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STICK TO THE PLAN?

A Revealed-Preference Study of Behavioural Impacts of Traffic Information#

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Abstract

We estimate a revealed-preference scheduling model of morning peak behaviour that allows us to determine the impact of traffic information on traveller behaviour. Specifically, we distinguish between the marginal impact of expected travel times versus that of deviations from this expectation upon user behaviour. We find that participants that chose to receive a smart-phone with traffic information as a reward in our experiment respond to the deviation of actual travel times from the expectation, which they did not do before. This we interpret as evidence that traffic information indeed affects behaviour. We also find that participants who did not choose the smart-phone, but instead opted for monetary rewards, also respond to the deviation of actual travel times from the expectation. This suggests that these drivers use other sources of information to help their trip planning.

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1. Introduction

Advanced traveller information systems (ATIS) are generally believed to have a potentially significant impact on the performance of road transport networks. Real time traffic information enables road users to make decisions on the basis of more accurate estimates of travel times on different routes and at different moments. Individuals will have the tendency to avoid unexpected severe congestion, and doing so may in turn limit expected travel times in case of an incident once more people get informed. There is a large literature on the possible impacts of traffic information. Reviews were provided by, *inter alios*, Emmerink and Nijkamp (1999); Chorus *et al.* (2006); and Bonsall (2008). The studies described in these reviews vary from analytical and numerical network models to empirical studies using data derived from, for example, questionnaires and travel simulators. Chorus *et al.* (2006) note that revealed preference (RP) studies in this field are scarce, often simply because data are unavailable; or, as remarked by Bonsall (2008), because it may be hard to identify the impact of the information system *per se* as its implementation may have been part of a general service upgrade. The data then cannot be used (easily) to calibrate behavioural models.

This paper aims to help filling this gap. We present an empirical revealed-preference analysis of the behaviour impacts of an in-car information system, based on micro-data of repeated observations of individual vehicles during the morning peak, with and without the provision of real-time traffic information. These data were gathered in the context of a wider experiment, called *Spitsmijden* ('Peak Avoidance'), which looked at the impact of incentives upon morning-peak behaviour of road users on a specific road segment in The Netherlands (see also Knockaert, Tseng and Verhoef, 2009). Participants were free to choose the type of incentive. One possibility involved a 'smart phone' that provided dedicated travel information. Because the experiment involved electronic registration of vehicle passages, and because we have observed behaviour both with and without the provision of this information, we can assess whether the information provided has a distinguishable impact on traveller behaviour.

Specifically, we will be estimating a simple scheduling model in which we explain the participants' behaviour from a number of trip attributes. By distinguishing between expected (that is, averaged over working days) travel time at a certain moment on the one hand, and day-specific deviations from this expected value as communicated by the information system on the other hand, we can see to what extent the latter explains observed behaviour. Moreover, by having a similar specification for participants who did not have the information system, we can investigate whether these other drivers used alternative sources of information, and if so, whether these alternative sources had more or less impact on observed behaviour than the information system that we are analyzing.

Our paper has a simple structure. Section 2 describes the *Spitsmijden* experiment and the data collection in some more detail. Section 3 discusses the discrete-choice model that we will be using to describe observed behaviour. Section 4 presents and interprets the empirical results. Finally, Section 5 concludes.

2. Experiment and data collection

The trial

The *SpitsMijden* project aimed to study the impact of 'positive incentives' on road user behaviour. The trial was launched on October 2, 2006. The test area was the Dutch A12 motorway corridor from Zoetermeer towards The Hague. On weekday mornings, this stretch of motorway is heavily congested with vehicles heading towards The Hague. There are few alternative routes or on- or off-ramps on this stretch of motorway, which made the trial relatively easy to control. The morning rush-hour was defined as lasting from 07.30 to 09.30h, since this period has the highest reported traffic densities. The participants in the trial could earn a reward for not travelling by car from Zoetermeer to The Hague during the morning rush hour.

Before the start of the experiment the participants had an electronic device, the 'on-board unit' (OBU) installed in their cars, allowing for the registration of their car travel behaviour in the corridor under consideration. The registration system was complemented by licence plate recognition cameras, in order to extend the coverage of the study area. The trial lasted for ten weeks. Observations in the two weeks preceding the trial, as well as the week after the trial, covered reference behaviour under unrewarded conditions.

Upon registration, the participants were asked to choose between two types of reward. The first type of reward concerned monetary rewards for each morning rush hour that the participant avoided. The second type of rewards comprised credits that, when a sufficient number were earned, allowed keeping, at the end of the trial, the Yeti 'smart-phone' that they could use for free (except for costs of phone calls) during the trial. The Yeti smart-phone can offer e-mail and Internet access, and an agenda, in addition to normal telephone functions, at any time or place. As a special application, the participants were able to receive detailed and real-time traffic information via the Yeti smart-phone.

The majority of the participants chose a monetary reward, and a minority chose the Yeti. As the trial was set up to test both reward types, the participants who had said that they did not have a preference for one reward type over the other, were assigned to the Yeti variant. However, to prevent participants ending up with an unwanted and hence lowly valued reward type, we allowed them to switch to the other type until the start of the trial. As a result 232 out of 340 participants faced the monetary incentive, while the remaining 108 drivers became 'Yeti participants'.

