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Modeling household fleet choice as a function of fuel price using a multiple discrete-continuous choice model

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ABSTRACT

- ¹ In this Paper, a new model of fleet choice for households is presented that uses the multiple
- ² discrete-continuous extreme value (MDCEV) model as a framework. The aim of the model is
- ³ to establish a model to allocate car types to activity based microscopic agent based transport
- ⁴ simulations. What is new in the presented model, is that in addition to socioeconomic attributes
- ⁵ of households, the choice is also influenced by fuel price. To model a range of fuel prices up to
- 6 20 USD/gallon a data base from a sophisticated stated adaption survey about mobility residential
- ⁷ choice among approximately 400 Swiss households was used. The model had a choice set of 17
- ⁸ alternatives distinguishing car type and drive train. In the MDCEV model, a household chooses
- ⁹ multiple car types and distributes an overall budget of vehicle miles traveled among the chosen
- ¹⁰ alternatives. The model shows that fuel price has a much greater influence on the selection of
- the car type than on the use (VMT) of the car. In a certain range of fuel prices, households tend to switch from gasoline to diesel cars. The paper also contains an assessment of the residuals of
- $_{13}$ the simulation that shows a reasonable performance of the model.

INTRODUCTION

1 Context

- ² One of the mayor global ecological problems is the expected rise in average world temperature
- ³ due to the greenhouse effect, known as global warming. According to the Intergovernmental
- ⁴ Panel on Climate Change (1), the increasing concentration of green house gases (GHG) is the
- ⁵ main anthropogenic cause for this phenomenon. Of all GHG, the biggest impact has Carbon
- ⁶ Dioxide CO₂ which is emitted burning fossil fuel. In Switzerland, 34% of energy consumption
- ⁷ is in the transportation sector (2), therefore various policies and taxes are discussed to reduce
- ⁸ carbon emission in the private transport sector, which could incorporate an significant rise in
- ⁹ fuel prices. Regulatory agencies therefore are interested how an increase in fuel prices change
- the fleet composition, vehicle miles traveled (VMT) and the resulting energy and CO_2 savings.

But also other factors can influence fuel prices, mainly the world oil-market. The increase in demand of the developing countries as well as stagnation and shortages on the supply side (crude oil as well as refineries) influence the oil price. The Reference scenario of the oil price projections of Energy Information Administration (EIA) (3) is substantially higher than the price

¹⁵ spike in 2008.

16 Research Question

The main research question now is how these unprecedented changes in fuel costs affect fleet choice and usage, how this can be modeled and how the resulting models can be implemented in existing transportation models.

In sophisticated transport models like the SACSIM model of the Sacramento Area, California 20 (4), the ILUTE model in Toronto (5) or the Albatross model from the Netherlands (6), choice 21 modeling is used to capture a wide range of behaviors, such as mode choice, fleet choice or 22 route choice. Discrete choice models in their standard formulations cannot integrate multivariate 23 choices and associated continuous attributes of these choices. Still, there a number of questions 24 where this capability would allow the modeler to improve the realism of the description. One 25 prime example is the composition of the fleet of mobility tools (7, 8, 9, 10) and their associated 26 mileage. The recent development of the MCDEV framework by Bhat (11) offers a new approach 27 to address this gap. 28

The overall transport model currently developed at IVT in collaboration with TU-Berlin is MATSim (*12*, *13*, *14*), an agent based micro-simulation tool for travel demand and traffic flow modeling. The present paper is part of the ongoing work to implement multiple discretecontinuous extreme value (MDCEV) models into the model frameworks of different fields.

In MATSim travel demand is activity based and generated using activity chains from the Swiss national travel diary survey, the Mikrozensus (*15*). The Mikrozensus is conducted every five years. In the current version of MATSim, the agents can conduct activities (e.g. home, shopping, work, leisure, etc.) inside facilities (buildings). In the iterative solution process the agents optimize their given activity chain. The agents are not part of a household and they have no specific car type allocated to them yet. They only have an attribute that describes their car availability for the mode choice processes.

