in equation (1) is valid for  $\alpha \leq 1$ : the limit  
 34 case when  $\alpha = 1$  for all alternatives represents absence of satiation effects, and when  $\alpha$  moves  
 35 downward from the value of 1, the satiation effect for alternative  $k$  increases ( $\alpha \rightarrow -\infty$  represents  
 36 the case of immediate full-satiation). The primary role of the  $\gamma_k$ , called location parameter,  
 37 is to allow for corner solutions (i.e., zero CO<sub>2</sub> reduction for some alternatives) and it is also  
 38 related with satiation effects. The location parameter is defined  $\gamma_k \geq 0$ , such that when its value  
 39 increases, there is a stronger preference (or lower satiation) for alternative  $k$ . Finally,  $\psi_k$  is named

1 baseline utility function, and it represents the marginal utility of one ton of CO<sub>2</sub> reduction of  
 2 alternative  $k$  at the point of zero consumption for the alternative. To guarantee the positivity of  
 3 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  
 4 characterize alternative  $k$  and the households (including a constant),  $\beta$  is a vector of parameters  
 5 influencing baseline utility, and  $\epsilon_k$  captures the idiosyncratic (unobserved) characteristics that  
 6 impact the baseline utility of good  $k$ .

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

$$\begin{aligned} V_k + \epsilon_k &= V_1 + \epsilon_1, \text{ if } x_k^* > 0, k = 2, 3, \dots, K \\ V_k + \epsilon_k &< V_1 + \epsilon_1, \text{ if } x_k^* = 0, k = 2, 3, \dots, K \end{aligned} \quad (3)$$

11 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  
 12 the joint probability expression of consumption patterns if the density function of the stochastic  
 13 terms is known. Following Bhat (24), we assume that the error terms are assumed to follow an  
 14 independent and identically distributed (iid) and standard Gumbel distribution. The probability  
 15 that the household choose  $M$  of the  $K$  alternatives is given by an elegant and compact closed  
 16 form structure:

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

17 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  
 18 (3) collapses to the standard multinomial logit structure. The model can be estimated using  
 19 standard maximum likelihood procedures.

---

<sup>3</sup>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

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

### 14 Model Estimation Results

15 In the context of head of the household characteristics, it is found that households with older  
16 individuals are less inclined install solar panels, automated ventilation and heat pumps. In  
17 particular, individuals aged over 75 years are less likely to reduce their CO<sub>2</sub> emissions via  
18 house refurbishment. This result is consistent with comments made by the interviews, who  
19 stated they were "too old to make major changes to the house" (18); in fact, Poortinga *et al.*  
20 (25) also concluded that younger participants find home alternatives more acceptable than older  
21 participants. Also, households with older individuals are likely to buy CO<sub>2</sub> certificates and more  
22 likely to reduce their meat consumption. Households where the head is a female, compared  
23 to men, are inclined to reach the CO<sub>2</sub> target by installing automated ventilation systems. The  
24 highest education level of the head of the household impacts the household choices. Households  
25 where the head has a Master degree are less likely to replace windows, but more likely to buy  
26 a certificate (because CO<sub>2</sub> certificates are an "abstract" option, people with higher levels of  
27 education may be more inclined to choose that alternative), and when the head of the household  
28 has a Bachelor degree, households are more likely to replace windows; this result is consistent  
29 with the finding of Achtnicht (15), who concluded that individuals, that are better educated are  
30 more likely to choose insulation alternatives than heating technologies (in our case, heat pumps).  
31 When the head of the household is a worker, they have a smaller probability to install a heat  
32 pump, but are more likely to reduce their air trips. This last finding is consistent with the notion  
33 that workers have less available time than non-workers, because they are constrained by their  
34 work schedule, and therefore prefer to keep their current number of flights per year in order to  
35 save time. As expected, people who declared have the household car always available, are less  
36 likely to reduce their mileage compared to people whose cars are not always accessible. Finally,  
37 workers whose workplace is located far from home (more than 50 Km and between 35 and 50  
38 Km away) tend to choose more often the reduction of traveled distance. A plausible explanation  
39 of these results is that individuals who have to travel every day long distances to work spend a  
40 considerable amount of time traveling; thus, they are willing to travel less. Among household  
41 characteristics, income has important consequences for the choice and amount of CO<sub>2</sub> reductions  
42 undertaken by the households. If the income is larger than 16,000 CHF/month, households  
43 are more likely to install automated ventilation systems and heat pumps (which, among house  
44 refurbishment alternatives, are two of the most expensive ones), to buy new/more efficient car  
45 (which also is an expensive alternative), to reduce air trips and meat consumption. Poortinga