During the ten weeks trial period, different levels of the reward were tested. The monetary reward amounted to €3 or €7 to avoid the entire morning peak interval (7:30 – 9:30); and a third, more refined scheme made the participant receive €7 when avoiding the entire morning peak, which was reduced to €3 if travelling in the shoulder periods (7:30 – 8:00 and 9:00 – 9:30).

For the Yeti reward, two different schemes were tested: there was one period where the participant could save credits to obtain the smart-phone (scheme S2), while in another period (scheme S3) no credits could be earned but traffic information was still provided via the smart-phone. This lead to two reward periods during the ten weeks trail, namely a five-week period in which one should avoid enough rush-hours in order to be allowed to retain the Yeti and information; and a five-week period in which drivers only received traffic information through the Yeti, with no possibility of receiving credits. This latter scheme was used to enable us to study the impact of information independent of the impact of the credit incentive. As illustrated in Table 1, the two schemes were offered in different orders, to avoid that exogenous shocks or developments, for instance in the quality of public transport (see below) or in weather conditions (the time of year was autumn), would affect our conclusions.

Plan	**Week**												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	S1	S1	S2	S2	S2	S2	S2	S3	S3	S3	S3	S3	S3
2	S1	S1	S3	S3	S3	S3	S3	S2	S2	S2	S2	S2	S3

Note: S1: no traffic information, no reward; S2: traffic information, reward; and S3: traffic information, no reward.

Table 1. The planning of the trial

Because the participants would earn their Yeti if and only if they would have gathered a certain number of credits during the trial, there may be observations in scheme 2 where the credit, if earned, in fact had a zero value. This would be the case if either the participant had already gathered sufficient credits to be allowed to keep the Yeti, or if the number of remaining working days in the S2 period would be insufficient to be able to meet the target. In what follows, we will therefore distinguish between ‘relevant’ (S2a) and ‘irrelevant’ (S2b) Yeti credits, where the latter of course refer to days in which a marginal credit had no value to the participant.

Data collection

The data used in our analysis were collected using different technological means. The first and probably most important source of behavioural observations concerns the *vehicle passages* registered by automated roadside equipment. Two automated observation systems were installed. A first system used license plate recognition by cameras. A second system used electronic vehicle identification (EVI) beacons that connected with an on-board unit (OBU) installed in the participant’s car. Both the EVI beacons and recognition cameras were installed at the exit of Zoetermeer on all roads belonging to the corridor studied. Although the dual setup obviously introduces redundancy, both systems have specific advantages. The EVI/OBU system proved to have an extraordinary reliability of 99.99%, but is of course limited to equipped vehicles. The reliability of the camera system is in the 94 98% range, but the camera system is more tamper-proof (there is no OBU in the participant’s car) and also allowed to follow up the use of other cars available to the participant (as far as registered in our database). In our analysis we will take from the merged table of both observation systems the observation (if any) that is closest to 8:30 as indication of the participant's behaviour in morning rush hour.

A second source of behavioural information is the 'logbook' (a travel diary). The participants completed for every weekday (Monday–Friday) a web form presented on a personal webpage. The form collected information on trip motive (commute or other), transport mode used (or telework) and possibly the use of the participant's car by a different driver or the participant using a different car. The data was automatically coded and saved in a database.

There are two other possible sources of data from the trial, which, however, we will not use in this paper. The first concerns two questionnaires and an SP survey that participants completed at different moments during the trial. The second concerns GPS data that were gathered for a limited number of participants.

Impacts of information and credits on observed travel behaviour

To get a first impression of the impact of rewards and information on our participants' behaviour, it is instructive to compare the distribution of morning peak choices across travel modes and travel times during the different schemes. Since this paper focuses on the effect of information, we will only present the resulting distributions for Yeti participants. Knockaert *et al.* (2007) present detailed and extensive analyses of the behavioural responses by 'money participants'. As explained, during the trial the Yeti participants faced three different schemes: 1) receiving no reward and no traffic information in the first two week test periods (S1); 2) receiving traffic information but reward relevant periods (S2a); and 3) traffic information only period (S3).

	S1 **Preliminary measurements** (No reward & no information)	**S2a** **Reward relevant** (Reward & information)	**S3** **Information only** (No reward & information
By car before 7.30h	21.0%	30.9%	21.9%
By car 7.30-9.30h	42.8%	15.0%	32.4%
By car after 9.30h	17.1%	25.3%	21.3%
Carpool, as a passenger	1.1%	3.0%	2.2%
Public transport	5.8%	13.2%	9.0%
Cycling	2.2%	0.8%	1.7%
Work from home	2.6%	5.1%	3.8%
Others	7.4%	6.7%	5.5%

Table 2. Aggregate choice frequencies during the three schemes

Table 1 presents the distribution (in percentages) of travel modes and departure time choices of Yeti participants during these three schemes. The percentage of car trips during the peak hour fell from 43% in the preliminary measurements to 15% when, under scheme S2a, relevant credits could be earned and information was provided. This decrease was realized by shifting the trips to earlier or later off-peak time periods, as well as a slightly increase use of public transport.

