Householdfleet adaptation as reaction to price regulations: A stated adaptation experiment on the promotion of electric vehicles

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SHORT SUMMARY

The goal to limit global warming requires a shift to electric vehicles and a reduction of vehicles in total. To achieve this transition, governments could design price regulations effectively. The potential effect of different price regulations has been assessed by surveying 466 respondents. After providing detailed information on all mobility tools in the household, respondents were faced with four scenarios with varying price regulations concerning prices for fuel, CO_2, electricity, and public transport. Given the reported mobility tools and supported by live calculation of resulting cost changes, respondents were asked to adapt their household fleet while being allowed to choose the mobility tools at a high level of detail. Results of a multinomial logit model show that increasing fuel prices, very low electricity prices, high EV subsidies and low public transport prices have the potential to decarbonize household fleets (remove conventional vehicles and/or replace by an electric vehicle).

Keywords: sustainable mobility, electric vehicle, political incentives, multinomial logit model, stated adaptation

1. INTRODUCTION

To reduce greenhouse gas emissions in the transport sector a shift from vehicles with internal combustion engine (ICE) to electric vehicles (EV) is required. For this purpose, governments are implementing policies to promote EVs. However, several studies investigate either isolated economic interventions such as fuel prices (see e.g. Erath and Axhausen, 2010; Jäggi et al., 2012; Liao et al., 2017). They show that only a great increase of fuel prices have the potential to increase the market share of alternative fuel vehicles (Jäggi, 2015; Lebeau et al., 2012). However, not only fuel price is of relevance to promote the shift from ICEs to EVs. Research has shown that higher operating costs have a negative effect on the preference of a vehicle (Beck et al., 2017; Helveston et al., 2015; Higgins et al., 2017; Jensen et al., 2020; Li et al., 2020). Free charging has a positive effect on adoption of EV and is after free parking the incentive with the highest willingness-to-pay for a vehicle (Langbroek et al., 2016). Further, persons intending to buy a new vehicle prefer lower purchase costs (Helveston et al., 2015). Studies show that price subsidies have a positive effect on the choice of EVs (Bjerkan et al., 2016; Higgins et al., 2017; Lebeau et al., 2012) and on the diffusion of EVs in general (Buchmann et al., 2021; Melton, 2020). Therefore, not only effects of fuel prices, but also EV purchase subsidies and electricity prices need to be investigated.

However, large majority of research either conduct stated preference studies to show, which prices have an effect on the choice of a vehicle type (Beck et al., 2017; Bjerkan et al., 2016; Helveston et al., 2015; Higgins et al., 2017; Jäggi, 2015; Jensen et al., 2020; Langbroek et al., 2016; Lebeau et al., 2012; Li et al., 2020) or simulation studies on market diffusion potentials (Buchmann et al., 2021; Melton, 2020). Revealed preferences studies mostly investigate the effect of socio-demographics (Brückmann et al., 2021; Jakobsson et al., 2016). However, to our best knowledge, there are no studies, which would model the effects of price regulations on fostering households' adaption of their household fleet. Therefore, this study is aiming to analyze the effectiveness of fuel prices, CO_2 surcharge on fuel prices, electricity prices, and EV purchase subsidies on household's stated decisions to either adopt an EV, replace an ICE by an EV, and to remove an ICE. Besides that, the effect of reduced prices for public transport will be considered, since the decarbonization of the transport sector requires not only the adoption of EVs but a general reduction in vehicle usage.

METHODOLOGY

Data and sample

Adults of 18 years and older were recruited via an introduction letter and a follow-up recruitment phone call from a sample of 6,107 addresses in the South-West of Germany. Computer-assisted personal interviews were conducted from January to December 2020. In total, 466 individuals completed the survey providing information on the household (for details on fieldwork see Gutjar et al. (2021); Gutjar and Kowald (2021a)). After data cleaning and exclusion of households without persons owning a driver license, data from 444 respondents will be considered for analyses.