The aim of this work is part of the future improvement of MATSim, so that the agents shall be members of households and specific car fleets will be allocated to the households. This will not only enable analysis of energy consumption on a microscopic level, but also allow the implementation of a behavioral model to forecast the development of the car fleet based on

² scenarios of different fuel prices and, as a result, of the energy consumption.

3 Literature

The model presented is estimated using the MDCEV approach by Bhat (11) on Stated Adaptation data collected in a survey conducted by Erath and Axhausen (16). To test the performance of 5 such a model for an application like MATSim, we applied a MDCEV model and analyzed the 6 residuals comparing the results to the actual choices in the experiment. Since 2004, when the 7 MDCEV model was originally developed to analyze time use (11), various researchers have 8 used it to estimate preferences: (17) presented a MDCEV Model in the context of examining 9 vehicle type, model and usage decisions of households in his dissertation Bhat and Sen (18). The 10 impact of demographics, built environment attributes, vehicle characteristics and gasoline prices 11 on the same issue are analyzed in (19). Pinjari et al. (20) analyzed residential self-selection 12 effects in time-use models and Spissu et al. (21) presented an analysis of weekly out-of-home 13 activity participation. Copperman and Bhat (22) analyzed the determinants of childrens week 14 end activity participation. In Pinjari and Bhat (23), the authors introduce the nested version of 15 the MDCEV, the multiple discrete-continuous nested extreme value (MDCNEV) model and 16 present an application on non-worker time-use behavior. A detailed description of the MDCEV 17 and the role of its parameters can be found in (24). 18 Early studies of household fleet composition models were undertaken by Lave and Train

19 (25) and Hensher and Le Plastrier (26). de Jong (27) found a negative relationship between fixed 20 and variable car costs on ownership and use respectively. A good overview over all different 21 types of car ownership and use models is given in de Jong et al. (28). All these models focus 22 on the influence of income and costs generally. The work presented focuses only on the part 23 of costs due to fuel. An increase in this area does not necessarily only mean a decrease in 24 use, but could also lead to a change of car type (to a type with lower fuel consumption) or to 25 a switch of drive-train technology. The spectrum of fuel price for revealed preference data is 26 small compared to what is expected to become reality within the next decades. Stated Preference 27 experiments with a fuel price variation in the expected range of up to +400% were not found in 28 the literature, except for the study whose data is used in this paper (16). 29

Other studies focus explicitly on the purchase of low consumption cars. A study about acceptance of alternative-fuel vehicles by Ewing and Sarigöllü (29) found that given equal performance, alternative fuel vehicles are preferred over conventional, particularly for younger and high income participants. Achtnicht (30) found in his model that emissions have a negative influence on car choice in general and particularly for younger and female individuals. Using a sophisticated consumer choice model for car purchase, de Haan *et al.* (31) showed how incentives for environmentally friendlier cars could decrease CO₂ emissions of new cars.

FIGURE 1 Screen shot of interactive computer software used in the survey



DATA

1 Survey

The primary data set used here was collected within a project funded by the Swiss Federal Office 2 of Energy and the Federal Office for the Environment on long term fuel price elasticity and 3 the effects on mobility tool ownership and residential location choice (16). In the survey, 409 4 households were questioned about their long term reactions to rising fuel costs. The survey 5 was divided in a part on socioeconomic and mobility tool related questions and a three stage 6 stated response survey. In the first part, the respondents are presented six scenarios of fuel prices 7 ranging from CHF 1.5/l to CHF 5.5/l for gasoline. The survey was conducted in face-to-face 8 interviews, in which the interviewer was equipped with a computer-software that simultaneously 9 calculated the personalized mobility costs (fixed cost separate from variable cost) based on 10 personal information collected previously. The respondents could choose their car fleet and 11 annual mileage for every chosen car at a high level of detail including car type, engine size, 12 drive-train, and if they would buy a new or a used car, while being supported by the real time 13 calculations of the computer. Public transport season tickets, a common alternative, was always 14 available as a choice. Figure 1 shows a screen shot of the survey. 15

They could also choose and/or change the mileage traveled by public transport. In the second stage of the respondents were confronted with six different residential locations as well as varying fuel prices and were again asked to choose the preferred mobility tool (and mileage) for each situation. For the third stage of stated preference experiment another six choice situations were created. The choice sets in this consisted of two alternatives, one from both previous stages each. The data used in this paper comes from the first stage only.