An interesting phenomenon occurred when participants only received traffic information, in scheme S3. In these cases, the number of car trips in the rush-hour was still significantly lower than during the pre-measurements. It is of course possible that the presence of traffic information enabled the participants to choose better travel alternatives, so the shifts of departure times or other transport modes (compared to the reference periods) were observed. This would suggest that these participants had biased expectations of these travel times before the trial started, which seems somewhat less plausible given the repetitive character of morning peak travel for these participants. But we also take into account the possibility that participants may have made arrangements at work and at home for the full duration of the trial, so that the behaviour observed during S3 is partly the result of an incentive they beforehand expected to face during those days, rather than solely from the incentive they did face. The models presented below will account for this possibility by considering the possible impact of a virtual incentive to avoid the peak hours during S3, besides the impact of information that we are primarily interested in.

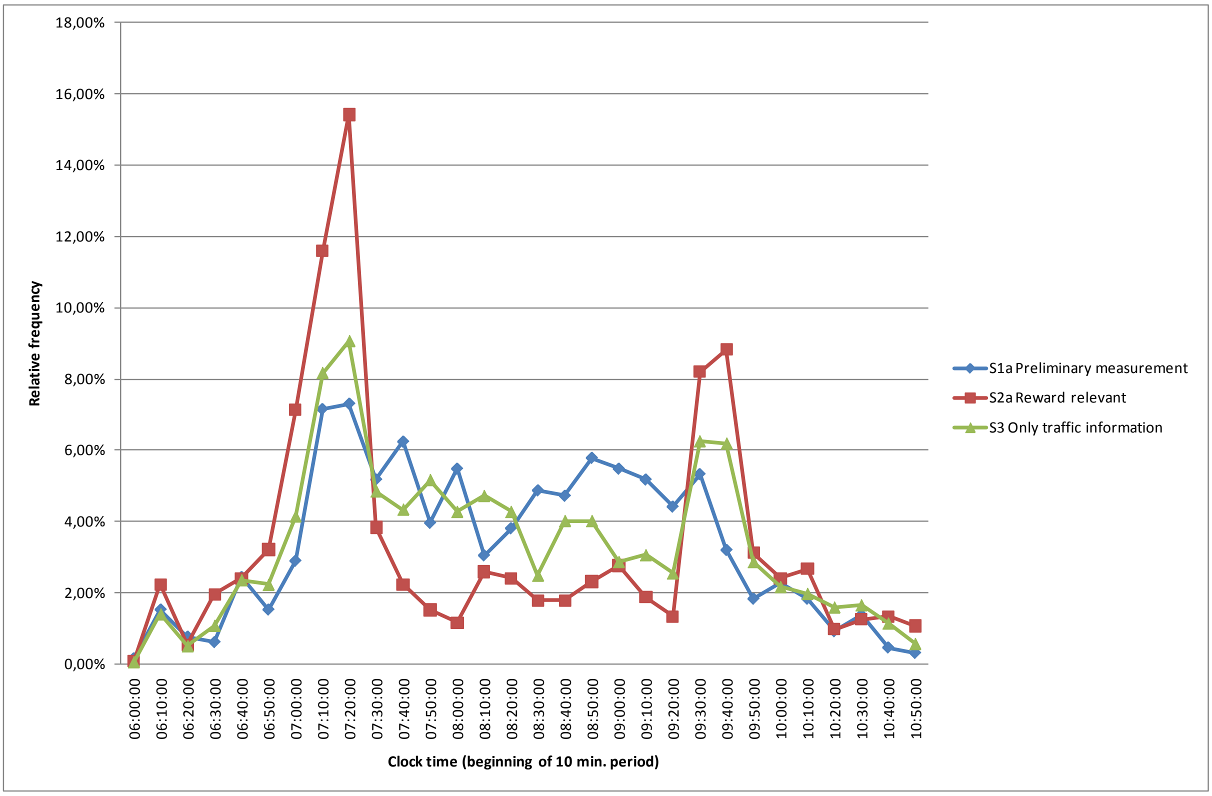

Figure 1. Time choice of participants

The more detailed time pattern of passages under these same three schemes, depicted in Figure 1, supports the hypothesis that also under the information-only scheme S3, some participants may have chosen departure times as if there were an incentive to avoid the peak between 7:30 and 9:30. Otherwise, the figure confirms the substantial impact that the incentive had on departure time choice, leading to significant peaks before 7:30 and 9:30, and reducing car travel in the peak.

Measuring actual and expected travel times

The actual travel times were based on the information provided, during the trial, by the Yeti, which was logged and hence available for our analysis, and which was based on real-time observations. Travel times are determined for 15-minute intervals and are treated fixed within such an interval. Since the actual travel times vary from day to day, especially during the peak hours, the expected travel time may be more important and relevant to travellers' decision-making. To determine the impact of information, we need to create a measure of expected travel time, so that the deviation of actual travel time from this expectation can be treated as the extra information that an informed driver possesses. The most common and simple way of specifying the expected travel time is to take the overall average of all actual travel times in a given time of day (i.e., in a 15-minute interval). Nevertheless, because traffic conditions may vary in a to some extent predictable way between days, we may need to refine the expected travel times in a more specific way.