Survey design

Firstly, the respondents provided information on the household (e.g. household income, housing type), the sociodemographic characteristics, and mobility behavior of every household member (e.g. age, gender, car availability). Further, to answer the research question a two-stage process was created:

In the first stage, revealed preferences (RP) for mobility tools in the household fleet were collected. Respondents provided detailed information on all vehicles (e.g. vehicle type, engine type, annual vehicle kilometers traveled (VKM)), motorcycles, and public transport subscriptions available.

Next, a stated adaptation experiment (Lee-Gosselin, 1996) was designed to assess the effect of price regulations, which are presented in **Table 1** together with their variation. Based on these price attributes and variation levels, an efficient experiment design (Rose and Bliemer, 2014) was created in Ngene (Rose et al., 2018) resulting in 20 scenarios divided into five blocks, so that every respondent was faced with four different tasks. Each task was designed as an iterative adaptation of the household fleet under a given scenario: Employing the RP data on mobility tools in the household, the survey program initially calculated the actual household fleet costs and additionally presented changes in monthly and annual costs for the actual household fleet as a consequence of the hypothetical price regulations given in the scenario. Respondents were asked to react to the scenario by adapting the household fleet under consideration of the financial restrictions and the mobility needs of the household. They could e.g. remove present and/or add new vehicle(s), motorcycle(s), and public transport subscriptions and adjust the annual VKM. For every adopted vehicle, a vehicle type and an engine type (gasoline, diesel, BEV, PHEV) had to be specified. Respondents were supported by a real-time calculation of the monthly and annually household fleet costs to allow a comparison of the resulting and current costs after every adaptation. Thus, they were able to adjust the mobility tools until they found the optimal household fleet under given price regulations (for details on the study design see Gutjar and Kowald (2021b) and Reckermann et al. (2021)). Finally, n=1,737 observations (stated adaptations) from 466 individuals will be analyzed.

Table 1. Stated adaptation experiment: price attributes and variation levels (Gutjar and Kowald, 2021b)

price attribute	variation levels	model changes
fuel price (€/l)	1.50* / 3.00 / 4.50	sum (continuous): 0 / 0.20 / 0.60 / 1.50 / 1.70 / 2.10 / 3.00 / 3.20 / 3.60
CO_2 surcharge (€/liter fuel)	0.00* / 0.20 / 0.60	
electricity price (€/100km)	0.00 / 3.50* / 7.00	-3.50 / 0 (reference) / +3.50
purchase bonus for EVs (€)	2,000 / 6,000* / 10,000	-4,000 / 0 (reference) / +4,000
public transport prices relative to today	free / 50% of today's price / as today*	-100 / -50 / 0 (reference)

Note: * = value at the time of fieldwork

Estimation

Since the aim of this study is to model adaptation (changes) of the household fleet, changes in price regulations in comparison to the reference values at the time of fieldwork will be modelled. For this purpose, fuel prices and CO_2 surcharge were summed to one continuous variable, while dummy variables were created for the remaining price regulations with no change in prices incorporated as reference category. The created variables to model changes in correspondence to the variation of the price regulations are presented in **Table 1**.
The changes between RP vehicle ownership and the final adapted household fleet as reaction to price scenarios will be modelled as the outcome with reference to no change (no adaptation to vehicle ownership):

- **add an EV** (if an EV was added as an additional vehicle to the household fleet; the alternative is always available)
- **remove ICE** (if at least one existing ICE was removed from the household fleet; the alternative is available to households with min. one ICE)
- **replace ICE by EV** (if at least one existing ICE was removed but an EV was included instead; the alternative is available to households with min. one ICE)
- **remove and replace ICE (**if at least two existing ICEs were removed and an EV included instead; the alternative is available to households with min. two ICEs)

The frequencies (absolute and relative) of alternative availability and actual choices (n=1,737 observations) are presented in **Table 2**.