Variable	MZ	Sample	Variable	MZ	Sample
	[%]	[%]		[%]	[%]
Sex					
Male	48.3	55.0	Car Availability		
Female	51.7	45.0	always	83.5	84.0
Age in years			occasional	16.5	12.8
18 - 35	27.2	25.0	Transit Season Ticket		
36 - 50	32.0	38.0	none	63.2	73.8
51 - 65	24.5	25.5	Half-Fare	29.9	16.1
> 65	16.4	11.5	GA	6.9	4.1
Highest Ed.			Cars in Household		
Compulsory Education	18.4	20.6	1	62.4	
Professional School	55.6	57.6	2	32.0	
Tertiary Ed.	26.0	21.8	> 2	6.6	
Household Inc. [CHF/month]			Car Type		
< 2,000	1.8	2.4	Sports Car	2.6	8.1
2,000 - 4,000	14.6	12.5	Luxury / SUV	6.3	6.3
4,000 - 6,000	28.6	25.7	Upper middle Class	22.3	17.9
6,000 - 8,000	23.6	17.6	Middle Class	22.3	17.9
8,000 - 10,000	14.3	15.4	Minivan/Van	14.1	13.3
10,000 - 12,000	7.8	10.3	Compact	23.1	20.3
12,000	9.3	9.0	Subcompact	19.0	18.1
n.a.	-	6.8	Micro	3.7	8.1
Persons per Household					
1	20.5	34.5			
2	38.9	39.1			
3	14.7	11.0			
4	18.0	12.0			
> 4	7.9	3.4			

TABLE 1 Sample Characteristics

1 Data Overview

The representativeness of the data in term of mobility tools, car ownership and socioeconomic 2 variables is summarized in table 1. The column MZ describes the targeted share according to 3 the Swiss national transport survey (15), the column sample the actual share in the survey. In 4 our data, male participants are slightly over-represented, as well as the age group of 36-50 years 5 old. We have also a significantly higher share of single person household and persons without a 6 public transport season ticket. In terms existing fleet composition, the most frequent car types, 7 such as upper middle class, minivan and compact, are under-represented while the 8 more special ones like sports car and micro are over-represented. The income distribution is 9 matched reasonably well, although there are more high income households than expected. 10

MDCEV

Review of Methodology

The methodology used in this fleet choice model is the multiple discrete-continuous extreme
 value (MDCEV) approach developed by Bhat (11). In his paper he gives a detailed description

and derivation of the model. The following section is a short summary of the third chapter of

⁵ the paper. The MDCEV was originally developed to estimate the influence of attributes on

⁶ the decisions of allocating time (continuous) to activities (discrete) within a 24-hour budget.

7 Because the various activities are equivalent and simultaneously chosen for each day the model

⁸ considers multiple chosen alternatives. In the presented model, the discrete choices are car types,

⁹ the continuous amount is annual mileage (VMT) and it is a multiple discrete model because

¹⁰ households can own and use more than one car simultaneously.

Kim *et al.* (*32*) defines the utility an individual obtains for his decisions as a sum over all j alternatives (in our case: car types):

$$U = \sum_{j=1}^{K} \psi(x_j, \varepsilon_j) (t_j + \gamma_j)^{\alpha_j}$$
(1)

