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A stated adaptation instrument for studying travel patterns after electric vehicle adoption

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Abstract

This paper describes and evaluates a stated adaptation instrument to investigate the effects of a transition towards electric vehicles on travel behaviour. The respondents were equipped with an "imaginary" electric vehicle with a specific range and were asked whether they wanted to make changes in an activity-travel schedule they had previously registered. It has been found that electric vehicle use may increase car use, and that activities are likely to be cancelled in case of problems with range limitations. In this paper, the validity, reliability and practical implementation of this stated adaptation experiment are discussed.

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Keywords: stated adaptation; electric vehicles; travel behaviour; survey instrument

1. Introduction

Technological advances such as using alternative fuels have been mentioned as one way to increase the sustainability of the transport system, others being decreasing the need to travel, decreasing the distance travelled and stimulating the use of alternative transport modes (Banister, 2008). A transition process is now going on, where a, still small, part of the car drivers has changed from using a conventional, internal combustion engine vehicle (ICEV) towards using an electric vehicle (EV). This change entails a different user cost structure (Hagman et al., 2016), with higher investment costs and lower marginal user costs, as well as a limited range. Because of the range limitations of

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EVs, EV-users are likely to sometimes need to make changes in their activity-travel patterns, which can have negative effects on their (perceived) mobility. By making less car trips, the beneficial environmental effects of a transition towards electric vehicles would be reinforced, but by not being able to perform the activities one has planned to do, an impoverishment would be faced. On the other hand, because of the much lower marginal use cost of EVs, EV-users might also increase their car use by making more trips or shifting their travel mode for some of their trips, as long as they stay within the range limits of their EV. This would imply a rebound effect together with an increase in (perceived) mobility. As the range of new electric vehicles is increasing, the expectation is that the impact of the relatively low operational costs will become more important into the future. Electric vehicles create cheap mobility, but what will the effects of increased car use be on congestion, air quality and greenhouse gas emissions? Most literature concentrates about range limitations connected to EV-use (e.g. Azadfar et al., 2015; Pearre et al., 2011). However, indications of rebound effects after transition to electric vehicles have been observed (Figenbaum and Kolbenstvedt, 2013) and predicted (Fridstrøm and Alfsen, 2014) in Norway.

In this paper, a stated adaptation instrument will be discussed. This instrument has been developed in order to explore the effects of a change to electric vehicle use on travel patterns. The aim of this paper is to compare this instrument with alternative ways of data collection about travel behaviour connected to electric vehicle use, as well as to evaluate the instrument in terms of validity and reliability. Finally, some ideas of developing the instrument in the future are discussed.

2. Background

Because of the fact that the market share of electric vehicles in the vehicle fleet is currently relatively low, the question is in which way information can be obtained in order to predict the effects of large scale electric vehicle adoption on the future transport system. There are several options, some of which have been implemented in earlier research. In the following paragraphs, these options will be shortly discussed.

A comparison of travel diary data of EV-users versus non-EV-users (as in Langbroek et al., 2017a), accounting for socio-economic and contextual variables, is one option to investigate the influence of EVs on travel behaviour. In that study, it appeared that the modal share of the car is on average higher for EV-users than for non-EV users. Moreover, the EV-users in the sample make more trips per day. However, current EV-users' characteristics might deviate from the general population, leading to a risk for self-selection bias.

A longitudinal study of people switching from ICEVs to EVs is another option. Following a person's travel behaviour before and after adopting an electric vehicle is likely to elicit information about changes in travel patterns. For example, Rolim et al. (2012) did a survey study among electric vehicle users, concluding that many people changed their travel patterns and a non-negligible number of EV-users make additional trips. This result has been confirmed by another survey study in Norway (Hjorthol, 2013), that concluded that public transport use among EV adopters decreased and car use increased. However, self-selection effects are still likely to play a role: people currently adopting an electric vehicle are so-called early adopters whose attitudes and behaviour might not be representative for the entire population.

A third possibility is an experimental setting where people participate in a study where they start using an electric vehicle for a limited amount of time. There are some examples of field trials where this is the followed strategy (e.g. Franke et al., 2012; Cocron et al., 2011 & Graham-Rohe et al., 2012). The aim of many of these studies has been to follow the learning curve of people switching to electric vehicles, as well as their attitudinal changes and changes in self-efficacy. The advantage of this approach is that the shown behaviour is very realistic and that also information about the reasoning of the respondents can be elicited in interview studies. The disadvantage of this approach is however that the risk for self-selection is high: only those people that are currently very interested in electric vehicle are likely to participate in field trial studies.

