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Activity-travel adaptations in response to a tradable driving credits scheme

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ABSTRACT

Although interest in the concept of tradable driving credits (TDC) has increased in recent years, empirical research into the potential effects of such a measure is scarce. The study reported in this paper employed an activity-based approach to investigate drivers' responses to two distance-based TDC scenarios. Three hundred and eight Dutch frequent car commuters participated in an online stated adaptation experiment in which they recorded their car use for 7 days and, in response to the TDC scenarios, had the opportunity to reorganise their car use pattern, if desired. This paper investigates adaptation behaviours at the trip level. The results show that approximately 30% of trips made for maintenance and leisure-oriented activities were subject to change. In cases of change, a travel mode change was the most preferred adaptation strategy. A mixed logit modelling framework is used to test the effect of a variety of activity/trip attributes, TDC scenario attributes, and individual characteristics on the preference for adaptation alternatives.

1. Introduction

In the ongoing search for instruments that aim to mitigate the steady growth of car use and associated problems of congestion and emissions in urban areas worldwide, tradable credit schemes have recently received increasing attention. Although the concept of tradable credits (TC) has been developed and applied in the environmental field for decades (Dales, 1968; Baumol and Oates, 1988), the exploration of the potential of 'cap-and-trade' measures in the context of personal transport is relatively new (Verhoef et al., 1997a; Viegas, 2001; Raux and Marlot, 2005; Buitelaar et al., 2007; Yang and Wang, 2011). This interest is part of a broader interest in new travel demand management (TDM) strategies that, as alternatives to the traditional approach of charging for all road use, which has proven highly controversial, propose to manage traffic flows through incentive-based and revenue-neutral approaches, such as the Dutch 'peak avoidance' experiment (Knockaert et al., 2012; Ben-Elia and Ettema, 2011) and the FAIR lanes in the US (Fan et al., 2016; DeCorla-Souza, 2005).

In a typical car use-tailored TC scheme, a regulatory body sets a cap on aggregate car use in a defined area and time period (e.g., defined as a total distance or emissions target). Credits representing an individual portion of the rationed quantity (e.g., kilometres, fuel consumption) are distributed to eligible car drivers, who can use these credits, purchase additional credits or sell excess credits in a market. Through this market mechanism, TC schemes can deliver certain goals at minimised social costs, in contrast with traditional 'command-and-control' measures (Verhoef et al., 1997a). Furthermore, the introduction of a freely allocated credit budget and the incorporation of a reward element are important favourable features for motivating behavioural change and public acceptability compared with conventional pricing mechanisms (Viegas, 2001; Kockelman and Kalmanje, 2004; Capstick and Lewis, 2010; Wadud, 2011).

Although several studies have conceptually explored the concept of tradable driving credits (TDC) with regard to design and function (for reviews, see Fan and Jiang, 2013; Grant-Muller and Xu, 2014), empirical research on driver responses is limited. Empirically grounded research is critical to come to understand the potential effects of TDC. As they are largely explorative in nature, current empirical studies only addressed the willingness to change car use under a TDC policy or approached behavioural adaptations under TDC in a generalised manner that did not consider car drivers' actual activity/trip patterns (for an overview, see Dogterom et al., 2017). As such, these studies have not addressed how daily activity/trip scheduling would be affected by such a measure. This is in contrast with the broad consensus among transport researchers that travel and its adaptations in response to TDM measures should be understood in the context of people's actual needs and desires to participate in different activities, the temporal and spatial characteristics of these activities and the complex interdependencies between them (Arentze et al., 2004; Ettema and Timmermans, 1997; Axhausen and Gärling, 1992). An exemption is the work of Harwatt et al. (2011), that used participants' reported one-week car travel as the starting point for analysis of the impact of a TDC

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scheme. However, this study remained largely descriptive in nature due to the small sample size.

The space-time fixity/flexibility of activities and travel have traditionally been central to a transport geographic approach of travel behaviour; these characteristics and other activity attributes such as the activity type and importance have been used to investigate patterns of activity/travel scheduling and modification (Hägerstrand, 1970; Cullen and Godson, 1975; Jones, 1979; Miller, 2005; Doherty, 2006; Schwanen et al., 2008). The attributes of people's activities, car travel and available alternative travel options determine the framework within which people make their actual adaptation choices based on trade-offs between the costs of car driving under the TDC, the costs of not performing the activity and the costs of organising their travel differently in terms of money, time and effort (Loukopoulos et al., 2006; Gärling et al., 2002). Based on these notions, we designed a stated adaptation experiment to analyse the impact of distance-based TDC scenarios on car drivers' behaviour and identify the role of activity/trip attributes on decisions concerning the types of trips to change and alternatives to choose under the scenarios in cases of change. As such, this paper extends a preceding paper (Author et al., under review a), in which change in car use was analysed on a more aggregate level, focusing on the willingness to change and the size of change. In the current paper, activity/trip attributes such as activity type, geographical context, importance, frequency, spatial and temporal flexibility, and the perceived ability to travel with other modes were used to examine car use adaptation behaviour at the trip level.

In the next section, we discuss our research design and data collection in more detail. Section 3 presents a descriptive analysis of behavioural change under the TDC scenarios. Section 4 describes the modelling approach and presents the estimation results. A mixed logit choice model is applied to model adaptation choice as a function of participant, scenario and activity/trip characteristics. Section 5 presents a conclusion and discussion.

2. Experiment and data collection

Detailed information about the design of the experiment, data collection procedure and participant recruitment can be found in Dogterom et al. (2018). This section summarises the essential details for the analyses presented in this paper.

In the first part of the experiment, participants were asked to fill out a car travel diary for a full week. Each car trip a participant made as a driver to arrive at an activity-location was defined as an individual trip, so trip chains were recorded in the format of separate trips. For each trip, participants entered a start and destination location that could be selected in a Google Maps interface and provided information about the type of activity carried out at the destination, the importance of the activity and the flexibility of the activity and trip (see Table 1 for the variables).

Based on the collected travel diaries, fixed individual budgets of 280 and 230 free credits (one credit representing 1 km) were defined for two scenarios that were presented consecutively. The sum of the credits available in the budgets for all participants corresponded to a 17.5% and 32.2% reduction of the total distance driven by the sample. The budgets, which were set directly after collection of the travel diary, were originally defined to represent 15% and 30% reductions, respectively, in total kilometres; the discrepancy was caused by participants with inconsistent data in the original or adapted travel diaries that was removed during post-data collection scrutiny. Setting equal credit budget sizes for all participants meant that some participants received more credits than needed and thus would already earn money in a situation without behavioural change: 45.4% and 35.1% of the participants faced a gain in scenario 1 and 2, respectively. Each participant was randomly assigned a fixed price level of 0.10, 0.15 or 0.20 Euros per credit, which had to be paid when buying additional credits or could be earned by selling credits.