In this utility structure, t_j is the continuous amount of annual mileage driven with car type j (j = 1,2,...,K), γ_j and α_j are satiation parameter to estimated within the model. These Satiation parameter are two different ways to account for the decreasing marginal utility of the continuous amount (VMT). The function $\psi(x_j,\varepsilon_j)$ gives the baseline utility function for the mileage driven with car type j. In section 3.1 of his paper, Bhat (11) presents a random utility function for the baseline utility:

$$\psi(x_j,\varepsilon_j) = \exp(\beta' x_j + \varepsilon_j) \tag{2}$$

In which β' is a vector of parameters that define the influence of the observed characteristics of the alternative x_j . ε_j captures the unobserved random utility. By combining the formulas (1) and (2) the overall random utility function for the MDCEV model can be defined as:

$$\bar{U} = \sum_{j=1}^{K} \exp(\beta' x_j + \varepsilon_j) \cdot (t_j + \gamma_j)^{\alpha_j}$$
(3)

By forming the Lagrangian and applying the Kuhn-Tucker conditions and assuming that the optimal allocation of annual mileage satisfies the budget constraint $\sum_{j=1}^{K} t_j^* = T$ (with T equals the total VMT of the household), the probability function can be derived. Bhat specifies a standard extreme value distribution for ε_i and assumes that it is independent from x_i as well as independently distributed across alternatives. The final result for the probability function is:

$$P(t_2, t_3, ...; t_M, 0, 0, ..., 0) = \left[\prod_{i=1}^M c_i\right] \left[\prod_{i=1}^M \frac{1}{c_j}\right] \left[\frac{\prod_{i=1}^M e^{V_i}}{(\sum_{j=1}^K e^{V_j})^M}\right] (M-1)!$$
(4)

² whereas:

$$c_i = \left(\frac{1 - \alpha_i}{t_i + \gamma_i}\right) \tag{5}$$

M is the number of alternatives chosen by the individual. If only one alternative is chosen, the model collapses to the form of a standard Multinomial Logit model. Therefore this model is an extension of the standard MNL model, allowing multiple choices of continuous amounts. The parameters of the model are estimated using the Log-Likelihood method that maximizes the sum of the log of P over all observations.

8 Model Specification

⁹ The model used for this paper has no outside good, meaning that there was no alternative that ¹⁰ was chosen in every observation. It is obvious that there is no car type which has to be chosen by ¹¹ all households, as for example 'in home time' in time use models or 'housing costs' in household ¹² budget allocation models.

For the estimation process, the Gauss code provided at Bhat's Web-page (33) is used. The programm 'No Outside Good' is used and two configurations were tested. In the first the estimated satiation parameters of the model are α parameters and the γ values are constraint to be equal to one for all goods. In this case, the specific utility function is:

$$U(t) = \sum_{j=1}^{K} \frac{1}{\alpha_j} \exp(\beta' x_j + \varepsilon_j) \cdot \{(t_j + 1)^{\alpha_j} - 1\}$$
(6)

In the other configuration tested γ parameters are estimated while α values are fixed to be equal 0. In that case, the specific utility function is:

$$U(t) = \sum_{j=1}^{K} \gamma_j \cdot \exp(\beta' x_j + \varepsilon_j) \cdot \ln\left(\frac{x_j}{\gamma_j} + 1\right)$$
(7)

The models estimated assumed satiation parameters that differ across individuals. The γ parameters are estimated as a function of household income, fuel price and a constant. We did not reach convergence for models using α parameters differing across individuals. Because of this, and because of the slightly better model fit, only results using γ satiation parameters are presented in this paper.

Alternative	Drive-train	Car Types	Observations
D0	Diesel	Micro	58
D1	Diesel	Subcompact	123
D2	Diesel	Compact	134
D3	Diesel	Mini MPV	103
D4	Diesel	Mid-Sized	127
D5	Diesel	MiniVan, Full-Sized	100
D6	Diesel	Luxurious, Sportscar	56
B0	Gasoline	Micro	135
B1	Gasoline	Subcompact	366
B2	Gasoline	Compact	289
B3	Gasoline	Mini MVP	149
B4	Gasoline	Mid-Sized	222
B5	Gasoline	MiniVan, Full-Sized	77
B6	Gasoline	Luxurious	69
B7	Gasoline	Sportscar	136
Other	Gas, Hybrid, Electric	All Types	268
OEV		Public Transport	