There are at least two concerns here. First, travel times may differ quite strongly by day of the week, and people may take this into account. This argument seems to be reinforced by Figure 2, showing that the travel times on Friday are in general shorter than on other weekdays. Second, we have to check if there is any systematic change of travel times during the 13-week trial period, as there may exist some (e.g., a seasonal) effect that influenced the travel times in a systematic way. People may then have developed some expectation to accommodate it. Figure 3 shows successive observations of travel times in two representative 15-minute intervals, one before the peak and one inside the peak, throughout the trial period. As can be seen in the figure, the fitted linear trends seem rather flat, despite the outliers in the early weeks. When we check travel times for all other intervals, a general finding is that the travel times inside the peak have a slightly declining trend, while the travel times before or after the peak have a rising trend. Since the trends are flat in general, we can expect that the expected travel times derived from the fitted trend are actually close to the overall average of all observed travel times in a certain 15-minute interval.

It is of course interesting to see whether a trend can be found for the weekday-specific travel times. But since our data only cover a thirteen week period, we have only thirteen (or less, in case of missing data) observations to determine a trend for every weekday. Therefore, the trend would be very sensitive for outliers. A pragmatic approach here is to simply take the unweighted average of the weekday specific travel times, not fitting a trend. We acknowledge that a better specification of the expectation of travel time would be desirable, and should take the weekday-specific trend into account when longer series of observations are available. We will consider two simple approximations: a linear trend for all weekdays pooled, and a weekday-specific average.

Finally, note that the variation in travel times seems quite substantial, meaning that there is reason to expect that real-time traffic information may have a value to drivers, and a possible impact on their choice behaviour. Whether this is indeed the case, is of course the question to which we turn now.

