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Human Factors and Political Price Regulations to Enhance Electric Vehicle Miles Traveled

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ABSTRACT

A shift to electric vehicles is necessary for transport decarbonization and requires the consideration of human factors in the design of political regulations. By applying the Theory of Planned Behavior this research identifies key motivational determinants of the decision to state a higher share of electric vehicle miles traveled. In a stated adaptation experiment, respondents were confronted with new price regulations and could adapt all mobility tools in their household, e.g. include an electric vehicle, and specify the annual vehicle miles traveled. The results of a structural equation model on data of 424 respondents show that the stated proportion of electric vehicle miles traveled is higher with a person's greater intention to buy an electric vehicle, while the intention itself is predicted by a person's attitude, subjective norm, and perceived behavior control of buying an electric vehicle.

Keywords: Sustainable mobility, Electric vehicle, Vehicle miles traveled, Theory of planned behavior, Structural equation model

INTRODUCTION

The adoption of electric vehicles (EVs) together with reduced use of internal combustion engine vehicles (ICE) has a high potential to decarbonize transportation. Thus, in near future, vehicle miles traveled (VMT) with an ICE need to be substituted by VMT with an EV. The market diffusion of EVs depends on multiple factors external to the individuals such as technological capabilities, economic performance, and political regulations. To accelerate the shift from ICEs to EVs, political interventions in terms of price regulations as providing bonuses for the use of an EV combined with malus factors for the use of ICE vehicles might be successful on the one hand. On the other hand, behavior is related to internal human factors such as personality traits and attitudes (Ajzen, 1991). Therefore, when designing interventions to enhance electric VMT, socio-psychological perspectives focusing on the motivational process concerning behavior need to be considered. For this reason, this study aims to answer the following research question: *What are the motivational drivers of individuals to perform a higher proportion of annual VMT with an EV?*

A widely used theoretical approach to predict and explain people's behavior under consideration of human factors is the *Theory of Planned Behavior*

(TPB) by Ajzen (1991). Since interventions based on TPB were shown to be successful in various behavioral domains (Steinmetz et al., 2016), TPB will be applied to answer the research question. Ajzen's (1991) TPB focusses on the *intention* to perform a behavior (IB) as the major determinant of the actual behavior. Individuals with strong IB are more motivated to put the required effort into performing the behavior, which results in a higher likelihood for its occurrence. However, IB depends on an individual's ability and resources to perform a certain behavior. In detail, IB is determined by the *attitude* (A) towards the behavior, *subjective norm* (SN), and *perceived behavioral control* (PBC). Concerning the performance of a certain behavior, A corresponds to a person's evaluation of its favorability, SN represents a person's perception of social pressure to its performance or avoidance, and PBC describes how far an individual perceives himself/herself to possess the required resources for its performance. Additionally, PBC is assumed not only to have a direct effect on IB but also on the behavior itself. Further, IB, SN, and PBC are intercorrelated latent constructs. However, Ajzen points out that depending on the behavioral field, not all outlined relationships are necessarily significant. Therefore, although the TPB has been widely used (Steinmetz et al., 2016), it has to be translated and adopted to investigate the impact of human factors on the decision to drive a higher proportion of electric VMT.

In the transportation sector, TPB was successfully employed to model the effects of A, SN, and PBC on the intention to use EVs (Moons & De Pelsmacker, 2015; Shalender & Sharma, 2021), EV sharing (Zhang et al., 2018), (shared) autonomous vehicles (Jing et al., 2019). Only a few studies modeled the impact of PBC and IB on the actual performance of a behavior. Javid et al. (2022) found a weak direct effect of PBC on willingness to use an EV but not on willingness to buy an EV, while IB showed a positive significant effect on both behavioral outcomes. Bhutto et al. (2021) found a positive significant effect of IB on willingness to pay more for an EV but did not specify the path from PBC to the behavior. Both studies consider latent (not directly observable) behavioral outcomes and do not investigate any manifest behavior. Moreover, none of the outlined research has focused on the substitution of VTM with an ICE by electric VMT, which will be done in the given study to close this gap. Based on TPB and empirical findings in the introduced studies, the following hypotheses were outlined (see *Figure 1* for graphical representation and empirical support):

- ***H1:*** Individuals with higher A towards EVs have higher intention to buy an EV;
- ***H2:*** Individuals with higher SN have higher intention to buy an EV;
- ***H3a:*** Individuals with higher PBC have higher intention to buy an EV;
- ***H3b:*** Individuals with higher PBC indicate a higher proportion of electric VMT;
- ***H4:*** Individuals with higher intention to buy an EV indicate a higher proportion of electric VMT.