A fourth possibility of trying to predict the effects of electric vehicle adoption on car use is more theoretical. In situations where the range suffices one can take the price elasticity of fuel into consideration. However, studies based on price elasticities (e.g. Odeck and Johansen, 2016) are often based on relatively small increments of the price of fuels. However, in case of electric vehicle adoption, there is a significant reduction in the fuel costs of up to 80 per cent (Hagman et al., 2016). Moreover, the use of price elasticities does not cover the effects that range limitations might have. In situations where the range does not always suffice, an approach to investigate the effects of electric vehicle adoption on travel behaviour is making use of micro-simulation. There is some literature (e.g. Weiss et al., 2017) on electric vehicle travel behaviour, based on the available range of EVs and with input from a field-trial with EVs in Berlin (Franke et al., 2012). In this study, there were merely considerations on range limitations making it impossible to do all trips that should have been done with ICEVs. The conclusion of that study was that electric vehicles drive significantly less than their conventional counterparts, resulting in a decrease of mobility (Weiss et al., 2017).

As an alternative to the approaches discussed above, this paper evaluates an instrument to use a stated adaptation approach. In the next section, an overview of stated adaptation studies within transport research is given.

3. Stated adaptation

Stated adaptation experiments are a specific type of stated preference experiments. The aim is, similar to that of other stated preference experiments, to elicit behaviour as a reaction to a certain stimulus given by the researcher (Janssens et al., 2009). What makes stated adaptation experiments different is the fact that the respondent's own behaviour is taken as a starting point. Generally, the respondent is relatively free in selecting a behavioural response.

Stated adaptation experiments have been designed in order to provide respondents with more realistic choice situations. The definition of stated adaptation experiments has developed over time. D'Arcier et al. (1998) mentioned that the specific characteristic of stated adaptation experiments is the fact that "the respondent is fully free to state which behavioural response he or she can imagine when faced with several hypothetical situations." D'Arcier et al. (1998) also considered stated adaptation experiments as a qualitative research method that can precede other stated preference studies such as stated choice experiments. Therefore, the stated adaptation experiment was described as an interview study with much emphasis on the processes leading to adaptations, as well as the reasons for a particular behavioural adaptation. After 15-20 respondents, the main components influencing choice processes will be likely to have been captured following this logic. Lesteven (2014) used a similar approach, where the respondents were invited for an in-depth interview after registering their travel behaviour in a travel diary.

Besides this qualitative approach, several stated adaptation experiments that can be analysed with quantitative methods have taken place over time. An early study that could be categorized as a stated adaptation study made use of the Household Activity Travel Simulator (Jones, 1979). The starting point for this experiment was a household travel survey. After changing some conditions of travel, the respondent makes an assessment about whether or not to adapt travel behaviour. A similar approach has been taken by Arentze (2005) in a stated adaptation study where respondents had to respond to congestion pricing scenarios. Cools et al. (2011) also investigated the effects of road pricing on travel behaviour, taking into consideration that socio-cognitive factors such as public acceptability of road pricing are likely to have an influence on the way people respond to road pricing. In this experiment, the current fixed vehicle is replaced by a taxation that is entirely based on the usage of the car rather than the ownership. Another study by Cools and Creemers (2013) investigated the effects of weather (forecasts) on travel behaviour.

Although there is a variety in the way stated adaptation experiments are conducted and analysed, the common factors are the following:

- The base is initial travel behaviour
- The researcher manipulates the circumstances that might affect travel behaviour
- The respondent responds to the new circumstances by changing or not changing his/her travel behaviour.

4. Methodology

The stated adaptation instrument that will be discussed in this paper is based on a one-day travel diary in which the respondents register all trips including the transport modes they have used, time of departure, address of origin, the number and location of transfers, address of destination and time of arrival. After receiving the answers of the online survey, a follow-up survey was prepared. This follow-up survey consisted of three stated preference tasks, out of which this stated adaptation experiment was the second task. This instrument should trigger behavioural adaptations resulting in less car travelling (because of range limitations) and should also create circumstances under which increased car travelling can occur (because of lower marginal costs) in order to get a complete image of the likely implications of a transition towards electric vehicles.