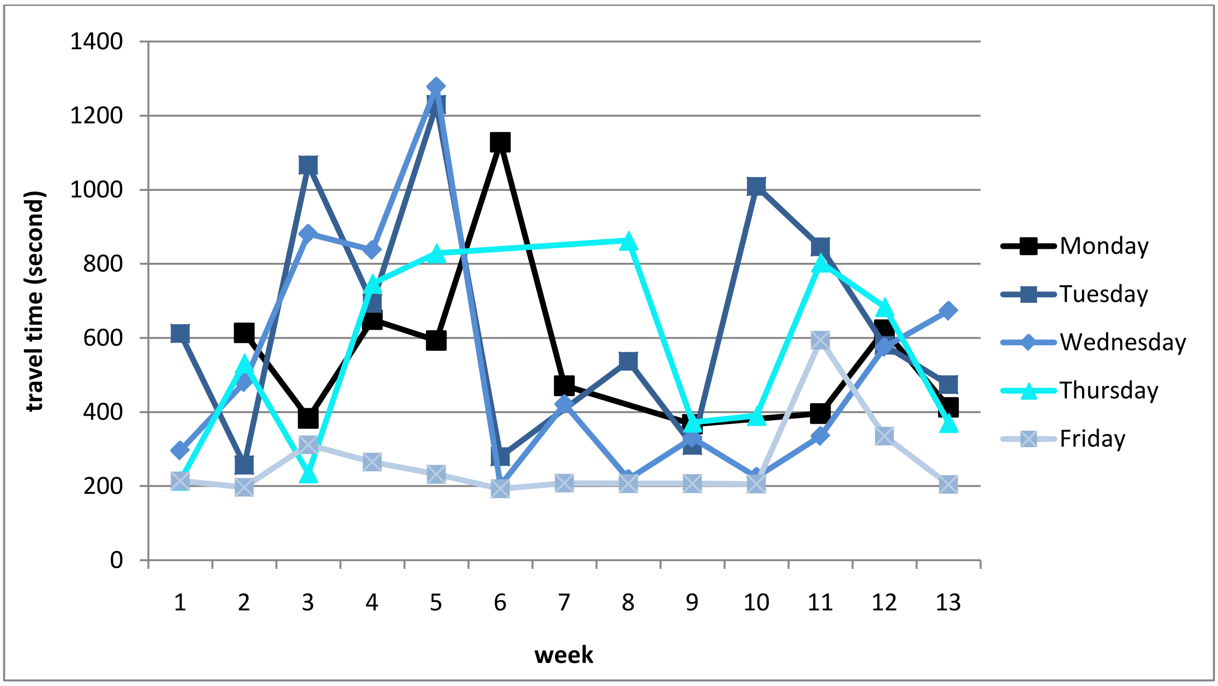

Figure 2 Travel times in the interval of 8.00-8.15 (peak) for different weekdays

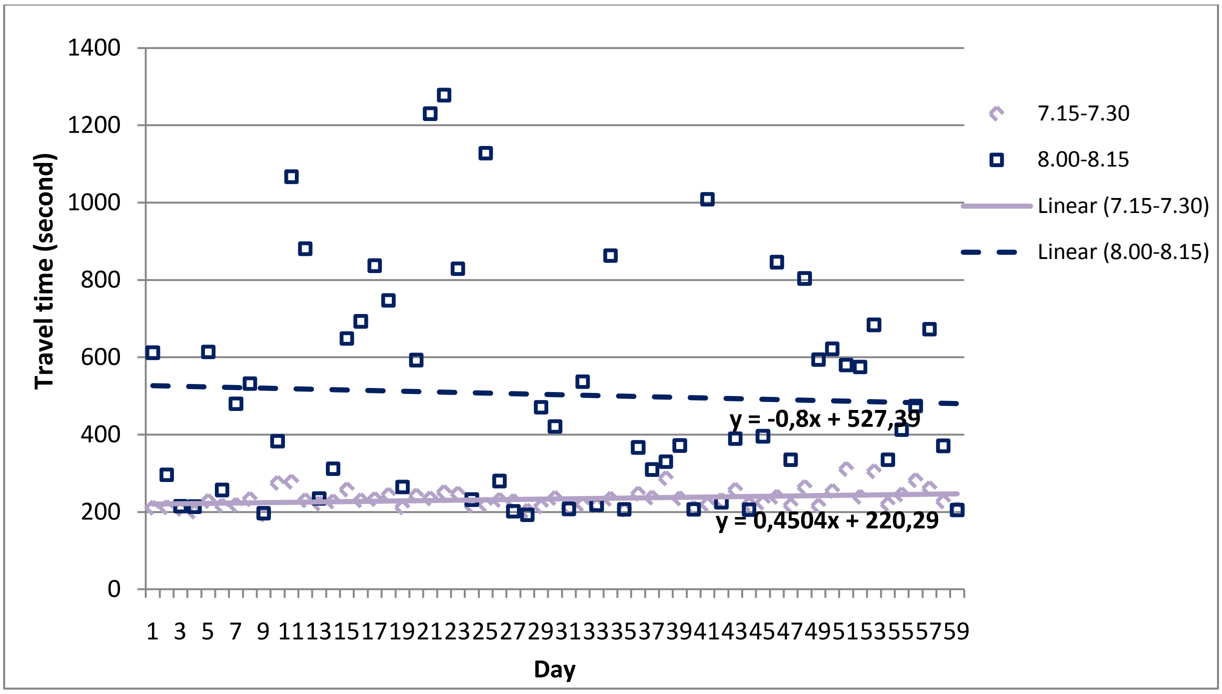

Figure 3 Travel times in the intervals of 7.15 -7.30 (pre-peak) and 8.00-8.15 (peak) for all working days

A discrete-choice model of morning peak behaviour

To model the behavioural effects of traffic information and of the reward, we adopt the discrete-choice modelling technique. Detailed reviews of discrete choice models, and econometric techniques to estimate these, are given by, *inter alios*, Ben-Akiva and Lerman (1985); and Hensher and Greene (2003). It is outside the scope of this paper to summarize these discussions. Instead, in this section, we will describe how we specify the choice alternatives and various attributes.

Travel times

As discussed above, the Yeti smart-phone provided the corresponding participants with traffic information, including instantaneous travel time on the corridor studied. This travel time information was based on real time speed-flow observations on the motorway, at different points (about one kilometre apart). To make departure time choice fit the discrete-choice framework, we work with 15-minutes intervals. We use the travel time at the middle of such an interval as the representative travel time for that interval. Since our data show that the actual travel time is highly variable during rush hours, travellers would experience a wide range of travel times even if they drive on this corridor always at the same time in the survey period. Moreover, travellers may not be aware of the actual travel time, and base their behaviour on an expected value only. Traffic information, however, gives the traveller a more accurate picture of the prevailing travel time. We thus use two travel time related attributes in the model: one is the expected travel time $E[T]$ and the other is the time difference $D[T]$, which is the difference between the expected and the actual travel times. As discussed earlier, the expected travel time can be determined by different considerations. We will use two approximations of $E[T]$: one is the travel times derived from the fitted trend of successive observations in a given interval during the trial period, and the other one is the unweighted average of the weekday-specific travel times in a certain time interval during the survey period on a specific weekday.

Schedule delays

Because our model will explain both mode choice and, for car travel, departure time choice, it is essential to include schedule delays in the specification. These are normally defined as the difference between the preferred arrival time and the actual arrival time at the destination. In our dataset, however, we do not have a variable describing the preferred arrival time at the destination unambiguously, nor do we observe actual arrival times. Moreover, because the travel time profile during the peak is unlikely to be affected by our small-scale experiment, it is in fact not the most preferred arrival time at work if travel delays were absent that is of most interest, the measure used in most scheduling models (e.g., Small, 1982), but rather the preferred moment of travelling given the current time pattern of travel delays. Given these considerations, we decided to define schedule delay as the difference between the passage time in the unrewarded reference behaviour (S1) and the actual passage time, both measured at the observation point.[1] The actual passage time is defined as the middle of the 15-minute time interval considered. The reference is defined as the middle of the 15-minute interval that corresponds to the average passage time in unrewarded behaviour. Although we do have an exact timestamp for all observed passage times, we decided to stick to the middle-of-the-interval approach, in order to ensure consistency with the representation of the non-chosen time-period alternatives in the choice set.

Rewards

In the experiment the stimulus to avoid rush hour car travel was consistently positioned as a reward in all communication with the participants. However, in our analysis we will define the stimulus as a marginal cost, defined as the reward the participant would lose by travelling during rush hour time periods. For the Yeti reward, the marginal cost becomes zero in S2b when the participant avoided rush hour car travel sufficiently to keep the smart-phone at the end of the experiment, or when the remaining time is insufficient to reach the threshold level.

