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Positive and negative spillover effects from electric car purchase to car use

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Abstract
This study reports the results of two online surveys conducted on buyers of conventional combustion engine cars compared to those of electric vehicles in Norway. The results show that electric cars are generally purchased as additional cars, do not contribute to a decrease in annual mileage if the old car is not substituted, and that electric car buyers use the car more often for their everyday mobility. Psychological determinants derived from the theory of planned behavior and the norm-activation theory show a high correlation between the purchase and use stages. Electric car buyers, have lower scores on many determinants of car use, especially awareness of consequences and close determinants of car use.

Keywords: electric cars; vehicle substitution, car buying

1. Introduction

To tackle the environmental problems associated with individual motorization, two paths are conventionally considered; improvements in the technical fuel efficiency of the car fleet or reducing the number of car trips. The first strategy began to be supported when several European countries started subsidizing electric cars; e.g. in Norway, there is no purchase or value added tax on electric cars, a reduced annual tax, free or cheap use of use toll roads, parking places, ferries, and bus lanes on the roads. In August 2012 Norway had the highest number of electric cars per capita (2.75%) and the highest percentage of electric cars among all passenger cars. In September 2012, 5.2% of all new cars sold in Norway were electric cars, an incremental increase of 143% over the same month in 2011. In some urban areas electric cars were the most widely purchased car in 2012.

The environmental benefit of electric cars is still unclear (Hawkins et al., 2012). At the macro level, because of the ways electricity is generated, the global environmental impact may be worse with more electric cars than with modern, fuel efficient conventional combustion engine vehicles (Hawkins et al., 2012), but at the micro level electric cars benefit the local environment because of their lack of local emissions and low noise levels[1]. Our main focus here, however, is the potential implications on traffic volumes of a greater use of electric cars. To this end we consider stated preference data collected as part of a large survey of car buyers in Norway.

2. Methodology

To consider the factors motivating the use of electric cars use is made of a sample based on data in the Norwegian Public Roads Administration (statens vegvesen) database. In April

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[1] Although reduced noise can lead to more traffic accidents involving pedestrians and bicyclists (Brand et al., 2012).

2012 an invitation letter was sent to all private households that purchased a new passenger car in November or December 2011, and the same letter to all households who bought an electric car in 2011. Electric car buyers were over sampled to obtain a reasonable group size. The letter included information about the study that involved two online questionnaires. The first questionnaire included questions related to car purchase, and the second consisted of questions about car use. The same psychological constructs were measured in both questionnaires and the electric car buyers received the same questions as the normal car buyers[2].

In all 13,362 letters were sent out; 12.000 to normal car buyers and 1362 to electric car buyers. This resulted in an overall response rate of 13.4 % for the first questionnaire (11.8% for normal car buyers and 27.3% for electric car buyers), and of 11.69 % for the second questionnaire (10.41% for normal car buyers and 22.98% for electric car buyers). The response rate for the normal car sample is within the range expected for an online study with long questionnaires (Deutskens et al., 2004); the response rate for electric car buyers is comparatively high.

Females constituted 23.5% of the sample, with no difference between the subsamples.The total respondents had a mean age of 49.9 years. The mean age among the normal car buyers was 51.0 years which is significantly different from 45.9 years for electric car purchases. The regional distribution of participants in the normal car group corresponds well with that for the country's regional distribution. In the electric car buying group, the regional distribution matches that of electric cars sold. The average household size was 2.9 people, with a significantly higher number in the electric car group. Further, 70.1% of the sample were either married or living in registered partnerships, 17.5% co-habiting, 6.3% single, 4.2% separated or divorced and 1.9% widowed. In the electric car group the rate of married or co-habiting people was significantly larger. Overall, 73.5% of the sample had a university or college degree - 85.6% in the electric car group and 70.3% in the normal car group indicating a significant over-representative of well-educated people. Eighty-three percent of the sample were in the workforce; 93.9% in the electric and 80.1% in the normal car groups.