Table 1
Summary of trip characteristics for different activity categories.

Trip characteristics	Description	Work & Education	Daily shopping	Non-daily shopping & Personal services	Sports, hobby & recreation	Social & Cultural	Pick up/Drop off	Other
Number of activities		1306	262	234	222	362	220	132
Presence passenger	% of trips made with passenger(s)	6.8	29.5	39.7	49.1	59.7	63.3	49.2
Part of trip chain	% of trips that are part of larger trip chain (i.e. combination of trips)	21.3	39.3	37.2	28.8	34.3	65.9	44.7
Distance	Mean distance in kilometers[1] (s. d. in parentheses)	27.6 (24.0)	3.2 (3.5)	10.3 (13.8)	16.0 (28.9)	30.6 (39.2)	9.1 (14.4)	14.1 (21.6)
Importance	How important is this trip to you (i.e. the need to make this trip)?[2] (mean)	4.75	3.98	3.79	4.16	4.17	4.45	4.48
Temporal flexibility	How easily could you perform this activity at another time?[3] (mean)	1.88	3.71	3.24	2.49	2.84	1.72	2.25
Spatial flexibility	How easy is it for you to perform this activity at another location?[3] (mean)	1.37	3.23	2.25	1.89	1.48	1.14	1.38
Bike alternative	How easy is it for you to replace the car by slow mode (bike, etc.) for this trip?[3] (mean)	1.87	2.62	2.30	2.73	2.11	2.09	2.19
PT alternative	How easy is it for you to replace the car by public transport for this trip?[3] (mean)	2.09	1.54	1.83	1.63	1.96	1.60	1.64
Carpool alternative	How easy is it for you to travel with somebody else by car for this trip?[3] (mean)	1.59	1.50	1.55	1.74	1.55	1.31	1.53
Frequency reduction capacity	How easy is it for you to reduce the frequency of this activity?[3] (mean)	1.42	2.79	2.64	2.39	2.48	1.73	1.92

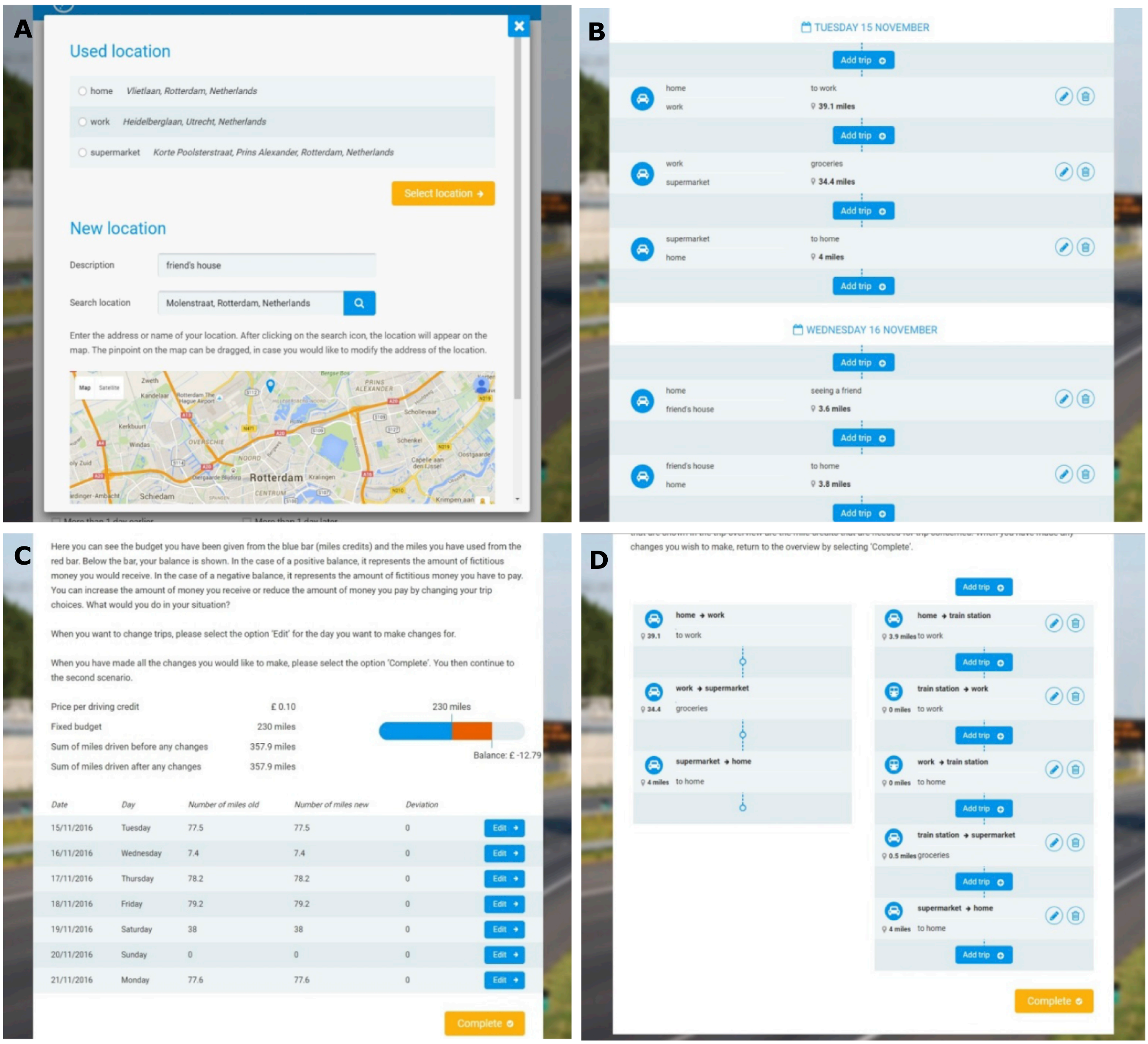

Fig. 1. Screenshots of the online application (English version). *(a)* When recording a trip in the travel diary, a new location could be entered or a previously used location could be selected. *(b)* A trip overview in the travel diary. *(c)* Presentation of distance driven per day, total credit availability and consequent financial balance in the adaptation part. *(d)* An original trip pattern and an adjusted trip pattern for a particular day in the adaptation part.