The respondents were asked if they would make any adaptations compared to what they had registered in their one-day travel diary in fictive situations where they were equipped with an electric vehicle with a certain range. The aim of this stated adaptation experiment is to elicit information about the way in which the characteristics of electric vehicles (range limitations and lower marginal cost of use) influence daily travel behaviour. Figure 1 illustrates that there is likely to be a zone where range limitations force to decrease car use, a zone where car use is likely to stay the same and a zone where abundant range may stimulate increased car use.

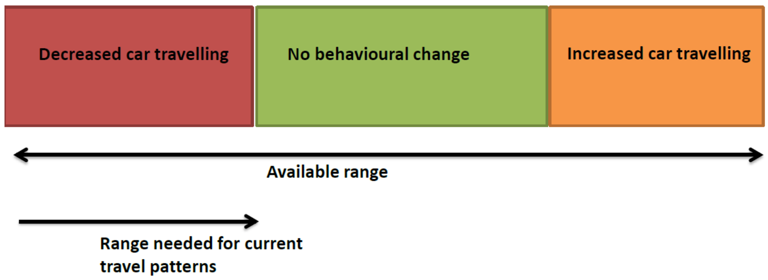

Fig. 1. Available range and behavioural change

In order to consider these different types of behavioural adaptations that can arise because of changing to an electric vehicle, the respondents were asked to respond in situations where the range of their "electric vehicle" was 60, 90, 120, 150 or 300 per cent of the distance they had travelled by car during the travel diary day in order to simulate situations with range shortage as well as situations with range abundance. For respondents that did not drive during their one-day travel diary, the kilometre budgets are based on their total travel distance.

The respondents were normally assigned to three out of five scenarios. However, the available range should always exceed 10 kilometres and not be more than 500 kilometres. This minimum of 10 km was set in order to avoid creating too similar scenarios, while the maximum of 500 km was based on the range of a Tesla Model S with a large battery pack at the time the survey was conducted. Because of these minimum and maximum values, overlapping scenarios could occur, so some respondents were only exposed to one or two scenarios.

In each scenario, the respondent had to imagine that instead of the vehicle that was available during the travel diary day (which may be an electric vehicle or a conventional vehicle), he or she has access to an electric vehicle with a certain range prior to the first trip of the day. The respondents were not allowed to charge their EV at any other location than at home. This rule has been set due to the fact that different people might have different knowledge levels about the supply of public charging infrastructure. By allowing (fast) charging out-of-home, it becomes hard to distinguish which behavioural effects are due to lack of possibilities to charge during the day and which effects are due to mere lack of knowledge about these possibilities. Furthermore, information is given about the electricity price per kilometre (around 2 euro per 100 kilometres), as well as information about the petrol price per kilometre (around 10 euros per 100 kilometres).

In order to facilitate the respondents participating in this stated adaptation experiment, the question of travel behaviour changes was divided into smaller questions. Firstly, it was asked whether the respondent would change anything in the current travel pattern. Respondents having driven more kilometres during their one-day travel diary than their new kilometre budget are supposed to decrease their car travelling. Respondents being exposed to the other scenarios or not having made any car trips during the one-day travel diary day might also change their travel patterns but in this case, this is not necessary.

The respondent was guided through a list of different types of potential behavioural alterations. It was asked whether the respondent would cancel trips, add trips, change the destination of any trip and change the travel mode of any trip from "car as a driver" to an alternative mode of transport or the other way around, chain trips, change routes or the departure time of any trip. The trips made were displayed to the respondents, showing the departure time, arrival time, origin and destination as well as all transfer points. With icons, the different transport modes that had been used were displayed. Moreover, for each trip leg, the distance was displayed in order to facilitate understanding of the respondent's self-registered travel behaviour (see Figure 2).