1 *et al.* (25) concluded too that, when asked about energy-saving scenarios, participants with a  
2 high or average income find alternatives more acceptable than participants with low incomes.  
3 When the household earns between 10,000 and 16,000 CHF/month its more likely to reduce  
4 their CO<sub>2</sub> output by installing a heat pump, although the effect is smaller than for households  
5 whose income is larger than 16,000 CHF/month. Regarding household composition, when the  
6 number of adults increases, the household is more likely to refurbish roof and facades, reduce  
7 the number of air trips and the meat consumption. The number of children in the house (defined  
8 as people aged less than 19 years old) decreases the chances to install a heat pump, but increases  
9 the probability of reducing meat consumption. This last result was unexpected, as we anticipated  
10 that households would not limit the amount of meat given to the children base on nutritional  
11 concerns. More research on the relationship between meat consumption and households-with-  
12 children based preferences might shed more light on this issue. It was also found that when the  
13 head of the household is a female and there are children in the house, the preferences change:  
14 these households are inclined to buy new/more efficient cars (similarly, Achtnicht (15) confirmed  
15 that women assess the emission variable more negatively than men do) and to reduce the house  
16 temperature. Regarding the number of persons in the household (without distinguish between  
17 adults and children), it was found that when the household consists of less than three persons  
18 is more likely to travel less Kenny and Gray (26), surveying households emissions, found that  
19 single and two person households travel the most; therefore, we can think that these households  
20 performed more non-mandatory trips, allowing them to easily reduce their traveled distance).  
21 Also, single-individual's households are less likely to install solar panels. Poortinga *et al.* (25),  
22 had a similar conclusion, as single participants found home alternatives less acceptable than  
23 couples and families), while households with two persons are less inclined to reduce their meat  
24 consumption. Several preference differences were found regarding the house characteristics.  
25 Among the characteristics that have a significant effect on the households CO<sub>2</sub> reductions are  
26 found age and size of the house, type of the house (row house compared to detached, attached  
27 to only one house and end-of-the-row houses), heating fuel, large insurance value (more than  
28 90,000 CHF) and mortgage, reason for renovation (seven ordinal levels, from only comfort  
29 to only energy savings) and condition of the roof and facades (good or bad, according to the  
30 respondent's perception). The accessibility of the municipality the house is located in has the  
31 expected effects on the transportation-related alternatives. Accessibility measures, defined in  
32 Section "Sample Characteristics", were standardized between 0 and 1 to reduce its variance. As  
33 result, the estimations show that people living in houses with good public transportation are less  
34 likely to reduce their traveled distance or flight trips. We believe that this effect is produced by  
35 the perception of high mobility, which discourages individuals to reduce the CO<sub>2</sub> emission via  
36 traveling less. On the other hand, people living in houses with good private transportation are  
37 more likely to reduce their traveled distance or flight trips, effect which is reversed when the  
38 accessibility is too high (more than 0.8, which correspond to the houses with accessibility equal  
39 or larger than 80% of the highest accessibility in the sample).