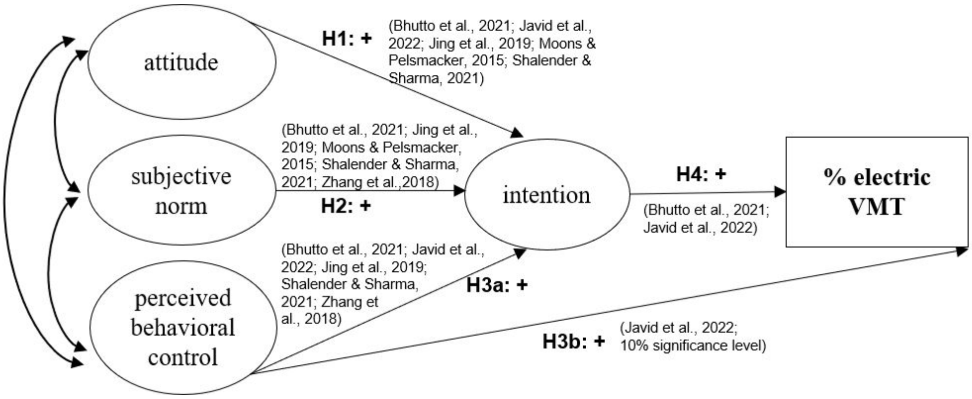

Figure 1: Theory of planned behavior (Ajzen, 1991, p. 182) with hypotheses and empirical support.

Latent variables are represented as ovals and the manifest variable as square. One-sided arrows represent direct effects and two-sided arrows represent covariances. Empirical support on the hypotheses is referenced in brackets.

METHODOLOGY

Computer-assisted personal interviews (CAPI) were conducted with respondents in the South-West of Germany. TPB constructs A, SN, PBC, and IB are latent constructs (Ajzen, 1991), which need to be reflected by manifest indicators (Brown, 2015). Therefore, for every TPB construct, four items were formulated as indicators to be measured on a seven-point Likert scale (items used in the final model will be presented in the results section). Furthermore, respondents provided information on socio-demographics and details on all available vehicles, motorcycles, and public transport tickets (PT). Based on these data, annual mobility costs of the household were immediately calculated by the survey program and directly implemented into a stated adaptation (SA) experiment designed to measure the effect of political price regulations on vehicle choices and VMT. In the experiment, respondents were asked to complete four choice tasks, whereby they were confronted with varying price regulations for fuel price, CO_2 surcharge on fuel prices, electricity price at EV charging stations, financial bonus for the purchase of an EV, and PT prices. The resulting changes in annual costs for the currently existing mobility tools in the respondent's household were presented as well. For each resulting choice situation, respondents were asked to react to these changes by adapting the mobility tools in the household. Hereby they could remove current and/or adopt new vehicle(s), motorcycle(s), and PT subscriptions for themselves and their household members. Annual VMT could be adjusted for every current and newly adopted vehicle. For every adopted vehicle, the engine type had to be specified: gasoline, diesel, battery electric vehicle (BEV), or Plug-In Hybrid (PHEV). After every adaptation, resulting costs were compared to the current costs so that respondents were able to adapt the tools until they were satisfied with their decision under consideration of the financial restrictions of their household (for more details on the study design, please consult previous reports by Gutjar and Kowald (2021)). The collected data allow a calculation of the stated annual VMT for each vehicle and engine type as a reaction to the hypothetical political price regulations. This study in particular aims to explain the chosen proportion of electric VMT as the finally stated behavior in the SA experiment situations by applying the TPB. As only BEVs drive completely electric and PHEVs only to a limited range (Shalender & Sharma, 2021), we consider only VMT with BEVs as electric. Finally, the behavioral aspect under consideration is the proportion of electric VMT (in %) (annual VMT with all stated BEVs divided by the total annual VMT with all stated vehicles and multiplied by 100). To allow its computation, observations not specifying a vehicle and/or VMT in the SA experiment were deleted. After data cleaning, the sample consists of n = 424 individuals and n = 1653 observations in the SA experiment (4 situations per respondent).