The following variables from both online questionnaires are used for our analysis: number of cars per household, estimated annual mileage irrespective of the used car, expected annual mileage for next year, self-reported percentage of car use for specific trips, attitudes (ATT), intentions (INT), perceived behavioral control (PBC), integrated personal norms (PN), introjected norms (IN), descriptive norms (DN), social norms (SN), awareness of responsibility (AR), awareness of need (AN) and ascription of responsibility (AR).

Cars per household and the estimated annual mileage in the previous year were recorded in the first questionnaire, while the expected annual mileage the following year was recorded in the second. The percentage of car use for specific trips was recorded separately for a number of trips (Figure 1); an eleven-point scale with 10% intervals beginning with 0% is used. Participants indicating that they never took such trips were excluded them from the analysis. For the analysis, 11-point scale was transformed into percentages assigning the middle of each category as the value. In addition electric car buyers were asked on how many of their car trips for the seven travel goals they use their electric car.

[2] As an incentive, all participants who answered both questionnaires were entered in a lottery of three iPads.

The psychological variables are measured with three items per variable and domain (buy/use) with two exceptions; the three items intended to measure perceived behavioral control were too different to be integrated into one latent variable so only the item with the highest face validity was selected and attitudes were measured with five items using a seven point agreement scale from -3 for totally disagree, to +3 for totally agree[3]. Examples and Cronbach's alpha for each scale can be found in Table 1.

[Insert *Table 1* about here]

3. Results

An analysis of variance indicates that participants who purchased an electric car have on average a significantly larger number of vehicles per household than those who purchased a normal car. Nearly 50% of normal car buyers only have one car per household, 44.5% own two, with only 6.1% own more than two. For electric car buyers, only 9.5% have it as their only car, whereas 75.7% own two cars per household and 14.9% own more than two. This means that electric cars are generally bought as an additional vehicle and not as a substitute for a conventional car; a result that differs from De Haan et al. (2006) in Switzerland.

Self-reported annual mileage was analyzed depending whether the car is electric or "normal", whether a household has one, two, or more cars, and the interaction between the two (Figure 1). While the main effect for car type is not significant, the annual mileage is increasing significantly with the number of cars per household in both groups. This increase, however, is even more pronounced in the electric car group resulting in a significant interaction term. In particular, the lower annual mileage for people that own an electric car as the only household car compared that who own only a normal car is noticeable. When the expected annual mileage for next year is compared, electric car and normal car buyers show no significant difference, unless the number of cars per household is controlled for when both the car type and the number of cars have a significant effect (Figure 2). In summary, electric car buyers expect to drive less; the more cars per household are owned, the higher mileage is expected.

[Insert *Figures 1 & 2* about here]

For people owning an electric car as a second or third vehicle there is no difference in annual mileage compared to combustion engine car owners, while individuals that only own an electric vehicle report lower annual mileage; a pattern also expected for future car use. One can only speculate on why this may be. It could be that only people that really substitute a traditional with an electric car reduce their driving and thus have a positive spillover and there are features of electric vehicles limiting this (e.g., range limits). People who become car owners by buying an electric vehicle, on the other hand may increase their personal mileage, although not by the same extent as conventional car users[4]. People that buy an electric car as an additional car show no positive spillover effect on their travel behavior.

We now turn to look at car trip by purpose; trips to work/school, transporting a child to school or kindergarten, shopping, visits of medical facilities, leisure activities, visits of friends, and holiday was compared for electric car buyers and normal car buyers (Figure 3). We find that electric car owners use their vehicles significantly more often than conventional

[3] For further descriptions of this approach see, Klöckner and Matthies (2004); Nayum, et al. (2013); Thøgersen (2006).

[4] In the sample only four participants bought an electric car as their primary vehicle.

car owners for any kind of trip, however, for most of the trips they use the electric vehicle. The implication of this, given the electricity generation mix in Norway (Hawkins et al., 2012), just focusing on vehicular use, and excluding vacation trips, is that the electric car use substantially reduced emissions. Those differences are most pronounced for work/school related trips, but also large for shopping, visits of the doctor, leisure activities and transportation of children.