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

## 1 **Model Simulation and Performance**

2 To test the model on its forecasting performance, the model was simulated using the same data set  
3 used for the estimation. We applied the forecasting procedure developed by Pinjari and Bhat (27).  
4 The algorithm sorts all alternatives according to their baseline utility and defines iteratively the  
5 number of alternatives with the highest utility that get chosen. Then, the optimal consumption,  
6 in this case CO<sub>2</sub> reduction, for the chosen alternatives is calculated. Every observation was  
7 simulated 50 times and averaged. The absolute differences between the simulated and the  
8 observed CO<sub>2</sub> reductions are calculated and summed up over all alternatives to compute the  
9 absolute residuals,  $R_{abs}$ . Relative residuals  $R_{rel} = R_{abs} / (2 \cdot BCO_2)$ , with  $BCO_2$  as the overall  
10 target of CO<sub>2</sub> reduction.  $R_{rel}$  gives the percentage of the overall budget that is allocated wrongly  
11 by the simulation. For the presented model, the average  $R_{rel}$  over all observations is 52.8%. To  
12 assess the performance of a model specification it needs to be compared to the performance  
13 of the random model, which is defined as a simulation with all parameters set to zero.  $R_{rel}$   
14 of the random model is 67.1%, meaning that the model specification brings an improvement  
15 that is visible but not excellent. Comparing the distributions of the models, as shown in figure  
16 2, indicates that because of the explanatory variables, many households could be predicted  
17 reasonably well, with  $R_{rel} < 0.4$ , result not obtained by the random model. Also, the number  
18 of very wrong predictions decreased. However,  $R_{rel}$  of the specified model is still high and too  
19 many predictions are inadequate despite the high number of estimated parameters.

## CONCLUSIONS

1 The present work studied household preferences for different energy saving alternatives, based  
2 on priority evaluator data. Alternatives included house refurbishment options and life-style  
3 changes. Specific information regarding socioeconomic characteristics of the household, house  
4 characteristics and accessibility measures were part of the survey. Because households were  
5 asked to reach a energy reduction target, measured in CO<sub>2</sub> emissions per year, and they could  
6 chose several alternatives simultaneously, the multiple-discrete continuous extreme value model  
7 MDCEV (24) was selected to model the household preferences. This model provides a number  
8 of advantages over other models. First, it is based on the random utility maximization framework,  
9 using the Khun-Tucker conditions to obtain the optimal allocation of goods. Second, it has a  
10 simple closed form for the probability expression, being a practical method for handling multiple  
11 choices of a large number of discrete consumption alternatives. Further, the model collapses  
12 to the conventional multinomial logit when consumers choose only one alternative. Third, the  
13 parameters have a clear interpretation related to the concept of satiation (that is, diminishing  
14 marginal returns), allowing for corner and interior solutions.

15 The model presented is based on a very unique data set. The tasks of the survey were not  
16 only fairly complex, but contained unusual questions. In the survey respondents had to treat  
17 all different kinds of CO<sub>2</sub> output together as one budget silo and make trade-offs between very  
18 different sectors. People or households have in most (if not all) cases have no experience at  
19 all such choices. This explains partly the relatively poor model fit. People are very used to be  
20 forced to distribute a fixed budget of for example time (24h) into predefined activities. CO<sub>2</sub>  
21 output reduction however most households don't regard as something they make decisions about  
22 and is therefore an externality. And the concept of a fixed budget of CO<sub>2</sub> is even less habitual.  
23 A second problem for the model arises from the PE survey design, which was optimized to  
24 reproduce reality through extended personalization: in reality a household cannot choose the  
25 amount of CO<sub>2</sub> emissions it wants to reduce with each measure, because that is determined by  
26 technology. The survey was not designed to get an optimal model fit or to estimate a precise  
27 willingness-to-pay for investments in energy efficiency but to test whether households consider  
28 their energy consumption as one budget silo or distinct between separate silos. The more general  
29 question was if and how this can be tested and what a good approach would look like.

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

1 compared to unobservable attributes.