Table 2. Description of choices (adaptations)

choice	n available	n chosen	% chosen overall	% chosen when available
no change	1,737	1,191	68.57	68.57
add an EV	1,737	74	4.26	4.26
remove ICE(s)	1,605	123	7.08	7.66
replace ICE(s) by EV	1,605	306	17.62	19.07
remove & replace ICE(s) by EV	701	43	2.48	6.13

Total	1,737	100	
Note: changes not modeled due to a small number of observations (n≤10): add ICE, remove EV, replace ICE by EV & add EV			

Since the presented adaptation alternatives are discrete choices, they will be analyzed by applying the random utility maximization theory, which assumes respondents rationally choose the alternative with the highest associated utility (Adamowicz et al., 1994; Louviere et al., 2010). An individual n confronted with j alternatives in t choice tasks associates an indirect utility U_{njt} for an alternative and chooses the alternative with the highest utility. The indirect utility U_{njt} of an alternative j is decomposed as

$$U_{njt} = V_{njt} + \varepsilon_{njt} = x'_{njt}\beta + \varepsilon_{njt} \quad (1)$$

where $\mathrm{U_{njt}}$ is not observed, $\mathrm{V_{njt}}$ is the deterministic utility of alternative j, and $\varepsilon_{\mathrm{njt}}$ is a random component not included in $\mathrm{V_{njt}}$; $\mathrm{V_{njt}}$ can be specified by $x'_{\mathrm{njt}}\beta$, where x is a vector of explanatory variables (e.g. attribute levels, socio-demographics), and β are the coefficients to be estimated. Further, alternative-specific constants (ASC) (Train, 2009) were estimated.

2. RESULTS AND DISCUSSION

Data analyses were performed with R using the package *apollo* (Hess and Palma, 2019; R Core Team, 2020) for the step-wise estimation of a multinomial logit model (MNL) (Louviere et al., 2000; Train, 2009). The results of the current MNL model are presented in **Table 3** (previous steps and sample descriptions are available upon request).

As expected, increasing fuel price (including CO_2 surcharge) has a positive effect on the decision to remove an ICE, replace an ICE with EV, and do both. A drastic reduction in electricity prices (for free) increases the utility to replace an ICE with an EV and to do both, remove and replace an ICE. However, it has also a positive effect on the adoption of an EV as an additional vehicle, which needs to be considered (rebound effect). Correspondingly, increased electricity prices decrease the utility to add an EV but also to adopt one as a replacement for an ICE. Interestingly, for the purchase bonus, no strong effects have been found. However, the reduction of the EV subsidy by 4,000€ reduces the utility to add an EV and to choose both remove and replace an ICE, while an increase by 4,000€ has a positive utility on the replacement of an ICE with an EV. Free public transport (-100%) has a positive impact on the removal of an ICE and to do both remove and replace existing ICEs.

In comparison to no change, the utility of adding an EV and doing both removing and replacing an ICE is decreasing with age, while it is firstly positive but becomes negative with higher age for the alternatives to remove an ICE or to replace an ICE. Interestingly, while highly educated respondents (in comparison to low-middle education) prefer to remove an ICE, replace an ICE and do both, low-educated persons prefer to adopt an EV as an additional vehicle (e.g. BEV might serve as a status symbol). Higher equivalized household income (considering the number and age of household members) decreases the utility of removing an ICE and to do both replacing and removing an ICE, but no remarkable effect was shown for the replacement of an ICE with an EV. Further, with increasing income, the utility to add an EV increases. To sum up, with greater income households associate disutility with alternatives required for transport decarbonization, because they can afford to keep their status quo. Intuitively, households with an equal or greater number of vehicles than persons with driver's license associate greater utility with removing and replacing an ICE, while they show a lower preference for adding an EV than persons in a household with fewer vehicles than drivers. Similarly, households with greater VKM associate increasing utility with removing, replacing, and doing both removing and replacing an ICE by EV.