Other alternatives

For choice alternatives other than private car travelling in or near the morning peak, alternative-specific constants (ASC) will be included in the model. Note that we define ‘car morning travel’ as travelling during the peak (the critical period 7:30 – 9:30 during which rewards can be lost) and in the nearest two 30-minute periods, so that it encompasses the period between 7:00 and 10:00. It is thus important to be aware of the difference between the ‘peak period’ (7:30 – 9:30) and the ‘morning period’ (7:00 – 10:00).

The estimated ASC’s will capture mode-specific preferences, insofar as these are constant over participants and over time. To account for the evolution in weather in relation to cycling, we also included the variable of observed maximum temperature in the alternative of cycling.

Summary of attributes and utility specifications

Table 3 summarizes the various model attributes. The specification of the deterministic utility of choice alternatives is next given in Table 4. The coefficients of monetary and yeti reward are estimated generically across all car morning travel alternatives. Also the travel time and schedule delay coefficients are estimated generically for these alternatives. Knockaert *et al.* (2009) have tested a series of logit models and utility specifications. More details about the results from different logit models and utility specifications can be found in that paper.

[1] To determine the average reference behaviour, we selected the observations between 7–10 a.m. where the participant indicated in the logbook to have commuted.

Attributes	Notation	Unit	Definition
Expected travel time j	$E[T]_j$	hour	a) The fitted travel times of the successive observations for linear trend in time interval j during the trial period b) The weekday-specific unweighted average of travel times observed in time interval j during the trial period
Time difference j	$D[T]_j$	hour	The difference between the actual travel time and the expected travel time in the time interval j
Money reward j	M_j	euro	marginal loss of monetary reward of peak hour car travel in time interval j
Yeti credit reward j	Y_j	credit	marginal loss of a yeti credit with peak hour car travel in time interval j (dummy). Subdivided in $Y_{R,j}$ ("relevant" for S2a); $Y_{I,j}$ ("irrelevant" for S2b); and $Y_{N,j}$ ("no credit" for S1 and S3).
Schedule delay j	SDE_j & SDL_j	Hour	the difference between the passage time in the unrewarded reference behaviour (S1) and the actual passage time at the observed location for choice alternative j
Weather (bike)	w	^{o}C	The maximum observed temperature of that day (only for the bike alternative)
Constant	ASC		Alternative specific constants for other travel options (dummies)

Table 3. Attributes used in the discrete choice models

Alternatives	Utility specification
Car morning travel (7:00 – 10:00), 12 alternatives, each representing 15-minute time interval	$ASC_{\text{car peak}} + \beta_t \cdot E[T]_j + \beta_{DT} \cdot D[T]_j + \beta_{SDE} \cdot SDE_j + \beta_{SDL} \cdot SDL_j + \beta_m \cdot M_j + \beta_Y \cdot Y_j$
Bike	$ASC_{\text{bike}} + \beta_w \cdot w$
Other alternatives (carpool, public transport, telework, car off-peak, other)	ASC_{carpool} , ASC_{PT}, ASC_{telework}, $ASC_{\text{car off peak}}$, ASC_{other}

Table 4. Specification of deterministic utility for various alternatives

3. Estimation results

In our revealed preference data, each participant was observed for a period of 13 weeks. Therefore, the presence of multiple observations from the same individual implies the potential of correlated responses across observations. To accommodate the correlation between choices drawn from the same individual, and to incorporate the panel structure of our data, we use the mixed logit model (ML). The mixed logit models are estimated with the Biogeme software (Bierlaire, 2008), using the simulated maximum likelihood approach. In particular, 10000 Halton draws were used to calculate the simulated likelihood function. We randomize one coefficient, namely the alternative specific constant for car morning travel.

Table 5 presents the results of some basic models that give a first impression of the disutilities that participants attach to the various attributes, and of how this varies between ‘money participants’ and ‘Yeti participants’. The models are basic in the sense that the two time attributes $E[T]$ and $D[T]$ are included generically for all drivers. The expected travel time here is defined as the fitted travel times of the successive observations in a given time interval during the trial period. The results with weekday-specific averages are given in the appendix.

Table 5. Default models: generic coefficient for ‘time difference’