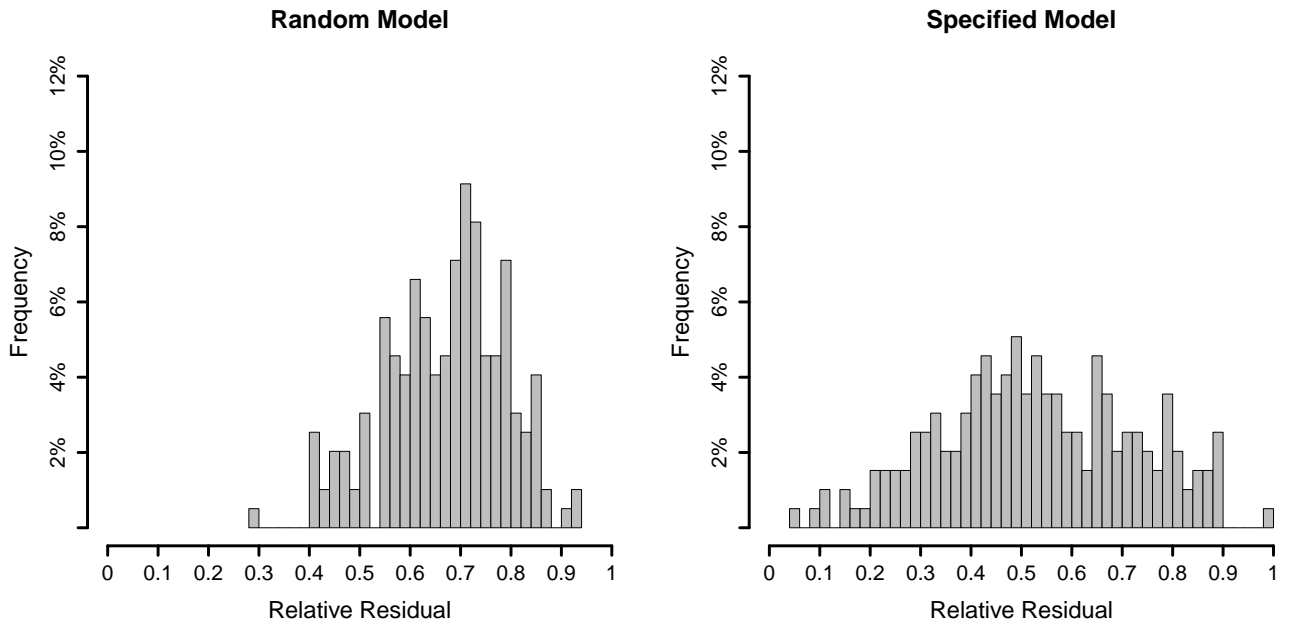
2 The difficulty to establish a model with highly significant parameters and a good simulation  
3 performance from the data set shows us that the hypothesis of one overall energy budget can  
4 be rejected. Despite sophisticated modeling efforts consistent trade-off behavior could not be  
5 found with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

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

**TABLE 1 Priority Evaluator Alternatives and Statistics of CO2 reductions**

Alternatives	CO <sub>2</sub> reductions Statistics [ton/year]				
	Mean	Chosen	Std.Dev.	Max.	Min
<i>House Refurbishment</i>					
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
<i>Lifestyle change</i>					
<i>Transportation</i>					
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
<i>Non-Transportation</i>					
10. Reduce house temperature	0.29	110	0.2	1.33	0.02
11. Buy a CO <sub>2</sub> 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
<i>Age Groups</i>		
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		
<i>Highest Education</i>		
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
<i>Car Availability</i>		
never/seldom/often	37.0	15.7
always	63.0	84.3
<i>Heating System of House</i>		<b>Houses</b>
Oil furnace		58.1
Natural gas furnace		23.6
Electricity		7.9
Wood stove		7.9
District heating		2.3
<i>Drive-train technology</i>		<b>Cars</b>
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**