Table 3. Results of the MNL

	add EV			remove ICE			replace ICE			remove & replace ICE		
	β	**r. se.**	**r. t-val.**	***β***	**r. se.**	**r. t-val.**	***β***	**r. se.**	**r. t-val.**	***β***	**r. se.**	**r. t-val.**
fuel price	-			0.61	0.10	5.94	0.50	0.06	8.78	0.68	0.14	4.96
electricity price (Ref. no change)												
minus 3.50€	0.64	0.29	2.23	-			0.85	0.17	5.04	1.29	0.31	4.14
plus 3.50€	-0.68	0.39	-1.74	-			-0.40	0.22	-1.78	*fixed*		
purchase bonus (Ref: no change)												
minus 4,000€	-0.50	0.23	-2.16				*fixed*			-0.48	0.31	-1.56
plus 4,000€	*fixed*						0.21	0.14	1.47	*fixed*		
public transport (Ref: no change)												
minus 100%	-			0.21	0.19	1.10	-					
plus 100%	-			0.45	0.20	2.30	-			0.47	0.35	1.35
ASC	-1.72	0.79		-7.41	2.44	-3.04	-4.19	1.13	-3.72	-2.46	1.07	-2.30
age	-0.03	0.01	-2.18	0.15	0.09	1.68	0.08	0.05	1.68	-0.03	0.02	-1.43
age2	*fixed*		-1.99	-0.00	0.00	-1.78	-0.00	0.00	-2.06	*fixed*		
education												
low	*Ref.*											
middle				*Ref.*			*Ref.*			*Ref.*		
high	-0.66	0.42	-1.56	0.54	0.30	1.78	0.32	0.221	1.44	0.80	0.57	1.41
equivalised household income	0.48	0.16	2.92	-0.25	0.14	-1.76	*fixed*			-0.61	0.30	-2.03
n vehicles ≥ n drivers (Ref: less)	-0.76	0.35	-2.19	0.45	0.31	1.44	0.23	0.206	1.09	*fixed*		
VKM	*fixed*			0.01	0.01	1.19	0.01	0.008	1.74	0.03	0.01	2.52
Number of individuals	444											
LL (final)	-1452.59											
Adj.Rho-square	0.3976											
AIC	2979											
BIC	3181											

Note: r. se. = robust standard error; r. t-val. = robust t-value; - = not estimated (e.g. no previous hypotheses); fixed = parameter fixed to zero during the step-wise estimation procedure (e.g. small and insignificant parameter, small number of observations (n<20)), Ref.= Reference category

3. CONCLUSIONS

Given study contributes to previous research by modeling potential adaptations of vehicle ownership as a consequence of political incentives and other price regulations relevant to transport decarbonization. Preliminary results have been presented. Next, this model will be extended by interactions of price attributes with socio-demographic characteristics to explain taste heterogeneity (e.g. are households with greater household income less sensitive towards price increases?). Further, an integrated choice latent variable (ICLV) (Abou-Zeid and Ben-Akiva, 2014) model will implement the effect of the latent factor intention to buy an EV as a direct predictor of behavior (Ajzen, 1991). All results along with policy implications will be presented at the conference if accepted.

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REFERENCES

Abou-Zeid, M., Ben-Akiva, M., 2014. Hybrid choice models, in: Handbook of Choice Modelling. Edward Elgar Publishing.

Adamowicz, W., Louviere, J., Williams, M., 1994. Combining revealed and stated preference methods for valuing environmental amenities. J. Environ. Econ. Manag. 26, 271–292. https://doi.org/10.1006/jeem.1994.1017

Ajzen, I., 1991. The theory of planned behavior. Organ. Behav. Hum. Decis. Process. 50, 179–211.

Beck, M.J., Rose, J.M., Greaves, S.P., 2017. I can't believe your attitude: a joint estimation of best worst attitudes and electric vehicle choice 21.

Bjerkan, K.Y., Nørbech, T.E., Nordtømme, M.E., 2016. Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway. Transp. Res. Part Transp. Environ. 43, 169–180. https://doi.org/10.1016/j.trd.2015.12.002

Brückmann, G., Willibald, F., Blanco, V., 2021. Battery Electric Vehicle adoption in regions without strong policies. Transp. Res. Part Transp. Environ. 90, 102615. https://doi.org/10.1016/j.trd.2020.102615

Buchmann, T., Wolf, P., Fidaschek, S., 2021. Stimulating E-Mobility Diffusion in Germany (EMOSIM): An Agent-Based Simulation Approach. Energies 14, 656.

Gutjar, M., Kowald, M., 2021a. Political Incentives to Promote Electric Vehicles: Results From a Stated Adaptation Experiment, in: Ryan C. P., W., Jiangping, Z., W. Y., S. (Eds.), Sustainable Mobility - Proceedings of the 25th International Conference of Hong Kong Society for Transportation Studies (HKSTS). Hong Kong Society for Transportation Studies Limited, Hong Kong, pp. 215–222.