After the scenarios were determined, the participants were invited to participate in the second part of the experiment, in which they were presented with the TDC scenarios and could make adaptations in response to the measure, if desired. The participants could reorganise their activity/trip pattern by cancelling, modifying (choosing a different activity location or alternative travel mode) or adding trips in their original trip sequence. Three different categories of alternative travel modes were available to them: the public transport and slow mode (cycling) options did not require any credits and the carpool option saved 50% of the credits relative to an unchanged trip. The activity/trip pattern could be changed as often as desired before participants confirmed they had made all adaptations that reflected their desired allocation of credits over their activity/trips of a full week. Fig. 1 shows screenshots from the different stages of the experiment.

Frequent car commuters were recruited for the experiment and data from 308 respondents was used in this research (see Dogterom et al. (2018) for a socio-demographic profile of the sample; note that two participants were removed from the original sample because more than half of their trips had missing data on the trip attributes relevant in this paper). The observed data consists of 2738 trips made to arrive at an activity location, which was the basis for the descriptive analysis. After removing trips with missing observations for several trip-specific attributes, 2599 trips served as input for the model estimation.

3. Descriptive analysis

Table 1 summarises several characteristics of the reported trips for 7 different activity categories. In the experiment, 10 different activity categories could be chosen; however, the categories *Work* and *Education, Non-daily shopping* and *Personal services*, and *Social* and *Cultural* were merged due to low frequencies and because the personal descriptions that people attached to their activities showed that people found it sometimes difficult to distinguish between these original activity categories. Table 1 includes trip attributes such as distance, the

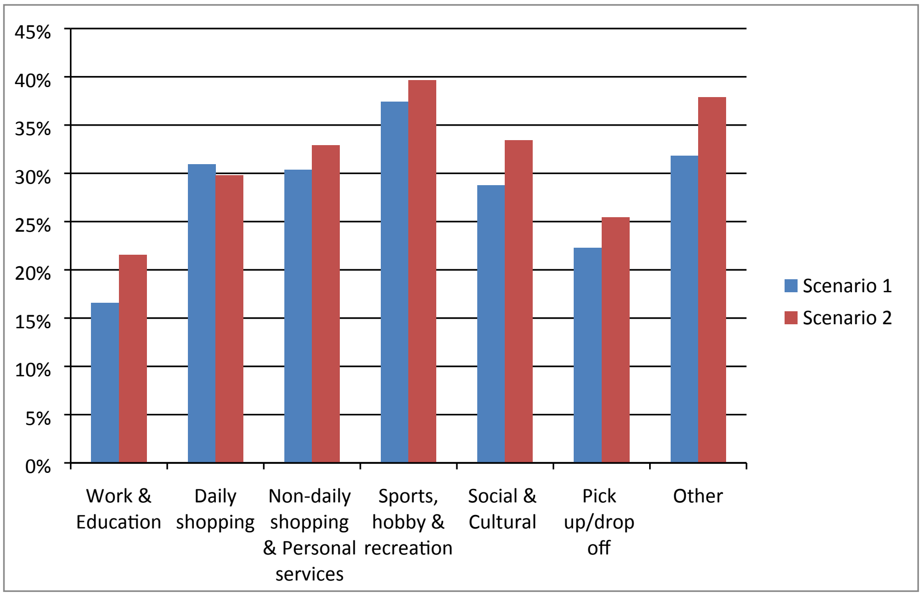

Fig. 2. Share of activities that is adapted in both scenario 1 and scenario 2.

share of trips made with passengers and the share of trips that are part of a larger trip chain, as well as the respondents' subjective evaluations of the need for the trip and the ease with which another location, time or travel mode could be used for the activity. Concerning trip chains (combined activities on one journey), most trip chains had the home location as the start and end location; however, sometimes other locations such as a partner's home, a second home or a holiday home were used to define journeys when these locations appeared as clear anchor points (e.g., an overnight stay) in the travel schedule and personal descriptions.

Fig. 2 presents an overview of the number of modified trips as a percentage of the total number of trips in the activity categories for scenario 1 and scenario 2. The figure shows that trips in the *Work & Education* category were modified the least, followed by trips in the *Pick up/drop off* category. This is not surprising, as it follows from Table 1 that these activity categories have the lowest scores on most flexibility items and have the highest reported importance along with the *Other* category. In many instances, *Pick up/drop off* trips appeared to be closely tied with work-related trips and involved bringing away/picking up children from school or nurseries on the way to/from work, making these trips relatively difficult to organise differently. The *Sports, hobby & recreation* category had the highest adaptation rate. Together with the *Social & Cultural* category, *Sports, hobby & recreation* activities can be classified as leisure-oriented; however, *Social & Cultural* activities show a lower adaptation rate, probably because these trips are generally longer and more often involve the presence of others, making it more difficult to change these trips. The adaptation rates for *Daily shopping*, *Non-daily shopping & Personal services, Social & Cultural* and *Other* (this category included a wide variety of remaining trip purposes that make this category difficult to describe) are comparable. Although the personal maintenance-oriented trips (*Daily shopping* and *Non-daily shopping & Personal services*) generally show higher flexibility levels, especially in terms of time, location and frequency, these activities may be more firmly embedded in daily structures and routines and therefore less likely to be changed relative to their reported flexibility.

When the amount of free allocated credits is reduced further in the second scenario, the largest additional change was realised in the activity category *Work & Education* (increase of 30.1% in the proportion of adapted activities), followed by the categories *Other* (19.0%), *Social & Cultural* (16.4%) and *Pick up/drop off* (14.3%). The increase in the proportion of the adapted activities as share of the total number of activities is more modest for the categories *Non-daily shopping* (8.5%) and *Sport, hobby & recreation* (6.0%). The category *Daily shopping*, comprising activities that on average are short and flexible, even shows a lower popularity for change (−3.7%). Apparently, more substantial changes were needed to fulfil driver's reduction goals when being confronted with a tighter credit budget. Overall, drivers generally made additional adaptations in the trip categories that are less flexible, showing that drivers first change the trips that are relatively easy to modify and enact more complex and costlier changes when confronted with greater financial costs (see Loukopoulos et al., 2006).