 TABLE 2
 Alternatives for Fleet Choice Model B

With the software application used in the interviews, the respondents could determine the 1 type of every car choosing among nine different car types, five classes of engine size, five 2 drive-trains(gasoline, diesel, natural gas, hybrid, electric) vehicle) and wether it would be a 3 newly bought car or a used car (used means either to keep the currently owned car or to buy a 4 second hand car). The options give $9.5 \cdot 5 \cdot 2 = 450$ alternatives, which requires a classification. 5 The choices were classified in 17 alternatives distinguishing between gasoline, diesel and 6 alternative drive-trains (ATD) and between the separate car types. 17 was an upper bound for 7 alternatives due to computational reasons. The list of alternatives is shown in table 2. The 8 variable observations is how often this alternative was chosen as first car to give a sense of the 9 distribution of the classification and explains why certain car types are put together. 10

ESTIMATION RESULTS

¹ The estimation results are shown in table 3. Please note that **boldly** written numbers are

² significant at a 95% level and numbers written in *italic* are significant at a 90% level. The

³ Alternatives are labeled according to table 2. For an easier and quicker reading of the table, an

⁴ indication is given in the column "Alternative", where the car type is indicated. Alternatives D0

to D6 are diesel cars, B0 to B7 are gasoline cars and other means all car types with alternative
 drive-trains.

⁷ In the next three sections, first the β parameters for the discrete choice are discussed with

⁸ the exception of fuel price, then fuel price is looked at separately and in the third section θ

⁹ parameters that determine satiation of the allocated VMT are analyzed.

10 Choice Model Parameters

To evaluate the model in terms of model fit, the mean log likelihood values are compared with mean log likelihood value when all parameters are set zero which is -6.1. That gives a pseudo ρ^2 of 0.55, which seems to be very high. However, this value should not be compared with pseudo ρ^2 of Multinomial Logit Models, but only with values of the same MDCEV modeling framework.

The variable Const is the alternative specific constant compared to the Diesel-Micro choice. In general (few exceptions) bigger cars have lower constant than smaller cars. The strongest negative constants have the two luxurious car types. But the constants are most likely also driven by the availability and market penetration of the car types in question. People are less used to and aware of diesel cars which reflects the lower constant. For Mid-Sized (="normal") cars this difference is particularly evident (diesel: -4.38, gasoline: 0.7). Alternative drive-trains (ADT) are favored over most conventional car types.

Income is defined in the model as gross household income in CHF 1'000 per month. The significant effect indicates, that high income households are less likely to use small and family cars and are also less likely to use public transport. Interestingly, cars with ADT are negatively influenced by income, although they are more expensive. This indicates that early adopters are not necessarily high income people. In general the effect of income is not as strong as expected. However, it has a stronger influence on the satiation parameters as discussed below.

Dist. is the respondent's distance between home and workplace in 100 km. The longer this distance, the more mileage the respondents have to allocate to commuting. All alternatives have a high parameter for commuting distance. That means that people with longer distance to the workplace tend to own more cars, because the utility of making the discrete choice for every car type increases. The difference between the car types is very small. We can see no effect, that people with longer commuting distances, and therefore higher consumption, would favor more efficient cars.

Male is a dummy for the gender of the respondent. ADT, public transport and gasoline are preferred by women, while diesel is preferred by men. This is a quite interesting finding, because it rejects the general assumption, that men are more interested in, and therefore more open to new technologies. The most visible effect is between diesel SUVs which are preferred by men and gasoline Micro cars preferred by women.