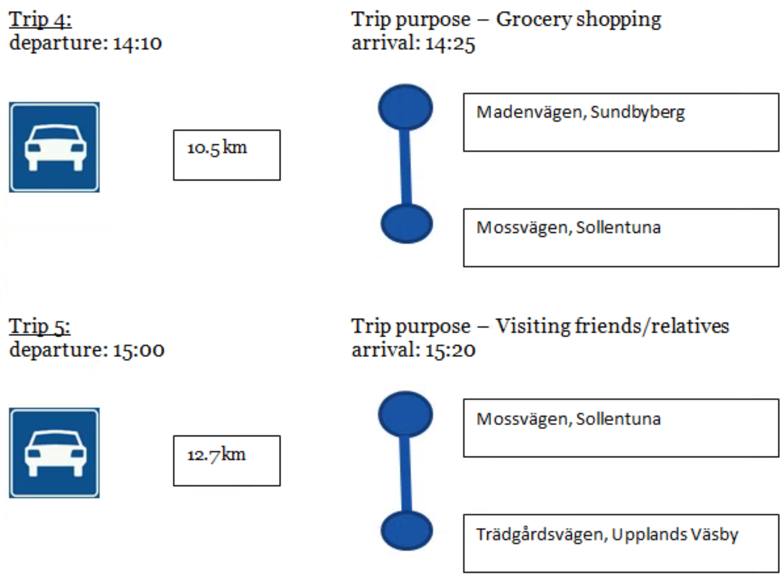

Fig. 2. Example of display travel diary data in stated adaptation experiment

The respondents were assisted by providing them with specific information regarding their trips. For example, if a respondent wanted to cancel an activity, he or she could see a list of all activities that were registered in the one-day travel diary, with trip purpose and address of that trip.

As opposed to the first part of the survey that was an online-survey, for the part including this stated adaptation experiment a paper-and-pencil survey was used. This was done in discussion with the survey company that was responsible for data collection. The consequence of using paper-and-pencil surveys rather than online-surveys is that it is rather easy to register traffic behaviour that would not be possible, such as surpassing the given kilometre budgets. In order to facilitate filling in the survey, the following additional information and warnings were provided to the respondent:

- The number of kilometres travelled by car in the situation registered in the respondent's travel diary
- As a part of the first question about whether the respondent wants to change anything as compared to the travel diary, there is a warning that the kilometre budget may not be surpassed: *"You can make any change you want, the only thing that is important is that you do not use your car for more kilometres than your EV's range allows to"*. If the respondent answers *"No"*, there is another warning stating *"if you according to the information in your travel diary drive further than the range of your car, you must answer yes to this question"*.
- As a part of the question whether the respondent wants to cancel any activity, there is a warning stating *"are you sure that you do not cancel any mandatory activity (such as working/going to school?"*
- When selecting an activity to be cancelled, there is a warning stating *"be aware that if you cancel any activity, your next trip will start at another location. For example, if you cancel a shopping activity after work, your next trip will start at your work location rather than at the shopping mall"*.
- When selecting a change of destination for a certain trip, there is a warning stating *"work locations, schools, dentists, friends and relatives are where they are"* as well as *"it must be possible to perform the selected activity at the new location (for example, you cannot swim if there is no swimming pool or open water)"*. These warnings are meant to assure that respondents select realistic destinations for their trips.

- When selecting a modal shift from public transport or active modes towards the EV, there is a warning stating *"Keep in mind that your EV has an available range of X km"*
- In the question concerning trip chaining in order to decrease car distance, there is some additional information explaining the concept of trip chaining to the respondent by giving an example of trip chaining: *"For example: instead of a trip home-work-home and another trip home-grocer's-home, you make a chained trip home-work-grocer's-home".*

This information and these examples are meant to make the respondents better informed about what is possible and what is not possible, as well as about the consequences of behavioural alterations.

5. Analysis

An application of this instrument was used in a survey of conventional and electric vehicle drivers in Greater Stockholm. The data has been collected in October 2014 – January 2015 and the results of the study have been reported in Langbroek et al. (2017b). The data was collected with the help of a survey company. Respondents got incentives to participate in all parts of the survey. Participants having completed both waves of the survey received cinema tickets as well as a voucher for a free 22-hour cruise in the archipelago of Stockholm. In the first wave of the survey, 294 respondents took part. In total, 273 respondents took part in the stated adaptation experiment, resulting in 699 observations. This was due to the fact that several respondents did not get three scenarios but only one or two. As the minimum range has been set at 10 km and the maximum range at 500 km, there were 120 scenarios that overlapped with another scenario. In these cases, the respondents were only provided with one or two scenarios rather than three scenarios.

In Langbroek et al. (2017b), analyses based on this application have been performed in order to investigate to which degree travel behaviour is affected by the range of electric vehicles. After a typology of the different behavioural adaptations and descriptive analyses, the influencing factors of the selection of a particular behavioural adaptation were modelled using multivariate analytical methods.