Participants' adaptations were classified into five distinct choice options for the analysis:

1 *Bike* – includes all trips for which the mode was changed into a slow mode, which we will frame as the use of the bike given its popularity among all slow modes in the Netherlands;
2 *Public transport* – includes all trips that are changed into a trip in which public transport is the sole or the main mode of transport (including trips in which the bike or car is used to get to a train station);
3 *Carpool* – includes all trips that are changed into a trip in which carpooling is the sole or the main mode of transport;
4 *Reschedule and location change* (henceforth *Reschedule*) – includes all trips in which the activity location was changed and all rescheduled trips (i.e., an alternative position in the trip sequence). Although they are two separate change categories, they were merged due to the low frequency of trips in which the change of location is the sole adaptation. Cases with a location change combined with a travel mode change were assigned to the travel mode adaptation category because we consider the desire to use another mode to be the trigger of the location change in these cases.
Cases of trip chaining (merging two separate activities into one trip) present rather complex situations in terms of defining the change. We do not have information about the time an activity was performed and only know the relative position of the individual activity in the larger trip schedule. Therefore, in some cases of trip chaining, it is not evident which of the trips was changed in time and, hence, is the rescheduled activity. Thus, for cases of trip chaining, both original trips were counted as rescheduled trips. This decision was made also because the attributes of both activities/trips might be relevant to facilitating trip chaining. Only trips that were merged with another trip and in which at least 90% of the distance remained unchanged were not counted as a rescheduled trip. In these cases,

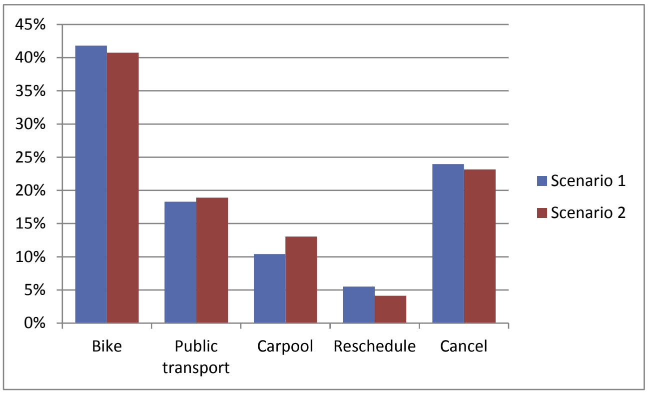

Fig. 3. Relative preference for adaptation options.

for example, people may add purchasing the groceries at a venue close to home to a trip from work to home, in which situation the latter trip has only experienced a very minor change that we do not consider relevant. In cases of adding a separate activity to a larger trip chain, only the activities that directly precede or follow the added activity were counted as rescheduled activities/trips;

5 *Cancel* –includes all cancelled trips. Participants may perform the activity at home, postpone the activity or stop performing the activity in any form.

Fig. 3 shows the preference for the different adaptation options in the cases of change. Overall, changing travel mode was the most popular adaptation strategy, followed by cancelling the activity/trip. Surprisingly, only approximately 5% of the trips were rescheduled. This might be because rescheduling activities could be a rather complex task for car drivers in daily life. Also, rescheduling activities often resulted in only a marginal credit savings in the experiment; this option is expected to experience increased popularity under a time-differentiated TDC scenario (see Verhoef et al., 1997b). The rather complex manner of handling this option in the experiment might have played a role as well. In cases of a travel mode change, the adaptation option *Bike* was chosen most frequently and was especially preferred for the shorter trips. The average distance of trips switched to bike was 6.3 km, while the distance of all trips that were not part of a trip chain was 21.2 km. The relative popularity of the option *Cancel* showed that there is considerable room for the reported activities to be performed at home, to not be performed at all, or to be postponed beyond the one-week horizon in the experiment. Unfortunately, we do not have information about the precise reasons for cancelling the activity. Not surprisingly, cancelled activities have a lower reported importance and a higher reported frequency reduction capacity. Finally, it is interesting to note that the relative preference for the adaptation options did not change much between scenarios 1 and 2. The relative preference increases for *Carpool* and – almost negligible – for *Public transport*, which are options that are generally preferred for the longer trips. This thus seems to be in agreement with findings from Loukopoulos et al. (2006) that show that people first choose alternatives that are less costly and opt for more costlier alternatives when they want to make more substantial car use reductions.

Fig. 4 presents the car use adaptation choices for each activity category and shows how the preferences for the travel alternatives, including the *Car* (no-change) option, differ by trip purpose. This figure and Fig. 5 and Fig. 6 only relate to scenario 1 to limit the number of figures. Fig. 4 shows that the option *Bike* was considerably more popular than the other travel modes for the *Daily shopping*, *Non-daily shopping & Personal services*, *Sports, hobby & recreation* and *Other* activity categories. Although *Bike* was chosen more often, *Public transport* followed closely in the *Work & Education* and *Social & Cultural* categories, which generally had longer distances. The *Sports, hobby & recreation* and *Pick up/drop off* categories had the highest rates for *Cancel*. People can likely more easily skip the activities in the *Sports, hobby & recreation* category, which are more individually-oriented, compared to the other leisure-oriented activities in the *Social & Cultural* category, which might be more frequently performed on a collective basis. Activities in the *Pick up/drop off* category are not likely to be cancelled; rather, people might organise the involved travel differently, e.g., allowing passengers to organise their travel themselves or assigning the task to others. Unfortunately, follow-up questions that would have yielded such information could not be included in the experiment to keep the experiment as simple and short as possible.

It is interesting to analyse whether adaptation patterns are different for participants with different income levels. Therefore, Figs. 5 and 6 show the total number of occasions of change (first column) and the relative preference for the adaptation options for three income categories for participants facing a gain and a loss, respectively. Several interesting trends can be observed. First, participants from the lowest income group on average show the lowest change rate in the case of a gain, but show the highest change rate in the case of a loss. Those with lower incomes are generally more price sensitive, but at the same time are also more constrained in their activity/trip agendas (Clay and Mokhtarian, 2004), which might explain why they more often stick to the status quo in a situation of gain, as the effort to realise changes in the activity/trip schedule would outweigh the prospect of a larger gain for these participants. Second, overall, there is only a modest higher preference for biking and rescheduling for those that loose as compared to those that gain, especially for the middle and higher income groups, whereas the other options show a significantly higher frequency of being chosen in a situation of loss for all income groups. Third, there are relative large gaps between the gain and loss situations for the highest income group concerning the options public transport and carpool, with the preference for public transport being considerably lower and the preference for carpool being significantly higher for those in a loss situation. It is difficult to explain this based on gain or loss per se, probably activity/trip attributes play a role here, which calls for a more systematic consideration of the role different activity/trip characteristics on adaptation choice.