[Insert *Figure 3* about here]

Finally we consider linkages between the decisions to buy a particular vehicle type and its use. The analysis involves a series of ten structural equation model comparisons outlined in Figure 4. Table 2 shows the results of the first model, where there is no interaction between purchase variables and car type, the Bayesian information criterion (BIC) for the second model and the relative improvement in model fit ∆BIC if the interaction is included. The results indicate that all models meet the basic criteria for a reasonable fit (Hu and Bentler, 1999). Further, negative ∆BICs suggest the inclusion of the interaction improves the fit of the model for awareness of consequences and injunctive norms. The table also shows the unstandardized regression weights for "use" on "buy" and car type (Model A) and "use" on "buy", car type and the interaction between the two (Model B). It indicates that all relationships between the same variables for the "buy" and "use" stage are significant and positive. The grade of congruency between use and purchase varies considerably: while the ascription of responsibility (AR), basically the degree to which a person is willing to accept responsibility for the negative outcomes of an action and rectify it, is largely stable across the domains, is perceived behavioral control (PBC), the degree a person feels capable to perform a certain action, depending heavily on the domain. Additionally, attitudes and intentions are relatively specific to buying and usage, whereas the norm related constructs are more overarching. Electric car buyers put significantly lower values on car use attitude, intention, integrated personal norm, introjected norms and awareness of consequences than other car buyers. Findings indicate that three interactions terms are significant: The relation between attitudes to buy an environmentally friendly car to the attitude to reduce car use is significantly weaker for participants that bought an electric car. The same results are seen for introjected norms and awareness of consequences.

[Insert *Figure 4* and *Table 2* about here]

Figure 5 shows the standardized regression weights of the two predictors. We see that the general norm related constructs (SN, DN, AN, AR) exhibit both a high congruency between the purchase and use stage and small impacts of the purchased car type on the mean. The more individual representations of norms are rather domain unspecific but weaker among electric car buyers. Awareness of consequences, intentions and attitudes are both relatively specific and weaker for electric car buyers. Finally, perceived behavioral control is very domain specific but not weaker for electric car buyers.

[Insert *Figure 5* about here]

While the estimated annual mileages do not suggest any negative spillover effect, the analyses of the psychological determinants of car use behavior indication some. Although many variables have a high correlation between the purchase and use stage and thus point towards a positive spillover effect (Thøgersen, 2004, Thøgersen and Ölander, 2003, Thøgersen and Noblet, 2012), the significantly lower scores for electric car owners on all variables that are close to behavior (intention, integrated personal norms, attitudes, and introjected norms) indicate that electric car owners may feel they had already 'done their share' to reduce the negative impacts from car travel[5]. The notable results of awareness of consequences being reduced might also explain the other effects, for instance: If people own an electric car the consequences of their personal car use for the environment are reduced drastically. Even if they still think that car traffic is a problem for the environment (AN) and that they should take responsibility (AR) they feel that their behavior no longer has negative consequences, thus their integrated personal norms will not be activated. They will also have less bad conscience (IN), even if their perception of other people's expectations and other people's behavior remains constant. It is theoretically satisfying to note that perceived behavioral control is very specific to the two domains while all norm-related variables are strongly congruent between the two domains. Perceived control should be related to a specific behavior and feeling able to purchase an electric car may be totally different to feeling able to reduce car use[6].

The significant negative interaction between the purchased car type and awareness of consequences as well as introjected norms indicates that the congruency is particularly impaired. The latter indicates that people that purchased electric cars possess a weaker relation between their bad conscience to buy a big car and their conscience to use the car, which again can be interpreted along the lines of Thøgersen and Noblet (2012), people that feel unable but have a conscience about their ability to reduce their car use may realize that by buying an electric car.