The influence of age of the respondent is modeled linearly, because neither a quadratic function nor a division in age groups showed better results. But it is still hard to make clear

Alternative	Const	Income	Fuel	Fuel2	DistW	Male	Age	Urban	Inertia	Ac.1	Ac.2	GA	HT	θ_{C}	θ_I	$\theta_F \cap$
D0 (Micro)														4.30	-0.39	0.39 d
D1 (Subcompact)	0.95	-0.07	0.30	-0.05	6.71	0.12	-0.07	-0.54	1.73					5.55	-0.30	-0.34 🛓
D2 (Compact)	-0.96	0.00	0.24	-0.05	7.14	0.31	0.13	0.16	2.73					3.38	-0.22	0.53 la
D3 (MiniMVP)	-1.70	-0.10	0.69	-0.13	7.12	0.41	0.20	0.01	2.69					0.89	2.69	1.95 ^e
D4 (MidSized)	-4.38	0.14	1.34	-0.23	7.01	0.18	0.27	-0.32	2.37					3.56	-0.09	-0.29
D5 (FullSized)	-2.00	0.12	-0.06	-0.02	7.30	0.15	0.11	-0.19	3.84					4.24	-0.26	0.02 .<
D6 (Luxus)	-5.13	0.00	0.98	-0.15	6.62	1.45	0.40	0.39	3.59					0.50	0.08	0.09
B0 (Micro)	-1.12	0.00	-0.01		7.68	-1.40	0.25	0.19	3.00					1.00	-0.13	0.06
B1 (Subcompact)	0.89	-0.11	-0.19		6.71	0.08	0.22	-0.13	2.33					1.93	-0.10	-0.12
B2 (Compact)	0.14	-0.06	-0.32		7.38	-0.15	0.12	0.30	3.20					2.20	-0.13	-0.01
B3 (MiniMVP)	-2.00	0.08	-0.73		6.90	-0.60	0.21	0.36	5.65					1.37	-0.17	0.15
B4 (MidSized)	0.68	0.00	-0.40		7.38	-0.02	-0.12	0.70	3.38					1.77	-0.16	0.31
B5 (FullSized)	-0.37	0.01	-0.53		7.06	0.57	-0.08	-0.59	4.31					3.17	-0.22	-0.02
B6 (Luxus)	-7.14	-0.09	-0.59		6.48	-0.56	-0.23	0.29	14.57					0.00	-0.05	0.34
B7 (Sport)	-1.43	0.12	-0.81		7.75	-0.38	-0.03	-0.01	6.85					-2.23	-0.04	0.45
Other	-0.51	-0.08	0.17		6.95	-0.91	0.33	0.22	3.24	0.08	0.16			0.39	2.32	1.37
Public Transport	4.12	-0.12	-0.24		7.11	-0.28	0.22	0.22		0.00	-0.02	2.39	1.04	-4.25	0.11	0.08

TABLE 3Estimated β and θ Parameters of Fleet Choice Model, mean log likelihood: -2.70

statements about the influence for the linear formulation.

Urban is a dummy which is equal one for people living in inner city or urban areas and zero for people in suburbs and rural areas. Resident location has not a big influence on fleet choice, except that public transport and ADT are preferred in urban areas, which is plausible. SUV, which are cars designed and advertised for the use in rural, mountainous regions have a positive sign for urban environment. This indicates that the possibility of driving off road is more appealing to people that need it less.

Inertia is a dummy to capture inertia effects. It is one if the chosen car type is one of the 8 actual cars types the household already owns. This has the expected significant and substantial 9 influence, because it can be considered as capturing a substantial part of unobserved influence 10 that led to the decision for the specific car type. The higher this parameter, the more likely the 11 car type is chosen because it is already known. To lower this parameter, the more this alternative 12 is considered to be a car type to change to. The parameter is smaller for all diesel alternatives, 13 indicating that households switch from gasoline to diesel. The smaller the car type, the more 14 likely it is to be switched to. Inertia effects are especially high for three different car types: 15 Luxurious, sports and family gasoline cars. Luxurious and sports cars in many cases fulfill 16 the purpose of a status symbol and thus bring an increased utility from unobserved emotional 17 attributes. Because they have an already high fuel consumption in general, these car types are 18 chosen in the case of rising fuel prises predominantly because they are already owned. In the 19 case of MiniMVP it is rather its function than status that limits the choice to household that 20 already have one. 21