4. Multivariate analysis: mixed logit model for adaptation choice

In this section of the paper, we use a discrete choice modelling framework to estimate the effects of various activity/trip attributes and individual characteristics on the probability of choosing the car-use alternatives identified above. Our model is based on participants' adaptations in scenario 1 only. Scenario 1 was defined in a way that represents a realistic TDC setting in which we aimed for the total credit availability to be a reasonable 15% reduction of the total kilometres by car, whereas the second scenario was developed to test the effect of a stricter budget in a situation in which the total credit availability was a less realistic and rather harsh 30% reduction in total car kilometres.

4.1. Modelling approach

For each trip, the model describes whether and how the trip is adapted in response to the TDC scenario. The five discrete adaptation options defined above are the choice alternatives. The estimated parameters represent trip-related, scenario-related and personal explanatory variables. With each participant having multiple trips that must be decided upon under a TDC scheme, the data is structured as panel data in which the trip-specific factors vary across each participants' observations but the individual and scenario-related characteristics are stable. Because participants evaluated multiple choice situations in the experiment, the participant's choices could be correlated due to expected preference heterogeneity among participants, violating the classic assumption of independently and identically distributed error terms (IID) that underlies standard discrete choice models. Mixed

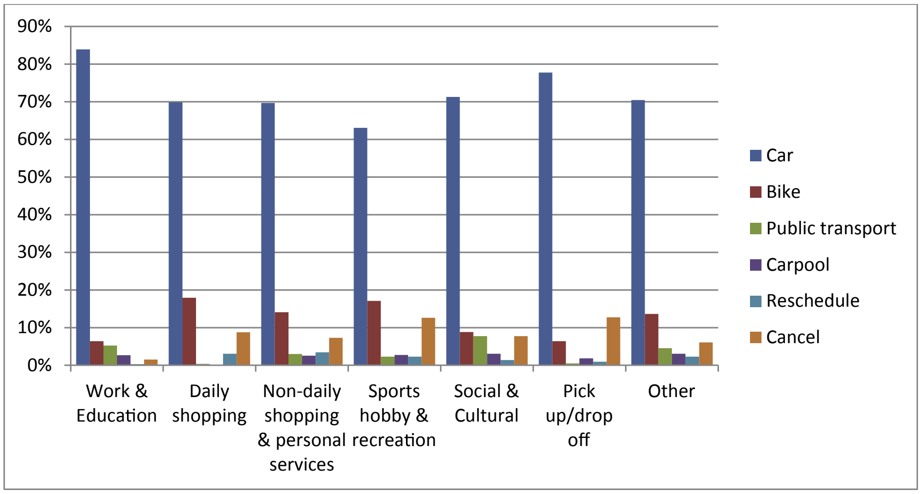

Fig. 4. Relative preference for adaptation options per activity category.

logit models can accommodate for these panel effects by allowing for the specification of random parameters that can capture preference heterogeneity among decision-makers (Revelt and Train, 1998; Train, 2009; Hensher and Greene, 2003).

The mixed logit model builds upon the standard logit model. In de standard logit model, the utility of alternative i out of J alternatives in choice situation t for individual n is:

$$U_{nit} = \beta_i x_{nit} + \varepsilon_{nit} \tag{1}$$

where x_{nit} is the vector of observed explanatory variables (trip-related, scenario-related and personal characteristics). β_i and ε_{nit} are the stochastic part, as they cannot be observed, with ε_{nit} being vector of an independent and identically distributed (IID) extreme value type 1 error terms. Now, as already said, this IID assumption is violated in situations where the individual's preference for alternatives is correlated across choice situations. The mixed logit modal can accommodate this violation by diving the stochastic part into two parts: one that is only varying across individuals, reflecting unobserved individual preferences, and one that is IID distributed over individuals and choice situations. As such, in the mixed logit model, the utility of alternative i out of J alternatives in choice situation t for individual n becomes:

$$U_{nit} = \beta_i x_{nit} + [\, \alpha_{ni} + \varepsilon_{nit} \,] \tag{2}$$

where α_{ni} is a vector of individual-specific error terms that include the unobserved correlation between choices of the same individual. The distribution for α is denoted by density $f(\alpha|\Omega)$ where Ω is the vector of the parameters of the density function. The normal distribution is assumed for $f(\alpha|\Omega)$, with 0 mean and variance σ.

For a given α, the conditional choice probability is a standard logit because ε_{nit} is IID extreme value type 1:

$$L_{ni}(\alpha) = \frac{e(\beta' x_{ni} + \alpha_{ni})}{\sum_{j \in J} e(\beta' x_{nj} + \alpha_{nj})} \tag{3}$$

Because α is not known, the unconditional choice probability (the mixed logit probability), is obtained by integrating the standard logit formula over all values of α weighted by its density:

$$P_{ni} \int L_{ni}(\alpha) f(\alpha|\Omega) d\alpha \tag{4}$$

The integral has no closed form and therefore the probability is simulated by randomly drawing values from density function $f(\alpha|\Omega)$. Halton draws are used for simulation, which are taken for each individual. The software platform ‘R’ with the ‘mlogit’ package has been used to carry out the statistical analysis (R Core Team, 2016; Croissant, 2013).

4.2. Results

Table 2 presents the model estimation results, with the option *Car* (no change) used as the reference category. Models with 1500 Halton draws or more produced stable results, and therefore the model based

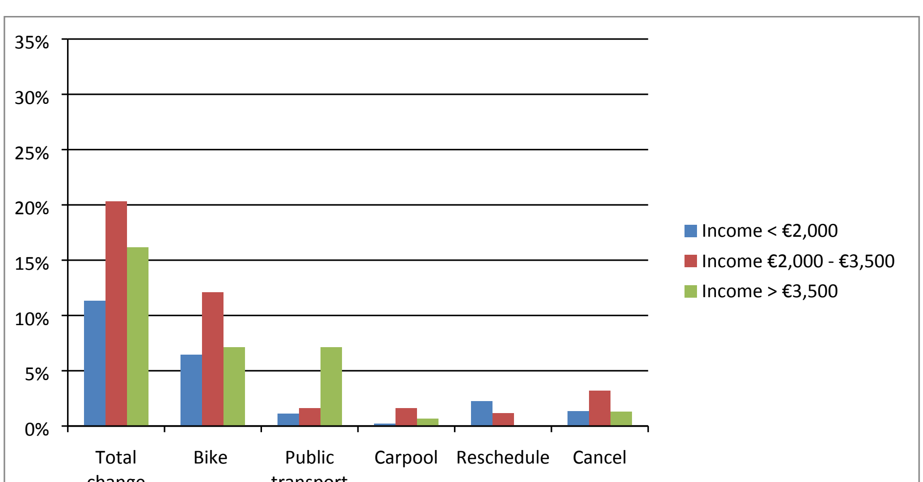

Fig. 5. Relative preference for adaptation options as percentage of total trips changed into this option for different income categories (Gain situation).