Explanatory variables	**All participants**		**Money participants**		**Yeti participants**	
	Coeff.	Robust t-stat.	Coeff.	Robust t-stat.	Coeff.	Robust t-stat.
Standard deviation of ASC for car morning travel	**1.65**	21.72	**1.61**	18.38	**1.64**	12.30
ASC for car morning travel	**1.80**	10.80	**2.13**	10.06	**1.13**	4.07
ASC for carpool	**-2.28**	-10.81	**-2.24**	-8.84	**-2.34**	-6.36
ASC for public transport	**-0.750**	-5.03	**-0.645**	-3.48	**-0.921**	-3.69
ASC for bike	**-3.83**	-7.89	**-3.36**	-6.71	**-5.40**	-3.82
ASC for other alternatives	**-2.46**	-7.17	**-2.57**	-5.89	**-2.31**	-4.30
ASC for telework	**-1.72**	-12.34	**-1.66**	-9.26	**-1.81**	-8.24
Weather (bike) (max temp, ***w***) [^{o}C]	**0.117**	5.03	**0.110**	4.63	**0.156**	2.17
Money reward (***M***) [€]	**-0.324**	-17.05	**-0.323**	-17.82	**-**	-
Yeti_relevant credit ($\boldsymbol{Y_R}$) (S2a)	**-2.02**	-11.62	**-**	-	**-2.02**	-12.08
Yeti_irrelevant credit ($\boldsymbol{Y_I}$) (S2b)	**-1.27**	-5.11	**-**	-	**-1.27**	-5.33
Yeti_no credit ($\boldsymbol{Y_N}$) (S1, S3)	**-0.862**	-5.86	**-**	-	**-0.863**	-5.79
Mean travel time (***E[T]***) [hr]	**-4.63**	-4.89	**-4.99**	-4.07	**-3.90**	-2.46
Time difference (***D[T]***) [hr]	**-0.997**	-3.24	**-0.946**	-2.63	**-1.08**	-1.92
Schedule delay early (***SDE***) [hr]	**-2.09**	-16.40	**-2.12**	-11.95	**-2.05**	-11.99
Schedule delay late (***SDL***) [hr]	**-2.26**	-23.54	**-2.28**	-20.00	**-2.20**	-12.03
# observations	14365		9823		4542	
Log-likelihood	-31492.64		-21430.51		-10005.28	
Adjusted-R-sqrd	0.241		0.245		0.237	
Willingness to pay (€/hr)						
Value of time (VOT)	**14.29**		**15.45**		-	
Value of time difference (VODT)	**3.08**		**2.93**		-	
Value of schedule delay early (VSDE)	**6.45**		**6.56**		-	
Value of schedule delay late (VSDL)	**6.98**		**7.06**		-	

It is reassuring to see that the generic coefficients for marginal loss of reward, mean travel time, time difference, and schedule delays all have the expected sign. The same is true for the weather coefficient and the alternative specific constants have plausible signs. The standard deviation of the random coefficient is highly significant, confirming that there is indeed strong heterogeneity in this respect. It is striking that the coefficients that are used for both groups often have comparable point estimates, suggesting that a joint model estimation, with generic coefficients, need not be too problematic. The pattern of Yeti credit coefficients suggest that, although the biggest effect occurred when a credit was given and relevant, participants also responded to irrelevant credits (in S2b), and also avoided the peak (7:30-9:30) to some (but smaller) extent when no credits were offered (relevant or irrelevant). The significance of irrelevant credits may very well reflect the relative complexity of the reward schedule: people may not have realized that they already had the required number of credits, or had become incapable of reaching the target. The significance of non-existing credits may reflect our earlier hypothesis, that people may have made arrangements for the full duration of the trial. Whichever explanation holds, we see the statistical significance of these coefficients as a good reason for including them in the model. Otherwise, the correlation of these variables with travel times (because they refer to peak hours) could bias the estimates of our time coefficients.

Another remarkable finding is that money participants and Yeti participants seem to react to the same extent to the time difference variable, $D[T]$. This suggests that they have comparable information, and may mean that the significance of $D[T]$ for the Yeti drivers does not reflect the behavioural impacts of Yeti information, but rather the impact of information sources that may have been available also before the trial. We will test this in the next model specification, but before doing so we observe that the estimated values of time and schedule delay in the 'all participants model' amount to a value of expected travel time of € 14.3, a value of time difference of € 3.1, a value of schedule delay early of € 6.5, and a value of schedule delay late of € 7.0. These values are in a plausible range. Moreover, the finding that the value of travel time differences is lower than the value of expected travel times seems plausible in the sense that savings in stochastic differences can be used less effectively than savings in the expected value, for which daily schedules can more effectively be optimized. The relatively low values of schedule delay, especially that for 'late' schedules (which is frequently found to exceed the value of time), are consistent with the fact that an experiment of this type can be expected to attract relatively flexible travellers.

To investigate the impact of Yeti travel information further, we distinguish, for Yeti drivers, between days in which they did and did not have Yeti traffic information available. And for the pooled model, we allow the time difference coefficient to vary between Yeti and money participants. The results are given in Table 6. First of all, we observe that all other coefficients are robust with respect to this change in specification. Next, specific for the effect of information, we see an interesting pattern emerging. That is, the money drivers still seem to respond to $D[T]$ in a way comparable to what we found in Table 5. This suggests that these money reward participants may use other sources of information for their daily commutes, (e.g., radio), and this also gives one of the possible reasons why these people chose to have money reward instead of Yeti reward in the first place. For Yeti participants, the effect on $D[T]$ increases when having the Yeti information available. At the same time, $D[T]$ no longer as a statistically significant impact on their behaviour, and has a lower point estimate, for days where they had no information.