In the analyses, the travel diaries where an adaptation has been registered resulting in decreased travelling have been distinguished from the travel diaries where it was possible to increase travelling. In the former case, the research question was which was the behavioural adaptation under the condition a behavioural adaptation resulting in decreased car travelling was made. Trip cancellation (71 observations), trip destination change (17 observations) and mode choice change (61 observations) were the behavioural adaptations that were taken into consideration here. The main results of this analysis were the following: trip cancelation and mode choice change were most frequently selected behavioural adaptations. The probability to cancel a trip increases in the absence of good public transport alternatives on the selected trajectory. Moreover, non-mandatory trips such as visiting friends and shopping were more likely to be cancelled.

In case the available range was sufficient or there was even abundant range, there were a non-negligible number of respondents stating that they would make more trips (35 observations). Most additional trips were shopping trips or leisure trips. In this case, there was a slight negative effect of income, stating that people with a high income are relatively less likely to make additional trips in case they would have an EV with abundant range. People that tend to make many car trips during weekends are more likely to add trips in case they would have an EV with abundant range. This finding is in coherence with the fact that shopping and leisure trips were the most likely trips to be added to the existing trips (29 observations). Moreover, respondents currently using an electric vehicle are less likely to add trips in this stated adaptation experiment. This might be due to the fact that they have the EV as their reference point, so that they will not face a decrease in marginal cost of car use.

Finally, the analysis of a modal shift from public transport modes or active modes towards the electric vehicle was analysed by a typology of the circumstances under which these behavioural alterations occurred. Generally, there are indications that trips with relatively many transfers or a high travel time factor (the ratio between public transport travel time and private car travel time) are more likely to result in a modal shift from public transport towards EV.

These results imply that rebound effects are likely to occur in case people can make use of an electric vehicle with abundant range and relatively cheap electricity. Moreover, in case of range limitations, the mobility level of respondents is likely to decrease, because trip cancellation was a commonly selected behavioural adaptation in this case study in Greater Stockholm.

6. Evaluation

In this Section, the survey instrument will be evaluated, where the validity and reliability of the instrument will be explored.

6.1 Validity of the stated adaptation instrument

Assessing the validity of stated adaptation experiments is no straightforward task. Cools and Creemers (2013) used a stated adaptation experiment investigating the influence of different weather conditions on travel behaviour changes, where they considered the validity of the study as the level of congruence of two measurements (one with real weather conditions and one with weather forecasts), as well as investigating whether real weather conditions have a higher influence on stated adaptation behaviour than weather forecasts, as it was hypothesized in the literature. In this paper, validity is discussed regarding internal and external validity.

The internal validity of a study can be defined as the degree in which there is a causal relationship between the treatment and outcome of the experiment. As this stated adaptation experiment starts with the respondent's own behaviour, after which he or she will be exposed to an electric vehicle with a combination of a certain range and a certain per kilometre cost, this method is considered to score relatively well on internal validity. Hypothetical bias (e.g. Hensher, 2010) has been mentioned as one of the inherent disadvantages of stated preference studies. Because of the fact that choice made in stated preference experiments do not have real implications, respondents might take different decisions than if they were to make "real" decisions having real consequences. However, as the basis for the respondents is their own travel behaviour, the experiment is supposed to be more realistic than if other survey methods such as stated choice experiments would have been used, which may decrease the risk for hypothetical bias.

Other factors than exposure to the experimental setting (EV with a certain range) are rather unlikely to have a systematic effect because the respondents' own initial behaviour is the starting point for the experiment. Socio-economic characteristics and contextual variables are believed to have an intermediate role on the outcome of the experiment, but these are object of study as well.

The external validity of a study is influenced by the degree to which the results can be generalized. Currently, this instrument has been used in a specific context (Greater Stockholm) but it can easily be used in different locations or at several locations simultaneously. More importantly, the heuristics based on which the kilometre budgets have been constructed have advantages and disadvantages. In the current version of the stated adaptation instrument, the kilometre budgets have been computed from the travel diary data. In case car trips were made, the kilometre budgets were based on the car kilometres.

Despite the fact that there is a minimum range of 10 kilometres and a maximum range of 500 kilometres, it is questionable whether people are likely to start a new day with as few as 10 kilometres of battery range in their electric vehicle. Earlier research (Langbroek et al., 2017a) has shown that current EV-users are likely to charge their vehicle regularly, in order to avoid problems with range limitations.