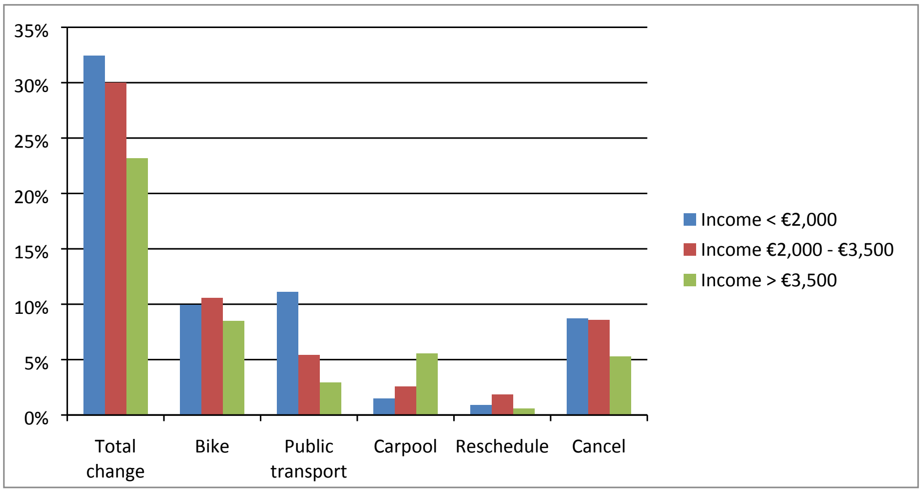

Fig. 6. Relative preference for adaptation options as percentage of total trips changed into this option for different income categories (Loss situation).

on 1500 draws is presented here. The adjusted R^2 of 0.254 indicates a good model fit. The means and the standard deviation of the random alternative-specific constants are significant. This indicates that there is an unobserved preference for certain alternatives among participants that could not be captured by the participant-specific variables alone and that, consequently, a mixed logit framework is an appropriate modelling approach in this context. Overall, the model can identify very few (marginally) significant effects for the *Reschedule* alternative, which likely relates to this option being preferred in a limited number of cases.

To maintain a sufficient number of observations per activity type, the *Daily shopping* and *Non-daily shopping & Personal services* activity categories, that were two separate categories in the descriptive analyses section, were merged into the *Maintenance* category. Note that distance as a factor was not included in the model, because a considerable portion of trips ware part of a larger trip chain and thus it is not possible to determine a useful distance indicator for the individual trips on which the model is based. All other objective activity/trip characteristics (frequency, part of a trip chain, the presence of a passenger, location), reported in Table 1, were included in the model. The subjective evaluations regarding the importance and flexibility of the activity/trip have not been included in the model because their effects could mask meaningful effects of the objective measures. Furthermore, the effects

Table 2
Estimation results for adaptation choice (mixed logit model).

	Bike	Public transport	Carpool	Reschedule	Cancel
Constant	−3.396***	−2.067***	−5.054***	−14.057**	−6.228***
Standard deviation of non-IID residuals	1.984***	1.929***	2.551***	−2.635*	2.042***
Activity/trip characteristics					
Activity (ref = Work & Education)					
Maintenance	2.286***	−1.588***	−2.102**	2.946**	2.833***
Sports, hobby & recreation	1.998***	−0.918	−0.417	2.085	3.471***
Social & Cultural	1.311***	−0.051	−1.049	2.519*	2.332***
Pick-up/drop off	0.723	−2.263*	−1.007	2.563	3.027***
Other	1.508***	−0.778	−0.859	2.758	1.823***
Trip part of chain	−1.382***	−1.637***	−0.851	−0.592	−0.222
Presence passenger(s)	−0.375*	0.026	1.439**	−0.693	−0.712**
Frequency (ref = once per week or more)					
Once per week – once per month	−0.165	1.433***	0.758	0.743	0.523
Less than once per month	−0.535**	1.196***	0.671	0.081	1.164***
Destination is in rural neighbourhood	−0.536**	−0.809**	−0.851	−1.656	0.001
Scenario characteristic					
Price per credit (ref = €0.10)					
€0.15	−0.333	−0.906**	−0.193	0.842	0.550*
€0.20	0.213	−0.378	−0.775	3.476	0.777**
Kilometres driven gain (value is 0 if in loss situation)	−0.0040**	−0.0196***	−0.0115*	−0.0079	−0.0230***
Kilometres driven loss (value is 0 if in gain situation)	−0.0001	0.0012	0.0002	−0.0039	0.0009
Individual characteristics					
Male	0.883***	0.790**	0.606	0.268	0.307
Age > 45	0.417**	0.027	−0.512	0.830	0.070
Presence of children in household	0.462**	−0.707**	−0.275	1.335	0.598**
Monthly disposable net household income > €2500	−0.167	−0.010	0.862	−2.516	−0.595**
Would rather not state income	0.107	−0.953	1.331	−1.144	−0.504
More than 1 car in household	−0.203	−0.834**	−1.077**	2.296*	0.275
Working hours more than 30 h per week	−0.612**	−0.901*	0.096	3.446	−0.005
Residence is in rural neighbourhood	−0.505**	−0.078	−1.587*	1.048	−0.126
Log-likelihood (0)	−1907.7				
Log-likelihood (β)	−1689.3				
Adjusted ρ^2	0.259				

*Significant at 0.1 alpha level; ** Significant at 0.05 alpha level; *** Significant at 0.01 alpha level.

of the subjective measures were found to be highly self-evident (e.g., trips with a higher perceived ability to be changed to public transport showing a higher propensity to be changed into a public transport trip). However, in the discussion of several effects of objective attributes, we use these subjective evaluations to try to understand the underlying reasons for the preferences found by the model. In the following, we only discuss the effects that are significant at the 0.05 alpha level.