Acc.1 and Acc.2 are two variables for accessability, coming from a factor analysis of private 22 transport accessability and public transport accessability, based on a national aggregate transport 23 model (34). Ac.1 stands for general accessability of the respondent's home municipality (or 24 quarter in the case of a city) and Ac.2 for any differences in public transport accessability. The 25 parameter is only estimated for alternative fuel alternatives and public transport, because differ-26 ences between conventional alternatives regarding accessability impacts are neither expected nor 27 found. ADT are more often chosen in areas with higher accessability in comparison to gasoline 28 and diesel cars, and the effect is even greater for the public transport accessability. ADT cars 29 have not yet the same capability level as gasoline or diesel cars. This can be less space (Toyota 30 Prius), small network of fuel stations (natural gas cars) or less range (electric cars). Thus it 31 cannot necessarily be used for every occasion and the more suitable the public transport option 32 is, the less important is the described lack in its capability. 33

The parameters for GA, HT and SC describe the influence of existing mobility tools for the public transport use in the model which includes public transport. GA (Generalabonnement) is a dummy for a season card for the whole of Switzerland, HT (Halbtax) one for a half-fare card for the whole of Switzerland and SC for a regional season card. The presence of such a mobility tool has the expected strong positive effect on the choice to use public transportation.

39 Influence of Fuel Price on Fleet Choice

Fuel is the fuel price, varying in the experiment from 1.5 CHF/l to 5.5 CHF/l, Fuel² is the square of the fuel price. The impact of these parameters is summarized in figure 2 which shows the influence of fuel price on the utility and thus on the decision of the household for every alternative. Higher utility means that the alternative is more likely to be chosen. The graph assumes all other parameters equal to make the different curves of the alternatives comparable.



FIGURE 2 Influence of Fuel Price on Utility of Model B

The x-axis indicates the fuel price from 0 to the maximum of CHF 5.5 per liter (USD 1 27 per gallon as of July 2011); the value range in the survey. Three different shapes can be 2 distinguished: linearly negative for gasoline cars and Full-sized diesel cars, parabolic for other 3 diesel cars and Micro gasoline cars linearly positive for ADT. The best visible parabolic curves are for these three diesel cars: MiniMVP, Mid-sized and Luxus. Households do not want do 5 down-grade initially when fuel gets expensive but rather switch to diesel cars that have a lower 6 consumption. Switching increases up to a price level of about CHF 3.0 per liter (USD 15 per 7 gallon), after that level utility declines also for diesel cars. Car types with higher consumption 8 tend to be more negatively influenced by fuel prices as expected. 9

Utility of ADT increases with fuel prices, although only weakly. The maximum differences between the maximum and minimum is only about a fifth of the differences for gasoline sports cars. But still the results indicate that households begin to switch also to ADT cars, but only when fuel prices get very high, or in other words: Fuel needs to be extremely expensive to overcome the lack of comfort and capability of ADT cars that still exists. We can assume that results would look different in ten years if the comfort gap was shrunk by then.

16 Individual Satiation of VMT

Above we stated that the influence of income on choice is smaller than in the allocation of VMT. 17 This makes sense considering the following: Households with higher income may also have 18 more cars than ones with lower income and the second or third car is often a smaller than the first. 19 That means that car types are more equally distributed over income levels than VMT allocated 20 to them. The satiation parameter determines how much VMT is allocated to a car type once it is 21 chosen. Satiation for Sport-cars and Luxus-cars is low, that means that if a household owns such 22 a car, it is likely to be used often. This is also true for Public Transport and to MiniMVP-cars, 23 which are often used by families. Small diesel cars are used less frequently when chosen than 24

their gasoline counterparts, indicating that they usually function as secondary car.