The question is what a realistic range of a future electric vehicle would be at the start of a day. This will depend on the battery capacity of future EVs, as well as future charging behaviour of EV-users. Seen the current development of electric vehicles, where it is expected that from 2019, more high-range EVs will enter the market at a considerably lower price than the current Tesla Model S, range limitations are likely to become more and more rare in daily life. On the other hand, many current EV-users have the possibility to charge their electric vehicle at home. In case of more widespread EV-deployment among urban residents not having access to their private parking place, charging might still be an issue and situations with rather low states-of-battery might still be realistic.

On an aggregate level, there are selection biases of this particular study due to the fact that current electric vehicle users were oversampled. This has been done because EV-users are considered to be a particularly interesting group to analyse. For prediction purposes, efforts should be made to take account for these factors. For example Cools and Creemers (2013) have used weighted results to get a more representative sample.

No different treatment has been made for people that used the car as a driver during the one-day travel diary as opposed to the people that did not use the car. Therefore, the percentage of observations where abundant range is provided is relatively high.

6.2 Reliability of the stated adaptation instrument

Despite the fact that the question of which alteration(s) to select was broken down into several less complicated questions, the survey task might still be complicated. Some respondents did not take any action despite the fact that their range did not suffice to make all car trips that were registered in their travel diary. This happened in 59 cases (out of 699 observations). Because of the fact that the stated adaptation experiment was presented as a paper and pencil survey, there were no other mechanisms preventing respondents from using the electric vehicle more than its available range than the warnings described above.

Also the concept of trip chaining was complicated for people to understand. Trip chaining was proposed as one of the strategies that the respondents could select in order to decrease their travel distance by car. However, there were many cases where the respondent wanted to make a trip chain consisting of two trips or to make a trip chain of trips that were already chained. Therefore, trip chaining has not been taken into consideration for the analysis of this survey instrument (Langbroek et al., 2017b).

In reality, many people have the possibility to make use of the rather extensive network of charging infrastructure that is available in Greater Stockholm. Not allowing anyone to charge elsewhere than at home limits the level of realism of this study and thus the external validity. However, allowing them to charge at public charging places would imply that people's knowledge about the available charging infrastructure would be a crucial factor influencing the travel patterns and cause a bias.

Finally, behavioural adaptations should be internally consistent. This implies that in case a respondent is faced with two scenarios where the range is not sufficient, the respondent is supposed to make a behavioural alteration in both cases. At the same time, if a respondent has made any additional trips when having a range equalling 150% of the current distance driven, it would be logical if he or she also makes additional trips when having a range equalling 300% of the current distance driven. Even though there are only a few cases where inconsistent behavioural alterations were reported, it is important to pay attention to these inconsistencies.

7. Discussion

The fact that people's own travel behaviour is taken as a starting point is an important advantage of this stated adaptation experiment. However, after having used the instrument in a case study in Greater Stockholm, some issues have arisen giving food for thought about the conceptual idea of the instrument and its practical implementation.

Firstly, the stated adaptation experiment seems to be challenging for a part of the respondents. Efforts have been made to facilitate answering the survey. Nevertheless, some respondents have replied not to make any behavioural adaptations to their original travel and activity patterns even though that would be necessary. Certain other aspects were also poorly understood. A potential solution for this problem could be feedback from the researcher, reminding that certain options are not possible considering the given kilometre budget. Two directions are possible: either using interviews, where the task of the interviewer is to keep track of the kilometre budget while the respondent registers behavioural alterations, or using an on-line instrument, where the respondent gets automated feedback if the respondent tries to surpass the provided kilometre budget. The advantage of using interviews is that the interviewer can obtain more information about the process leading to the registered behavioural alterations. The disadvantage of using interviews is the fact that they are time-intensive. Moreover, there is a danger that the interviewer influences the respondent to a larger degree than keeping track of situations where the kilometre budget is surpassed.