4.3. Activity/trip-specific characteristics

Compared with trips made for work and educational purposes, trips made for all other purposes have a higher chance of being changed into a bike trip, except for trips in the *Pick up/drop off* category, which, in many instances, involve bringing/picking up children to and from school/nursery and are often closely tied to trips to or from work. This pattern might be largely explained by distance, as work trips are usually made over larger distances (see Table 1 for the mean distances for non-chain trips). Compared with work and educational trips, trips made for other activity reasons are more likely to be cancelled, which is not surprising given the mandatory nature of work and education-related activities and their high priority and low frequency reduction capacity (see Table 1). This is also true for the *Pick up/drop off* trips, which is rather remarkable in light of the relatively high importance and inflexibility attached to trips in this category. However, whereas the activities of people being brought to or picked up might be rather important and inflexible, there might be considerable room for those people to travel differently, e.g., mobilise others or travel by bike or public transport if they are not too young. Further activity effects are only present for *Maintenance*, with trips in this category being less likely to be changed into a public transport or carpool trip, probably because these modes are less efficient for the relatively shorter trips and these activities might involve the movement of goods. Maintenance activities are more likely to be repositioned in the activity pattern than work and education-related activities because these activities are generally less fixed in time (see Table 1).

Trips that are part of a trip chain are less likely to be conducted using another travel mode. This is an expected outcome as doing so would generally require significant reorganisation of a travel pattern that might have been formed by participants to be more efficient. The presence of other passengers reduces the probability a trip is cancelled but increases the likelihood of choosing carpool. The latter effect is rather remarkable; one reason might be that participants already travelling together in the original situation simply chose this option in the scenarios as the experiment did not differentiate between different vehicle occupancy rates in determining credit usage in the base situation. The car is less likely to be substituted by public transport if the activity is performed at least once per week. The fact that overall public transport is less time-efficient can explain the preference for the car relative to public transport if the trip involves activities that are a more central part of daily routines and are therefore generally planned more tightly. The preference for cancelling clearly increases if the activity is performed occasionally (less than once per month). Apparently, incidental activities generally less urgent and can be skipped more easily.

The final activity/trip characteristic is the urbanity level of the activity location, measured at a neighbourhood level. We attached a level of urbanity to each activity location, as measured by Statistics Netherlands (CBS) using a 5-point scale. In our model, we used a dummy variable to distinguish between urban (5 = very strongly urbanised, 4 = strongly urbanised, 3 = moderately urbanised) and rural areas (2 = weakly urbanised, 1 = not urbanised). As expected, the bike and public transport are less preferred as alternatives to car use in the rural areas, which was also found in another Dutch road pricing study (Arentze et al., 2004).

4.4. Individual-specific characteristics: scenario attributes and socio-demographic characteristics

In the scenario, the sum Euros to be gained or lost in the base situation was a function of the amount of kilometres travelled ($<$ 280 km led to a gain; $>$ 280 km to a loss) and the per credit price that was randomly assigned to the participant. When the amount of kilometres travelled for those who gain becomes smaller, there is a general reduction in the preference to use credit-saving alternatives. This is a natural outcome given the expectation that people who anticipate a higher financial benefit without changing their behaviour are more satisfied with the status quo. Only the rescheduling option had no significant association with the size of gain. If there is room for rescheduling, this strategy can likely be implemented relatively easily without much cost, so participants with higher gains in the base situation consider it worthwhile to reschedule activities. The size of loss does affect none of the adaptation options. However, when we look at the other element that defines the total gain/loss, we see that people who are assigned a higher credit price are more likely to cancel their trips. Cancelling is a rather rigorous measure, which people apparently only choose when under a higher credit price (for most participants leading to a larger loss). For the other credit-saving strategies, no significant effects were found, which suggest that it are rather the trip/activity attributes that define the likelihood of being chosen rather than the price per se. There is only an effect for the credit price of 0.15 Euro in the case of public transport, however, this effect is hard to explain as this involved the middle category of the three price levels used.

Regarding losses, the size of the loss only has a significant positive association with cancelling, meaning that people are more prepared to cancel activities/trips to lower the loss faced if the loss is larger. For the other kilometre-reducing strategies, it appears that the trip/activity attributes define the likelihood of being chosen rather than the size of the loss, demonstrating that people did not simply tick options but realistically situated their decisions in the context of daily life.

Regarding the socio-demographic characteristics, males systemically more often chose to replace their car trips with biking or public transport than females. Concerning the perceived ability to make the trip by bike or public transport, males indicated they generally find it easier to do (*t*-test: *mean difference* = 0.136, $t = 2.61$, $p = 0.009$ and *mean difference* = 0.124, $t = 2.90$, $p = 0.004$, respectively). It could be that women are more car dependent because they generally are more responsible for household tasks than men, irrespective of their employment status, and therefore, might experience a tighter travel schedule (Hubers et al., 2011; Schwanen et al., 2007). Further, women might already be travelling with alternative modes when possible more often than men, as women are found to cover a smaller share of their travelled distance by car (Matthies et al., 2002), leaving men with a potential larger capacity for mode change. Participants aged 46–65 were more likely to choose the bike as an alternative to their car use than younger participants. As older participants reported a lower average kilometres travelled per trip for non-chain trips (*t*-test: *mean difference* = 3.879, $t = 3.13$, $p = 0.002$), the bike is likely a more viable alternative for older participants because of the shorter distances they generally drive.

The presence of children positively impacts the likelihood to change to the bike but has a negative effect on using public transport. Those with children living at home have a higher reported ability to use biking (*t*-test: *mean difference* = 0.389, $t = 4.88$, $p = > 0.001$), possibly related to the significantly shorter average distance they travel for non-chain trips (*t*-test: *mean difference* = 3.176, $t = 2.60$, $p = 0.009$). There was no significant lower perceived ability to travel by public transport for those with children, but participants with children living at home might have a travel schedule that is more constrained by household tasks and the activities of their children, which makes the use of public transport less efficient in terms of time. Participants with children living at home also cancel their activities/trips more often. Those with higher incomes are less inclined to see cancelling as an alternative than those with lower incomes, which is rather difficult to explain given that the overall importance attached to activities and the perceived ability to reduce the frequency of activities does not differ systematically between participants with higher and lower incomes. Participants with lower incomes likely see cancelling the activity as an option more frequently in the trade-off between the meaning of the activity and the money saved by cancelling it due to a higher marginal value of money.