<b>Variable</b>	<b>Households</b>
	[%]
<i>Income</i>	
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
<i>Wealth</i>	
< 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	
	$\beta$ -par	t-stat.	$\beta$ -par	t-stat.	$\beta$ -par	t-stat.	$\beta$ -par	t-stat.	$\beta$ -par	t-stat.	$\beta$ -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 $\gamma$	0.09	4.75	0.13	4.67	0.08	5.80	0.30	3.62	0.12	2.92	0.34	5.05
<i>Household (Head)</i>												
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						
<i>House</i>												
Age House [years]			0.01	2.98					-0.02	-1.98		
House > 200 old			-4.61	-2.61							-1.22	-1.93
Size [m <sup>2</sup> ]							-0.01	-2.27				
House > 250 m <sup>2</sup>									1.21	1.72		
Row house							-0.56	-1.21				
<i>Heating fuel</i>												
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				
<i>Reason for renovation</i>												
Only energy savings									-2.05	-1.96	0.57	2.23
<i>Current condition</i>												
Good roof			-0.69	-2.21								
Good facade							-0.81	-2.22				
<i>Costs</i>												
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	-0.21	-1.33

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

Variable	More efficient Car		Reduce VMT		Reduce air trips		Reduce Temp.		Buy Certificate		Reduce meat cons.	
	$\beta$ -par	t-stat.	$\beta$ -par	t-stat.	$\beta$ -par	t-stat.	$\beta$ -par	t-stat.	$\beta$ -par	t-stat.	$\beta$ -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 $\gamma$	0.1849	5.274	0.1189	5.809	0.1678	5.039	0.0229	6.275	0.2963	3.455	0.0644	4.283
<i>Household (Head)</i>												
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
<i>Heating Fuel</i>												
Oil							0.6207	1.841				
Nat. Gas							0.7585	2.119				
<i>Public Transp. Acc.</i>												
linear			-0.7525	-1.646	-0.975	-1.897						
<i>Private Transp Acc.</i>												
linear			2.4834	2.152	3.3764	2.479						
Acc. > 0.8			-1.2733	-1.489	-2.3283	-2.108						
<i>Costs</i>												
Carbon Costs New Car	-0.0569	-1.523										

**REFERENCES**

- 1 1. Environmental Protection Agency (2011) Greenhouse gas emissions, <http://www.epa.gov/climatechange/emissions/index.html>.
- 2
- 3 2. Pachauri, R. K. and A. Reisinger (eds.) (2007) *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Intergovernmental Panel on Climate Change, Geneva.
- 4
- 5
- 6
- 7 3. Hansen, J. s. H. ., R. Ruedy, M. Sato and K. Lo (2010) Global surface temperature change, *Reviews of Geophysics*, **48**, RG4004.
- 8
- 9 4. Parry, M. L., O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (eds.) (2007) *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.
- 10
- 11
- 12 5. United Nations (2007) Climate change and tourism: Responding to global challenges, [http://esa.un.org/marrakechprocess/pdf/davos\\_rep\\_advan\\_summ\\_26\\_09.pdf](http://esa.un.org/marrakechprocess/pdf/davos_rep_advan_summ_26_09.pdf).
- 13
- 14 6. National Research Council (2008) *Potential Impacts of Climate Change on U.S. Transportation*, Transportation Research Board, Washington, D.C.
- 15
- 16 7. World Health Organisation (2010) Climate change and health, webpage, <http://www.who.int/mediacentre/factsheets/fs266/en/index.html>.
- 17
- 18 8. European Environment Agency (2010) Ghg trends and projections in switzerland, webpage, <http://www.eea.europa.eu/themes/climate/ghg-country-profiles/tp-report-country-profiles/switzerl>.
- 19
- 20
- 21 9. Federal Office for the Environment (FOEN) (2010) Emissionen nach CO<sub>2</sub>-Gesetz und Kyoto Protokoll, webpage, Available:<http://www.news.admin.ch/NSBSubscriber/message/attachments/19852.pdf>.
- 22
- 23
- 24 10. Banfi, S., M. Farsi, F. Massimo and M. Jakob (2008) Willingness to pay for energy-saving measures in residential buildings, *Energy Economics*, **30** (2) 503–516.
- 25
- 26 11. Achtnicht, M. (2010) Do environmental benefits matter? a choice experiment among house owners in germany, *Working Paper*, **10-094**, Center for European Economic Research.
- 27
- 28 12. Grösche, P. and C. Vance (2009) Willingness to pay for energy conservation and free-ridership on subsidization: Evidence from germany, *Traffic Engineering Journal*, **30** (2) 135–154.
- 29
- 30
- 31 13. Kwak, S.-Y., Y. Seung-Hoon and S.-J. Kwak (2009) Valuing energy-saving measures in residential buildings: A choice experiment study, *Journal of Energy Policy*, **38** (2) 673–677.
- 32
- 33 14. Ewing, G. and E. Sarigöllü (2000) Assessing consumer preferences for clean-fuel vehicles: A discrete choice experiment, *Journal of Public Policy & Marketing*, **19** (1) 106–118.
- 34
- 35 15. Achtnicht, M. (2009) German car buyers' willingness to pay to reduce co<sub>2</sub> emissions, *Working Paper*, **09-058**, Center for European Economic Research.
- 36