Secondly, the external validity of this stated adaptation experiment is negatively influenced by the fact that the experiment is based on a one-day travel diary that has been filled in for a random Thursday, Friday or Saturday. Rebound effects are, as hypothesized, likely to occur under these conditions, so additional trips or transport mode changes from public transport or active modes towards the private car are likely to be registered if they would occur. However, the representativeness of these situations where the kilometre budget has been surpassed might be limited due to the fact that in many cases, the daily trip distances are rather low and can easily be covered by EV. An alternative option would be to focus on respondents making long-distance trips. The advantage of this alternative approach would be that the range limitations, as well as the behavioural alterations, would be more informative. An example would be a situation where a respondent was planning to make trips for 300 kilometres on a certain day. After adopting an EV, he or she would now face a range limitation of 180 kilometres. What would the respondent do in this case? However, this approach would not contribute to the same degree when it comes to investigating the hypothesized additional trips or mode choice change from public transport or active modes towards the car. In that situation, daily trips with relatively low distances are likely to increase due to the beneficial operational costs of electric vehicles. Long-distance trips by car are likely to decrease. A potential solution would be to register both a conventional travel diary day and the latest long-distance trip that the respondent has made as starting points for two different stated adaptation experiments.

Another issue is linked to the fact that the stimulus is given by the researcher, but there is such a wide variation of trips that there are few similar daily travel patterns that have been considered by a large number of respondents. A follow-up approach would be to have a more standardized stated preference experiment where the setting is much more fixed. For modelling reasons, this situation would provide much more data about the "same" situation: a specific combination of trips, each with their purposes and where there are clear and distinctive scenarios with significant shortage of range or abundance of range. These scenarios could be based on some typical situations that have been observed when analysing this stated adaptation experiment. For predictions of the effects of large-scale deployment of EVs, this approach might be valuable. However, the realism of this approach is lower, due to the fact that archetypical trips are taken as a starting point rather than the respondents' own travel diary data.

This stated adaptation instrument has been constructed on the basis of a one-day travel diary that was part of an online survey. The answers of the survey were extracted from the online survey and with the help of R-code, most information that is needed for preparing the stated adaptation choice tasks for a certain respondent could be extracted automatically and summarized in a table for each respondent. However, the preparation of the choice task, including the use of logos for the different transport modes and adapting the questions for the respondents, required manual adaptations. Therefore, the time needed to prepare a questionnaire for one respondent was on average 10-15 minutes. If it would have been possible to further automatize the preparation of the stated adaptation tasks, then the time needed to prepare the instrument would be shorter, which makes larger scale implementation more feasible.

When in the future, the aim of studying behavioural adaptations will change from explaining the mechanisms behind alterations towards predicting future travel demand given a certain deployment of electric vehicles having a certain range, this stated adaptation experiment might be useful for implementation in activity-based modelling. Because of the fact that the experiment considers the activity-travel patterns of an entire day rather than a specific trip, a more developed version of this instrument can be useful for making predictions of future travel demand and potential consequences of EV-deployment on specific parts of the network. However, in that case considerably larger samples would be needed.

8. Conclusions

In this paper, a survey instrument for investigating changes in travel behaviour due to a change from an ICEV to an EV has been discussed from a methodological point of view. The instrument has been developed as a reaction to the disadvantages of previously used methods: revealed preferences methods such as a direct comparison of travel patterns of EV-users versus travel patterns of non-EV users, field experiments where people are followed while being exposed to an EV for a specific period or theoretical approaches.

The fact that this stated adaptation instrument takes real travel behaviour as a starting point implies that the behaviour is very realistic and the internal validity is believed to be relatively high. However, due to the fact that current EVs have battery ranges well above many of the kilometre budgets in the Stockholm implementation of this instrument, the external validity might be negatively affected. Besides that, the reliability of the instrument might be problematic in its current form: some respondents have not understood that they should decrease their car travelling. Surpassing the kilometre budget is problematic for a subset of the respondents. In future research, there should be more attention for these types of warnings that can be given either in an interview setting or using an on-line instrument.

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References

Arentze, T., Timmermans, H., 2007. Congestion pricing scenarios and change of job or residential location: Results of a stated adaptation experiment. Journal of Transport Geography 15, 56–61.

Azadfar, E., Sreeram, V., Harries, D., 2015. The investigation of the major factors influencing plug-in electric vehicle driving patterns and charging behaviour. Renewable and Sustainable Energy Reviews 42, 1065–1076.

Banister, D., 2008. The sustainable mobility paradigm. Transport Policy, New Developments in Urban Transportation Planning 15, 73–80.

Cocron, P., Buhler, F., Neumann, I., Franke, T., Krems, J.F., Schwalm, M., Keinath, A., 2011. Methods of evaluating electric vehicles from a user's perspective - The MINI E field trial in Berlin. IET Intelligent Transport Systems 5, 127–133.