The presence of more than one car in the household negatively impacts the likelihood to change to public transport and to choose carpool. Car ownership level could be an indication of car dependency and/or 'car-mindedness' and therefore these results are not surprising. Working more than 30 h per week systematically reduces the preference for biking and public transport as alternatives, as they likely have less time available for a mode change. Finally, with regards to the residential context, those living in a rural neighbourhood show a lower probability to switch to biking as an alternative for their car use, which likely is related to the larger distances to be covered in rural areas to reach destinations. We also tested for the personal characteristics of education level and having a partner but, as these characteristics did not affect the selection of car-use alternatives, we excluded them in the final model estimation.

5. Conclusion and discussion

In this paper, we analysed the effects of a hypothetical distance-based tradable driving credit (TDC) scheme. In an interactive stated adaptation experiment, frequent car commuters could reorganise their reported one-week travel pattern by choosing from a set of car-travel alternatives in response to two scenarios that used a cap on the sample's total kilometres driven. This stated adaptation experiment was designed based on the assumption that we can only come to a realistic appreciation of the effects of transport policies in a context that uses the wider set of interlinked activities/trips as a starting point for analysis and allows participants fully account for the consequences of the available choices in the context of their concrete daily life. Whereas the value of stated adaptation approaches has been increasingly recognised in travel behaviour research (Arentze et al., 2004; van Bladel et al., 2008; Nijland et al., 2009; Weis et al., 2010), the use of a stated adaptation approach that enables the participant to interactively respond to a scenario and the researcher to perform statistical analysis on the data in the context of TDC is new.

The results show that approximately 30% of the trips made for maintenance-oriented (shopping and personal services) and leisure-oriented activities were subject to change and that, as expected, the change rates for the less flexible trips made for work, education and to pick up/drop off others were considerably lower. Biking was the most preferred alternative, being chosen in more than 40% of the occasions of change. The proliferation of the e-bike might play a role here. When the availability of credits was reduced further in the second scenario, we found that the activities/trips that are generally more difficult to change experienced the largest relative increase in reported adaptation compared with those in scenario 1. This is in agreement with earlier research on adaptations to travel demand measures that suggests that adaptations differ in costliness and effectiveness over trip purposes and alternatives and that, according to a cost-minimisation principle, people only enact adaptations that are costlier in terms of money and effort when they set larger car use-reduction goals for themselves (Loukopoulos et al., 2006; Gärling et al., 2000). The effects of activity/trip attributes, such as the activity type, presence of a passenger, the frequency and geographical context of the destination, and individual characteristics concerning the preference for various adaptation alternatives, were further investigated using a mixed logit model framework.

In a preceding paper (Author et al., under review a), males and those with children living in the household were found to be more willing to change their car use in response to the TDC scheme. By analysing adaptation patterns at the trip level, this paper showed that males had a higher reported ability to switch to alternative travel modes, suggesting that females generally have a less flexible activity/travel pattern and are more car-dependent (Hubers et al., 2011; Schwanen et al., 2007). Those with children at home showed making more trips that were shorter and generally had lower reported importance, which might explain their higher willingness to switch their trips to biking or to cancel the activity. Participants living in a rural area had a lower preference for biking and carpooling, options for which the attractiveness is normally facilitated by higher densities, possibly explaining these participants' lower willingness to change, as found in Author et al. (under review a).

One major contribution of this paper to TDC research is that it focused on the credit allocation process in the context of concrete activities/trips with an explicit link to the opportunities and constraints in the decision-context regarding reorganising car travel. The stated adaptation experiment used in this study is another contribution to the wider field of travel behaviour research, as it is a promising tool for capturing travel adaptations to TDM measures. The experiment was capable of capturing multidimensional adaptations, which is not the case in many other stated choice and stated adaptation studies. Participants sometimes made rather complex adaptations, showing that accounting for multidimensional choices enhances realism and suggesting that participants were engaged with the experiment.

As this study treated the individual as a rather isolated entity in the experiment, a valuable next step would be to account for the intra-household interaction involved in travel decisions, as it is acknowledged that such interactions play a large role in shaping and constraining opportunities for travel adaptations (Arentze and Timmermans, 2009; Bhat and Pendyala, 2005). Understanding the formation of TDC response strategies at the household level would be especially relevant if more specific assumptions would be made about the precise allocation of credits in a household context. For instance, would the credits be allocated to individuals, to households collectively or to cars? And, if credits would be allocated to individuals, would credits be freely transferable among household members? Assumptions based on these aspects have clearly implications for the extent to which certain actions (e.g., assigning car-based tasks to other household members or tapping the credit resources of other household members) could be considered a feasible response strategy in specific TDC contexts.

The TDC scheme investigated in this study was straightforward, as it did not differentiate in time and location and used fixed prices. We developed a relatively easy scheme design because we considered this study as a first step in the investigation of an innovative pricing policy and because a very detailed scheme might have led to the experiment being understood less well. A scheme that differentiate in time and location might be theoretically more effective in mitigating congestion and therefore more desirable when it comes to a potential implementation. We therefore suggest investigation of preference and adaptive behaviours under such more detailed types of TDC schemes. Our results show that the preference for rescheduling activities in time is considerably low, however, it is expected that schemes that differentiate between different times of the day would make people more prone to reschedule their car trips, as shown by studies on congestion pricing (e.g., Verhoef et al., 1997b). The presence of dynamic credit prices that follow the market dynamics of supply and demand for credits in a true credit market could also have a unique impact on drivers' adaptive strategies. It is likely that people's decisions will be affected by their expectations about future credit prices and price uncertainty. Understanding of TDC responses would be greatly enriched if future research included experiments designed to investigate these behavioural strategies in research settings that would facilitate trading between participants.

We acknowledge that the design used in this study inherently poses some limitations concerning a realistic and comprehensive understanding of these adaptations, which could be addressed in future research. First, a switch to another travel mode might involve alternative costs (e.g., tickets to ride public transport), that were not considered in the experiment and therefore might not have been fully appreciated by the participants. Therefore, changing to public transport might have been too attractive in the wish to conserve credits and thus integration with public transport operator's timetables and ticket prices might achieve a higher level of realism, although it would make the experiment more demanding for participants. Second, in the experiment, participants could state to cancel their activity/trip without being prompted to indicate why and how they would do so. Enquiring about the reason for cancelling the activity/trip in its current form (e.g., perform the activity at home, assigning the task to somebody else, postponing the activity, cancelling the activity in any form, etc.) would have provided an opportunity for more detailed analysis. But, again, this would have increased the complexity of the experiment.

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