To represent the latent TPB constructs and the set of relationships outlined by the hypotheses a structural equation model (SEM) (Brown, 2015; Byrne, 2010) was estimated. Before that, a measurement model was established for every TPB construct after running confirmatory factor analyses (CFA) and modifying the model by removing items with low factor loadings and consulting model fit indices (results are available upon request). The items included to serve as indicators for the TPB constructs in the final model along with their means and standard deviations are presented in Table 1. All data analyses were performed in R (R Core Team, 2020; Rosseel, 2012). Full information maximum likelihood estimation with robust standard errors (MLR) was applied to handle missing values and non-normality of the measurements (Brown, 2015; Rosseel, 2012; Schreiber et al., 2006). Results of the final SEM are presented in the following section.

RESULTS

The results on SEM estimation are presented in Table 2 and visualized in Figure 1. The estimated model shows an adequate model fit as CFI reached the value 0.95, RMSEA is up to 0.7, and SRMR is below 0.08 (Brown, 2015; Schreiber et al., 2006). For each latent TPB factor, all standardized factor loadings are high (β >0.5) (Brown, 2015). The latent constructs A, SN, and PBC show positive covariances as outlined by the TPB (Ajzen, 1991).

Concerning the outlined direct effects on IB, the data supports H1, H2, and H3a. Namely, the standardized direct effects of A (β=0.433, z-value = 11.636), SN (β=0.246, z-value = 7.062), and PBC (β=0.188, z-value = 5.156) on IB show significant positive estimates, with z-values greater than 1.96 (Brown, 2015). The explained variance of IB by the TPB constructs is 49% (R^2=0.493).

The relative amount of the total VMT respondents stated to perform with a BEV is positively related to an individual's intention to buy an EV. The standardized direct effect of IB on the percentage of electric VMT is significantly positive (β=0.356, z-value = 12.145), which supports hypothesis H4. The data does not support H3b, which postulates a direct effect of PBC on the

Table 1. Items as indicators for the TPB constructs.

construct		item	scale	mean	sd
A	A2	The purchase of an electric vehicle is ... for solving current challenges.	1 useful – 7 harmful	4.5	1.4
	A3	By using an electric vehicle, I … set myself apart from other road users.	1 positively– 7 negatively	5.0	1.5
	A4	All in all, the purchase of an electric vehicle makes a ... contribution to addressing current challenges.	1 positive – 7 negative	4.6	1.5
SN	SN1	People who are important to me emphasize the advantages of using electric vehicles.	1 applicable – 7 not applicable	3.4	1.9
	SN2	People who are important to me are hoping for a fast diffusion of electric vehicles.		3.6	1.8
	SN3	People who are important to me think I should buy an electric vehicle as my next vehicle.		3.1	2.0
	SN4	People who are important to me see the shift to electric vehicles as one solution to current challenges.		4.1	1.8
PBC	PBC1	The use of an electric car would be technically ... for me.	1 easy – 7 difficult	6.1	1.4
	PBC2	Performing a charging process would be ... for me.		5.8	1.7
IB	IB1	I am thinking of switching to an electric vehicle.	1 strongly agree – 7 strongly disagree	3.7	2.3
	IB2	The next time I buy a vehicle, I will consider buying an electric vehicle.		4.8	2.2
	IB3	I have a strong intention to buy an electric vehicle.		3.1	2.1
	IB4	I have already done some research on buying an electric vehicle.		3.6	2.5

Note: All scales were reversed for analyses to ease interpretation.

stated proportion of electric VMT (β=0.007, z-value = 0.233), which is not surprising, since there is only little empirical support for this relationship as reported previously. The explained variance in the stated behavior by IB and PBC (while PBC has no significant direct effect) is 13% (R^2=0.129).

Table 2. Results of the structural equation model (SEM).