Cools, M., Brijs, K., Tormans, H., Moons, E., Janssens, D., Wets, G., 2011. The socio-cognitive links between road pricing acceptability and changes in travel-behavior. Transportation Research Part A: Policy and Practice 45, 779–788.

Cools, M., Creemers, L., 2013. The dual role of weather forecasts on changes in activity-travel behavior. Journal of Transport Geography 28, 167–175.

D'Arcier, B.F., Andan, O., Raux*, C., 1998. Stated adaptation surveys and choice process: Some methodological issues. Transportation 25, 169–185.

Figenbaum, E., & Kolbenstvedt, M., 2013. Electromobility in Norway - experiences and opportunities with Electric Vehicles. Institute of Transport Economics (TÖI).

Franke, T., Neumann, I., Bühler, F., Cocron, P., & Krems, J.F., 2012. Experiencing range in an electric vehicle - understanding psychological barriers. Applied Psychology: An International Review, 61(3), 368-391.

Fridstrøm, L., & Alfsen, K. H. (2014). Vegen mot klimavennlig transport. Transportøkonomisk institutt. Retrieved from https://www.toi.no/getfile.php?mmfileid=36652

Graham-Rowe, E., Gardner, B., Abraham, C., Skippon, S., Dittmar, H., Hutchins, R., Stannard, J., 2012. Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations. Transportation Research Part A: Policy and Practice 46, 140–153.

Hagman, J., Ritzén, S., Stier, J.J., Susilo, Y., 2016. Total cost of ownership and its potential implications for battery electric vehicle diffusion. Research in Transportation Business & Management, Innovations in Technologies for Sustainable Transport 18, 11–17.

Hjorthol, R., 2013. Attitudes, ownership and use of Electric Vehicles– a review of literature. Institute of Transport Economics.

Hensher, D.A., 2010. Hypothetical bias, choice experiments and willingness to pay. Transportation Research Part B: Methodological, Methodological Advancements in Constructing Designs and Understanding Respondent Behaviour Related to Stated Preference Experiments 44, 735–752.

Janssens, D., Cools, M., Moons, E., Wets, G., Arentze, T., & Timmermans, H. Road Pricing as an Impetus for Environment-Friendly Travel Behavior. In Transportation Research Record: Journal of the Transportation Research Board, No. 2115, Transportation Research Board of the National Academies, Washington, D.C., 2009, 50–59.

Jones, P.M., 1979. 'HATS': A Technique for Investigating Household Decisions. Environ Plan A 11, 59–70.

Langbroek, J.H.M., Franklin, J.P., Susilo, Y.O., 2017a. Electric vehicle users and their travel patterns in Greater Stockholm. Transportation Research Part D: Transport and Environment 52, Part A, 98–111.

Langbroek, J.H.M., Franklin, J.P., Susilo, Y.O., 2017b., How Would You Change Your Travel Patterns If You Used an Electric Vehicle? Stated Adaptation Approach, The 96th Annual Meeting of Transportation Research Board, Washington, D.C., USA, TRB.

Lesteven, G., 2014. Behavioral responses to traffic congestion. Findings from Paris, São Paulo and Mumbai. Transport Research Arena 2014, Paris.

Odeck, J., Johansen, K., 2016. Elasticities of fuel and traffic demand and the direct rebound effects: An econometric estimation in the case of Norway. Transportation Research Part A: Policy and Practice 83, 1–13.

Pearre, N.S., Kempton, W., Guensler, R.L., Elango, V.V., 2011. Electric vehicles: How much range is required for a day's driving? Transportation Research Part C: Emerging Technologies 19, 1171–1184.

Rolim, C.C., Gonçalves, G.N., Farias, T.L., Rodrigues, Ó., 2012. Impacts of Electric Vehicle Adoption on Driver Behavior and Environmental Performance. Procedia - Social and Behavioral Sciences, Proceedings of EWGT2012 - 15th Meeting of the EURO Working Group on Transportation, September 2012, Paris 54, 706–715.

Weiss, C., Heilig, M., Mallig, N., Chlond, B., Franke, T., Schneidereit, T., Vortisch, P., 2017. Assessing the effects of a growing electric vehicle fleet using a microscopic travel demand model. European Journal of Transport and Infrastructure Research (EJTIR), 17(3).