4. Conclusions

The Norwegian market for electric vehicles is developing quickly. In some regions an electric car is the most sold car type. This development may lead to changes in the traffic structure of Norwegian cities and this study analyzed how ownership of an electric car potentially impacts car use patterns. There are several conclusions that can be drawn based First, most Norwegians who buy an electric car buy it as an addition to their household's car fleet. Only few people substitute their conventional car, but once bought, an electric car is used for a large proportion of all trips. Those that own an electric car, only drive less than conventional car owners if it is their only vehicle. At the trip level, the data indicate that electric car owners use their car more, which is rational given the incentive structure in Norway, and that owning an electric car reduces attitudes, intentions and perceived moral obligation to reduce car use. Most psychological determinants also show a rather high correlation between car purchase and use indicating potential positive spillover effects.

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[5] This is in line with findings about recycling and reducing packaging Thøgersen (1999).

[6] As Thøgersen and Noblet (2012) point out, people that buy electric cars might so because they feel unable to reduce car use.

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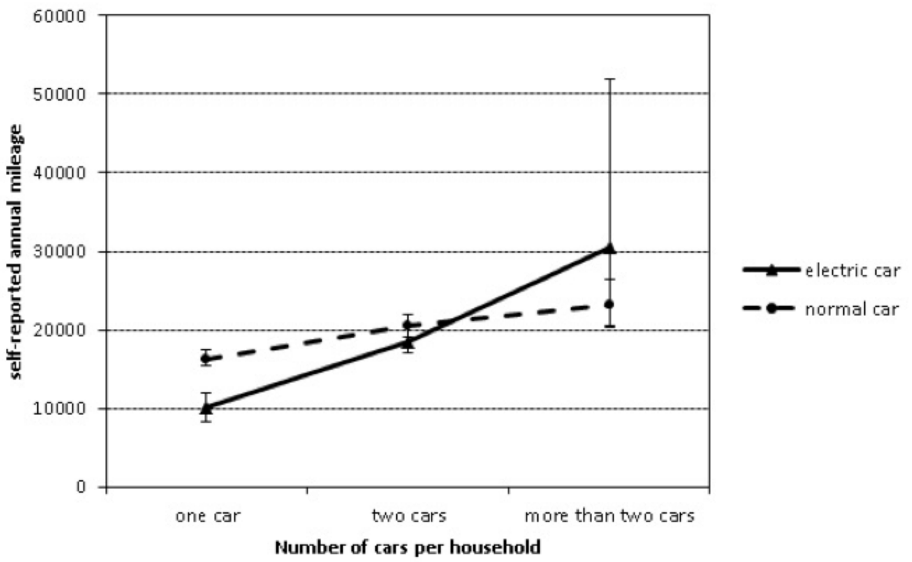


Figure 1: Reported annual mileage in the previous year against number of cars per household and purchased car type including bootstrapped 95% confidence intervals.