		β	B	se	z-value	p-value	R^2
Factor loadings							
IB	IB1	0.918	1.000				
	IB2	0.775	0.824	0.019	43.319	0.000	
	IB3	0.853	0.857	0.015	56.922	0.000	
	IB4	0.489	0.585	0.027	22.032	0.000	
A	A2	0.816	1.000				
	A3	0.674	0.823	0.036	23.082	0.000	
	A4	0.840	1.102	0.030	36.826	0.000	
SN	SN1	0.772	1.000				
	SN2	0.826	1.059	0.029	35.921	0.000	
	SN3	0.794	1.093	0.028	39.237	0.000	
	SN4	0.783	0.963	0.029	32.993	0.000	
PBC	PBC1	0.698	1.000				
	PBC2	0.559	0.954	0.121	7.910	0.000	
Regressions							
*Predictors of **IB***							0.493
A		0.433	0.772	0.066	11.636	0.000	
SN		0.246	0.367	0.052	7.062	0.000	
PBC		0.188	0.404	0.078	5.156	0.000	
*Predictors of **% electric VMT***							0.129
IB		0.356	5.396	0.444	12.145	0.000	
PBC		0.007	0.237	0.939	0.233	0.800	
Covariances							
A and SN		0.630	1.061	0.055	19.120	0.000	
A and PBC		0.316	0.367	0.050	7.381	0.000	
SN and PBC		0.259	0.362	0.053	6.842	0.000	
Model fit		χ^2	561.077				
		CFI	0.948				
		RMSEA	0.068				
		SRMR	0.043				

β = standardized parameter estimates (latent and observed variables are standardized); B = unstandardized parameter estimates; CFI = comparative fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual.

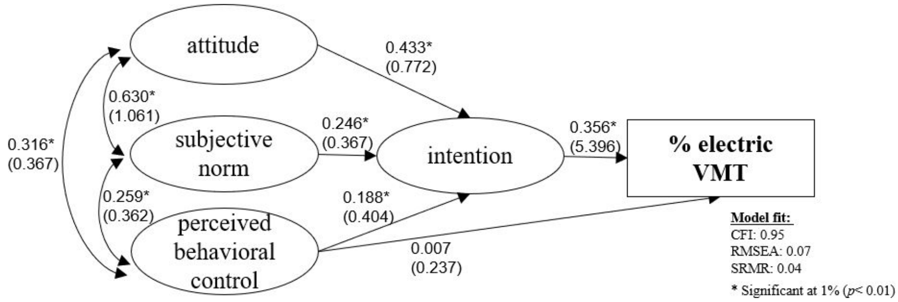

Figure 2: Final estimated structural equation model (SEM).

The figure presents standardized solution with unstandardized estimates in brackets. Indicators of latent variables and corresponding factor loadings are not displayed for readability.

DISCUSSION AND OUTLOOK

To derive recommendations for the design of political interventions to enhance the proportion of electric VMT, this study investigated the effect of human factors on the stated proportion of annual electric VMT as a reaction to new price regulations. For this aim, TPB (Ajzen, 1991) as a widely used approach to predict human behavior was applied. The analyses of the SEM found empirical support for a direct effect of intention to buy an EV on the stated proportion of electric VMT. IB in its turn is directly positively affected by A, SN, and PBC to buy an EV. Despite the lack of direct effect of PBC on the behavior, all TPB constructs are relevant to enhance electric VMT due to their indirect effect over IB. Therefore, interventions aiming to promote the shift from ICE vehicles to EVs need to target all latent TPB constructs (IB, A, SN, and PBC). In addition to financial incentives, such interventions can include, among other things, information support (Steinmetz et al., 2016).

The explained variance in the behavior (stated proportion of electric VMT) by the TPB construct IB seems to be very low (13%) at the first glance. However, the behavior considered here was the reaction to new price regulations presented to the respondent during the SA experiment, while their effects are not modeled, yet. Considering this fact, the effect of IB on behavior can be considered strong. In the next step, the presented model needs to be extended by investigating the effects of the price regulations varied in the experiment. Furthermore, socio-demographics and household characteristics are aimed to be included into the model to get further insights on human behavior. Yet, this is very rarely done in studies implementing TPB in a SEM (Shalender & Sharma, 2021).

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