As mentioned, the effect of Income on the satiation for allocating VMT is interesting. In 2 general the effect is negative, meaning that higher income means more VMT which this particular 3 car type. However, for MiniMVP (family-car) and ADT higher income means less use of this 4 type. While lower income people depend more on these car types, richer household can afford 5 own such a car for status reasons or because they are interested in the technology while relying 6 on other (conventional) car types for traveling. A direct policy advise that would follow from 7 this is if ADT are to be promoted for environmental reasons, it would be important to focus on 8 lower income families because here usage is much higher. 9

The influence of fuel price on satiation is much weaker, but is strongest also for family-cars 10 and ADT-cars. This is interesting insofar that high fuel prices gives additional satiation mainly 11 to cars that have already a high efficiency. When households decide to switch to more efficient 12 cars due to high fuel prices, they also reduce the allocated VMT, which is surprising in first view. 13 The interpretation resulting is that the VMT of an existing (or well known) fleet is very inelastic 14 to fuel prices and more determined by commuting distance and lifestyle choices. The first 15 reaction would be to change the car to a more efficient diesel or smaller gasoline car that fits the 16 accustomed lifestyle best. When fuel prices are so high that a more severe change is necessary, a 17 switch to ADT is needed that comes with a change of lifestyle and results in adjusted VMT. The 18 associated lifestyle change may come from the fact that the offer of ADT cars is much smaller 19 than for conventional cars and they still differ in convenience and range. If ADT-technology 20 manages to adapt further to the comfort and lifestyle level of conventional cars in the future, this 21 behavior may be different, and the usage of ADT begins at lower fuel prices and for broader 22 layers. 23

The satiation parameters $\gamma = f(\text{Income}, \text{ fuel price})$ describe the decreasing marginal utility 24 with an increasing amount of traveled kilometer. The θ constant is highly significant. The more 25 luxurious the car type, the lower that constant. That means that people are are more likely to 26 allocate their annual mileage in the more luxurious of two or more cars. For example: the main 27 car, with a higher mileage, is the bigger, more comfortable car and the second car is for the case 28 the first is not available. Cars with alternative fuel are not likely to be affected by reduction, 29 meaning that if one has for example a hybrid car, the person is not likely to have a second car 30 with which it drives even more. Income has the expected influence on the satiation such that 31 higher income gives less satiation throughout all car types except alternative fuels. Fuel price 32 has almost no significant impact on satiation which is surprising. 33

CONCLUSION

The model presented is not the first one using a multiple discrete-continuous framework to 1 model car choice and use simultaneously. But it is the first that includes a wide range fuel prices 2 as explanatory variable. The model gives insight in how car choice and car use is influenced 3 by fuel price. The low effect of fuel price on satiation and strong impact on car type choice 4 indicates that car use is inelastic regarding fuel price compared to car type selection. Household 5 are willing to change the car type, especially switch to diesel car with less consumption but 6 they will not reduce their VMT substantially. This indicates for further policy consideration 7 that, given a choice set with sufficient low consumption alternatives, a rise in fuel price would 8 lower the overall consumption and the environmental burden, but not diminish the mobility of 9 the population. But it also shows that for this purpose very high fuel prices are necessary. 10

A study of Ewing and Sarigöllü (29) using discrete choice experiments showed a preference 11 for cleaner vehicle in the case of equal comfort and capability. The gap between the current 12 level of fuel prices and the level where households switch to ADT can be seen as a willingness 13 to pay for the comfort differences between gasoline/diesel and ADT vehicles. A optimal policy 14 approach would consider a mixture of closing that gap by both increase fuel prices and decrease 15 the differences in comfort. Further research in this area would be to repeat a similar survey not 16 only in other regions than Switzerland, but also after a few years when the choice set of car 17 types with ADT has increased and the comfort gap has decreased. Further research should also 18 include electric vehicles more explicitly than in this work. When the survey was conducted only 19 few electric vehicles were available in the market and they were not broadly known. Given the 20 technological development in the field the situation might be very different within the next five 21 years. 22

The other conclusion we can draw from this work is that the multiple discrete-continuous framework used is appropriate and useful. Performance tests of disaggregate simulation of the model have confirmed this finding. The classification is reasonable although limited to 17 alternatives. Future work includes further exploration of the existing data set with a greater (or different) choice set classification and a nested structure to capture similarities between drive-train technologies or other attributes.

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