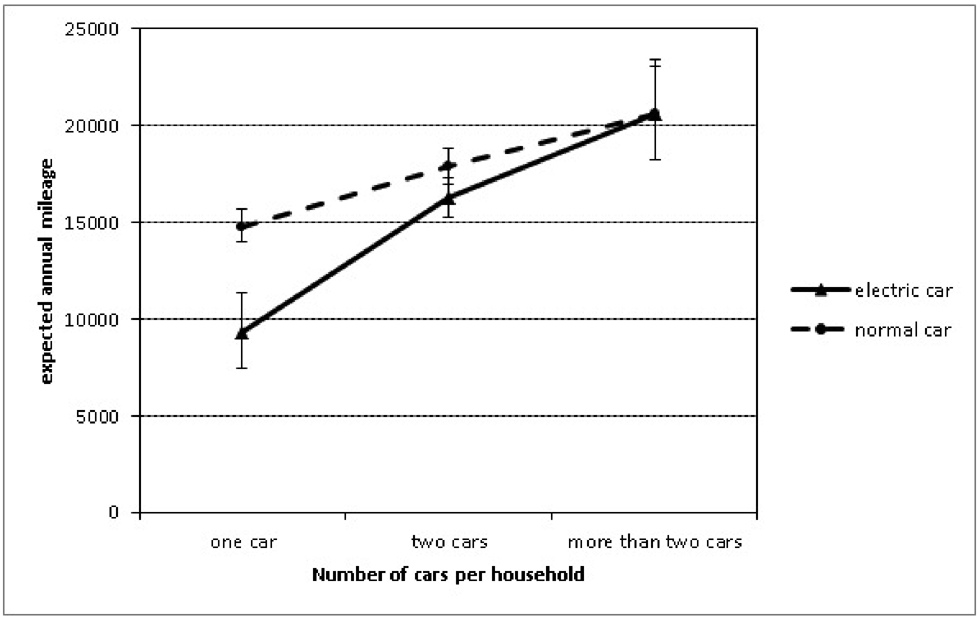


Figure 2: Expected annual mileage in the following year against number of cars per household and purchased car type including bootstrapped 95% confidence intervals.

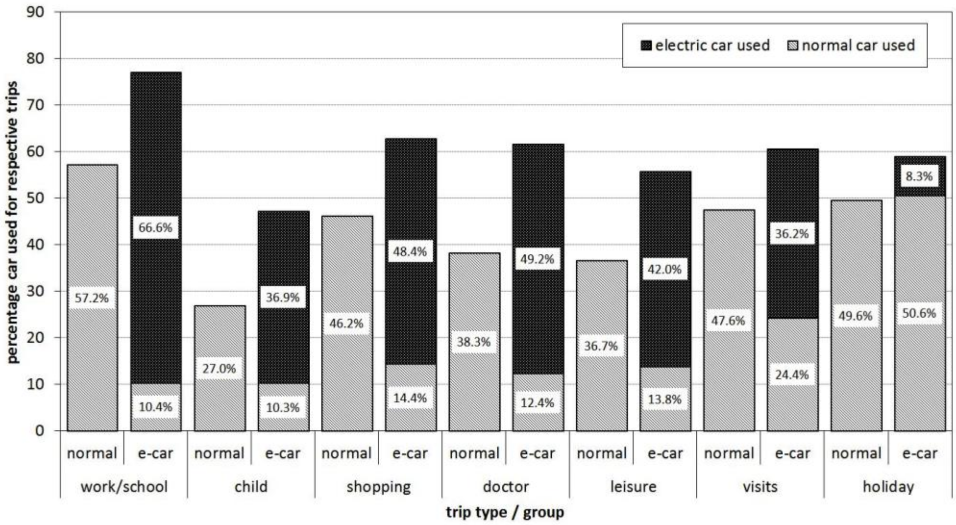
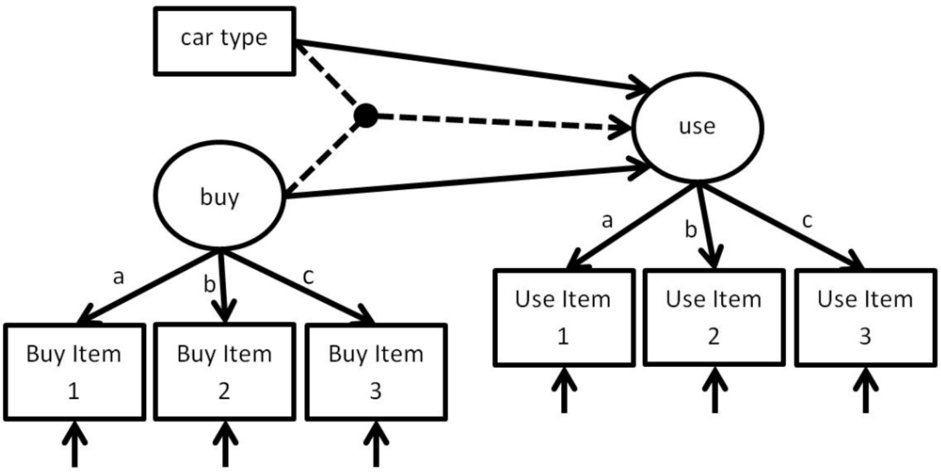


Figure 3: Self-reported percentage of car use for different trip types against car type



Note: Model test A without interaction, model test B with interaction
Figure 4: The structure of the model tested.