Gutjar, M., Kowald, M., 2021b. Electro mobility acceptance: The influence of political bonus and malus factors. Presented at the Symposium of the European Association for Research in Transportation, Symposium of the European Association for Research in Transportation, Lyon, France.

Gutjar, M., Plotz, N.E., Kistner, R., Kowald, M., 2021. Feldbericht zur sozialwissenschaftlichen Begleitforschung in „Electric City Rüsselsheim (Arbeitsberichte Fachgruppe Mobilitätsmanagement No. 014). Hochschule RheinMain, Wiesbaden.

Helveston, J.P., Liu, Y., Feit, E.M., Fuchs, E., Klampfl, E., Michalek, J.J., 2015. Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the US and China. Transp. Res. Part Policy Pract. 73, 96–112.

Hess, S., Palma, D., 2019. Apollo: A flexible, powerful and customisable freeware package for choice model estimation and application. J. Choice Model. 32, 100170. https://doi.org/10.1016/j.jocm.2019.100170

Higgins, C., Mohamed, M., Ferguson, M., 2017. Size Matters: How Vehicle Body Type Affects Consumer Preferences for Electric Vehicles. Transp. Res. Part Policy Pract. 100, 182–201. https://doi.org/10.1016/j.tra.2017.04.014

Jäggi, B., 2015. Decision Modelling on Household Level for Energy, Fleet Choice and Expenditure (PhD Thesis). ETH Zurich.

Jakobsson, N., Gnann, T., Plötz, P., Sprei, F., Karlsson, S., 2016. Are multi-car households better suited for battery electric vehicles? – Driving patterns and economics in Sweden and

Germany. Transp. Res. Part C Emerg. Technol. 65, 1–15. https://doi.org/10.1016/j.trc.2016.01.018
Jensen, A.F., Thorhauge, M., Mabit, S.L., Rich, J., 2020. Analyses of EV buying preferences SP method and model (DTU Management Rapport). Technical University of Denmark.
Langbroek, J.H., Franklin, J.P., Susilo, Y.O., 2016. The effect of policy incentives on electric vehicle adoption. Energy Policy 94, 94–103.
Lebeau, K., Van Mierlo, J., Lebeau, P., Mairesse, O., Macharis, C., 2012. The market potential for plug-in hybrid and battery electric vehicles in Flanders: A choice-based conjoint analysis. Transp. Res. Part Transp. Environ. 17, 592–597.
Lee-Gosselin, M.E.H., 1996. Scope and potential of interactive stated response data collection methods, in: Conference on Household Travel Surveys: New Concepts and Research Needs. pp. 12–15.
Li, L., Wang, Zhiqiang, Chen, L., Wang, Zixuan, 2020. Consumer preferences for battery electric vehicles: A choice experimental survey in China. Transp. Res. Part Transp. Environ. 78, 102185.
Louviere, J.J., Flynn, T.N., Carson, R.T., 2010. Discrete choice experiments are not conjoint analysis. J. Choice Model. 3, 57–72.
Louviere, J.J., Hensher, D.A., Swait, J.D., 2000. Stated choice methods: analysis and applications. Cambridge university press.
Melton, N., 2020. Which plug-in electric vehicle policies are best? A multi-criteria evaluation framework applied to Canada. Soc. Sci. 15.
R Core Team, 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing.
Reckermann, H., Kistner, R., Gutjar, M., Kowald, M., 2021. Die Berechnung von Pkw-Kosten: Vorstellung bestehender Ansätze und einer eigenen Methode (Arbeitsberichte Fachgruppe Mobilitätsmanagement No. 007). Hochschule RheinMain, Wiesbaden.
Rose, J.M., Bliemer, M.C.J., 2014. Stated choice experimental design theory: the who, the what and the why, in: Handbook of Choice Modelling. Edward Elgar Publishing, pp. 152–177.
Rose, J.M., Collins, A.T., Bliemer, M.C.J., Hensher, D.A., 2018. Ngene (Version 1.2.1.).
Train, K.E., 2009. Discrete choice methods with simulation. Cambridge university press, New York, NY, US.