- 1 16. Müller, M. and P. de Haan (2009) How much do incentives affect car purchase? agent-based  
2 microsimulation of consumer choice of new cars - part I: Model structure, simulation of  
3 bounded rationality, and model validation, *Journal of Energy Policy*, **37** (3) 1072–1082.
- 4 17. de Haan, P., M. Müller and R. W. Scholz (2009) How much do incentives affect car purchase?  
5 agent-based microsimulation of consumer choice of new cars - part II: Forecasting effects  
6 of feebates based on energy-efficiency, *Journal of Energy Policy*, **37** (3) 1083–1094.
- 7 18. Jäggi, B. and K. W. Axhausen (2010) Surveying energy efficiency in housing and transport  
8 using a priority evaluator, *Working Paper*, **636**, IVT, ETH Zurich, Zurich.
- 9 19. Hoinville, G. (1977) The priority evaluator method, *Working Paper*, **3**, Social & Community  
10 Planning Research, London, September 1977.
- 11 20. Turrentine, T. S. and K. S. Kurani (2007) Car buyers and fuel economy?, *Journal of Energy*  
12 *Policy*, **35** (2) 1213–1223.
- 13 21. Wardman, M. and A. L. Bristow (2008) Valuations of aircraft noise: experiments in stated  
14 preference, *Environmental and Resource Economics*, **39** (4) 459–480.
- 15 22. Sinden, J. A., P. O. Downey, S. M. Hester and O. Cacho (2008) Valuing the biodiversity gains  
16 from protecting native plant communities from bitou bush in new south wales: application  
17 of the defensive expenditure method, *presentation*, University of New England, Canberra.
- 18 23. Fröhlich, P., M. Tschopp and K. W. Axhausen (2006) Development of the accessibility of  
19 swiss municipalities: 1950 to 2000, *Raumforschung und Raumordnung*, **63** (6) 385–399.
- 20 24. Bhat, C. R. (2008) The multiple discrete-continuous extreme value (mdcev) model: Role of  
21 utility function parameters, identification considerations, and model extensions, *Transporta-*  
22 *tion Research Part B: Methodological*, **42** (3) 274–303.
- 23 25. Poortinga, W., L. Steg, C. Vlek and G. Wiersma (2003) Estimation of complete demand  
24 systems from household budget data: the linear and quadratic expenditure systems, *Journal*  
25 *of Economic Psychology*, **24** (1) 49–64.
- 26 26. Kenny, T. and N. Gray (2009) Relaxation criteria for iterated traffic simulations, *Environment*  
27 *International*, **35** (2) 259–272.
- 28 27. Pinjari, A. R. and C. R. Bhat (2010) A multiple discrete-continuous nested extreme value  
29 (mdcnev) model: Formulation and application to non-worker activity time-se and timing  
30 behavior on weekdays, *Transportation Research Part B: Methodological*, **44** (4) 562–583.