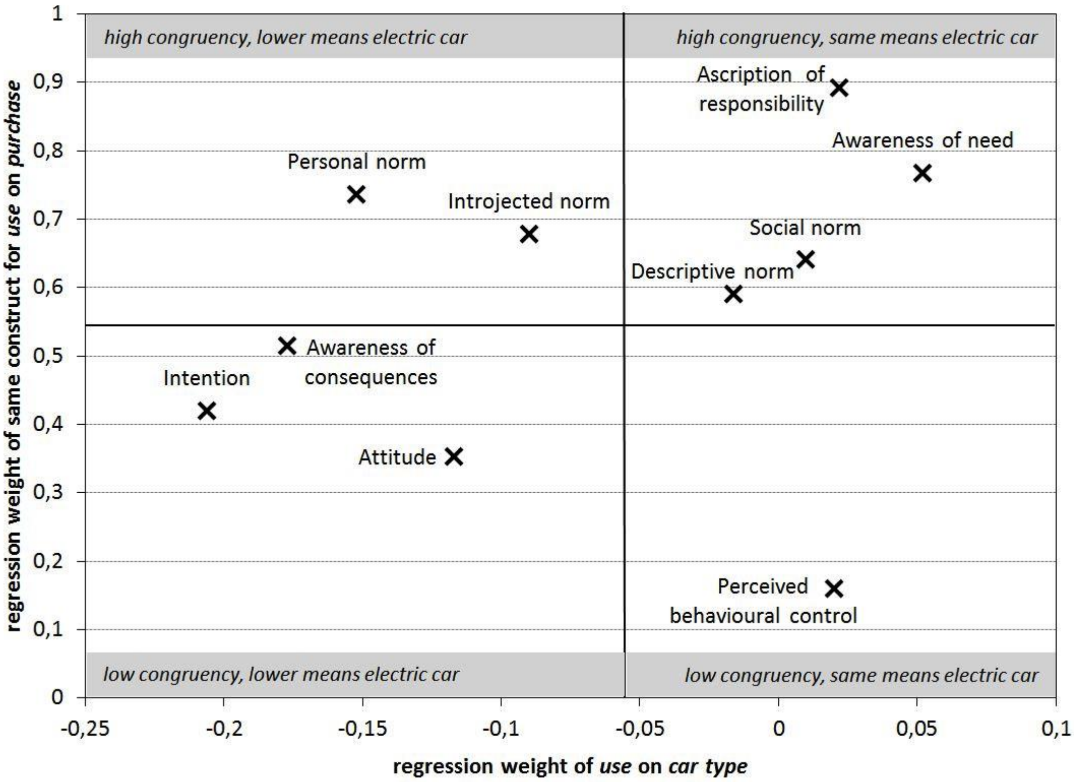


Figure 5: Standardized regression weights for "use" on "buy" and car type.

Table 1: Overview of the measures used.

	Definition	*N*	Parallel items	*Sample item purchase*	*Sample item use*	*Cronach's alpha purchase*	*Cronach's alpha use*
Attitude (ATT)	A global evaluation of how favorable a behavioral alternative is perceived	1715	5 of 5	"Do you think that buying a fuel efficient and environmentally friendly car would be very bad … very good?"	"Do you think that reducing your personal car use would be very bad … very good?"	0.91	0.88
Intention (INT)	Intention is the willingness to make an effort implement a behavior. Thereby it is a direct predictor of behavior and a result of ATT, PBC and SN	1774	2 of 3	"When I bought my car I planned to substitute my car with a fuel efficient and environmentally friendly car."	"I plan to substitute some of my car trips by other travel modes."	0.65	0.73
Perceived behavioral control (PBC)	Perceived behavioral control is a variable from the theory of planned behavior and captures to which degree a person feels capable to perform a certain behavior	1510	1 of 1	"If I wanted to I could have bought a fuel efficient and environmentally friendly car."	"If I want to I can easily reduce the number of car trips."	-	-
Integrated personal norm (PN)	An integrated personal norm is the feeling of moral obligation to act in a certain way. It is rooted in the personal value system of a person and triggered by AN, AC and AR	1774	2 of 3	"I felt obliged to save the environment when I bought my new car."	"I feel obliged to reduce the number of car trips."	0.86	0.77
Introjected norm (IN)	Introjected norms are the next to last step in the internalization process of social norms into integrated personal norms	1774	3 of 3	"To own a strong and big car gives/would give me sometimes a bad conscience."	"I get a bad conscience when I use my car unnecessarily."	0.89	0.83
Descriptive norm (DN)	The mental representation of what other people around a person do with respect to the behavior in question	1772	2 of 3	"Many people who are important to me own a fuel efficient and environmentally friendly car."	"Many people who are important to me reduce the number of their car trips."	0.79	0.60
Social norm (SN)	The mental representation of expectations relevant other people have about the behavior in question	1774	2 of 3	"I think that many people who are important to me expected that I should buy a fuel efficient and environmentally friendly car."	"I think that many people who are important to me expect that I should reduce the number of car trips."	0.74	0.70
Ascription of resposnibility (AR)	The degree to which a person is willing to accept responsibility for the negative outcomes of a behavior and taking action against it	1774	2 of 3	"I feel responsible for the environmental problems that result from the type of car I own."	"I feel personally responsible for problems that result from car use."	0.76	0.57
Awareness of need (AN)	The perceived degree for need to act against a potentially negative outcome	1774	2 of 3	"There is an acute need to do something about environmental pollution resulting from that people own big cars."	"There is an acute need to do something about environmental pollution resulting from car use."	0.86	0.82
Awareness if	The perceived amount of contribution of	1774	3 of 3	"My own decision which car I	"My personal car use contributes	0.85	0.81

consequences (AC)	one's own behavior to the negative outcomes of a behavior	should buy has a relevant impact in the environment."	to environmental problems (e.g. air pollution, noise, global warming."

Table 2: Unstandardized regression weights of Models A and B and selected model fit criteria.

	Model A				*Model B*				
	B_{use}	B_{type}	$BIC_{model\ A}$	*RMSEA*	B_{use}	B_{type}	$B_{interaction}$	$BIC_{\text{model B}}$	ΔBIC
ATT	0.340*	-0.276*	49314.13	0.086	0.374*	-0.232*	-0.173*	49314.79	0.660
INT	0.419*	-0.387*	35758.96	0.104	0.422*	-0.383*	-0.013	35766.41	7.452
PBC	0.142*	0.083			0.150*	0.199	-0.038		
PN	0.619*	-0.455*	34165.55	0.054	0.645*	-0.427*	-0.099	34168.48	2.926
IN	0.582*	-0.370*	33912.35	0.070	0.623*	-0.291*	-0.169*	33906.66	-5.691
DN	0.618*	-0.043	32224.39	0.062	0.620*	-0.045	-0.011	32231.85	7.456
SN	0.603*	0.031	32715.78	0.079	0.620*	0.015	-0.081	32721.52	5.743
AR	0.739*	0.051	34059.07	0.092	0.753*	0.063	-0.058	34065.04	5.970
AN	0.653*	0.151	32422.30	0.038	0.654*	0.152	-0.005	32429.77	7.468
AC	0.465*	-0.489*	32789.45	0.098	0.517*	-0.412*	-.233*	32780.96	-8.493

Notes: * significant at 5% (Bonferroni corrected)