Table 6. Final models: differentiated coefficients for 'time difference'

Explanatory variables	All participants		Yeti participants	
	Coeff.	Robust t-stat.	Coeff.	Robust t-stat.
Standard deviation of ASC for car morning travel	**1.65**	21.70	**1.64**	12.29
ASC for car morning travel	**1.81**	10.78	**1.14**	4.04
ASC for carpool	**-2.28**	-10.81	**-2.34**	-6.36
ASC for public transport	**-0.750**	-5.03	**-0.921**	-3.69
ASC for bike	**-3.83**	-7.91	**-5.41**	-3.86
ASC for other alternatives	**-2.46**	-7.17	**-2.31**	-4.30
ASC for telework	**-1.72**	-12.34	**-1.81**	-8.24
Weather (bike) (max temperature, ***w***) [^{o}C]	**0.117**	4.80	**0.157**	2.18
Money reward (***M***) [€]	**-0.323**	-17.26	**-**	-
Yeti_relevant credit ($\boldsymbol{Y_R}$) (S2a)	**-2.00**	-11.11	**-2.01**	-10.63
Yeti_irrelevant credit ($\boldsymbol{Y_I}$) (S2b)	**-1.26**	-5.00	**-1.25**	-5.05
Yeti_no credit ($\boldsymbol{Y_N}$) (S1, S3)	**-0.851**	-5.51	**-0.851**	-5.03
E[T]	**-4.71**	-4.80	**-4.05**	-2.22
D[T] _money drivers without info.	**-0.991**	-2.50	**-**	-
D[T]_yeti drivers without info.	-0.308	-0.25	-0.643	-0.42
D[T]_yeti drivers with info.	**-1.12**	-1.82	**-1.14**	-1.99
Schedule delay early (***SDE***) [hr]	**-2.09**	-16.40	**-2.05**	-12.01
Schedule delay late (***SDL***) [hr]	**-2.26**	-23.52	**-2.20**	-12.03
# observations	14365		4542	
Log-likelihood	-31492.36		-10012.21	
Adjusted-R-sqrd	0.241		0.236	
Willingness to pay (€/hr)				
VOT	**14.58**		-	
VODT for money drivers	**3.07**		-	
VODT for Yeti drivers with info.	0.95 (insign.)		-	
VODT for Yeti drivers without info.	**3.47**		-	
VSDE	**6.47**		-	
VSDL	**7.00**		-	

Note: Bold print is used for significant values at the 90% level

The estimation results shown in Tables 5 and 6 use the 'fitted trend travel times' as the measure for expected travel time. We also estimate the same models using the 'weekday-specific unweighted average travel times'. The results are similar to the ones shown in Tables 5 and 6. In particular, we again find an increasingly smaller impact for irrelevant and non-existent Yeti credits, and an insignificant $D[T]$ coefficient for Yeti participants when information is unavailable. The VOT is smaller in this alternative specification. This may be due to the fact that travel time variation is much larger, inducing a smaller value for the travel time coefficient. For reasons of space, these results are given in the appendix and are not discussed further here.

4. Conclusions

We estimated a revealed-preference scheduling model of morning peak behaviour that allowed us to determine the impact of traffic information on traveller behaviour. Specifically, we distinguished between the marginal impact of expected travel times versus that of deviations from this expectation upon user behaviour. We found that participants who chose to receive a smart-phone with traffic information as a reward in our experiment responded to the deviation of actual travel times from the expectation, which they did not do before. This we interpret as evidence that traffic information indeed affects behaviour. The implied value of time, however, is around four to five times as big for expected travel times as it is for deviations from this expectation. This is plausible in the sense that savings in stochastic differences can be used less effectively than savings in the expected value, for which daily schedules can more effectively be optimized. We also found that participants who did not choose the smart-phone, but instead opted for monetary rewards, also responded to the deviation of actual travel times from the expectation. This suggests that these drivers use other sources of information. To some extent, this may even explain why they did not opt for the smart-phone in the first place. Our results imply that traffic information in a revealed preference setting has behavioural impacts that are often found or assumed in other settings, but also that the currently unserved markets for traffic information may be limited, because drivers already seem to have access to rather accurate traffic information.

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Appendix

The estimation results of using 'weekday-specific unweighted average of travel times' as the expected travel time

Table A1. Default models: generic coefficient for 'time difference'

Explanatory variables	All participants		Money participants		Yeti participants	
	Coeff.	Robust t-stat.	Coeff.	Robust t-stat.	Coeff.	Robust t-stat.
Standard deviation of ASC for car morning travel	**1.66**	21.67	**1.61**	18.39	**1.64**	12.32
ASC for car morning travel	**1.65**	10.81	**1.98**	10.38	**0.984**	3.82
ASC for carpool	**-2.28**	-10.81	**-2.24**	-8.84	**-2.34**	-6.36
ASC for public transport	**-0.750**	-5.03	**-0.645**	-3.48	**-0.921**	-3.69
ASC for bike	**-3.89**	-7.92	**-3.43**	-6.74	**-5.47**	-3.83
ASC for other alternatives	**-2.46**	-7.17	**-2.57**	-5.89	**-2.31**	-4.30
ASC for telework	**-1.72**	-12.34	**-1.66**	-9.26	**-1.81**	-8.24
Weather (bike) (max temp, ***w***) [^{o}C]	**0.121**	5.12	**0.114**	4.70	**0.161**	2.20
Money reward (***M***) [€]	**-0.337**	-17.37	**-0.336**	-17.76	**-**	-
Yeti_relevant credit ($\boldsymbol{Y_R}$) (S2a)	**-2.09**	-12.03	**-**	-	**-2.10**	-12.70
Yeti_irrelevant credit ($\boldsymbol{Y_I}$) (S2b)	**-1.35**	-5.41	**-**	-	**-1.35**	-5.71
Yeti_no credit ($\boldsymbol{Y_N}$) (S1, S3)	**-0.924**	-6.26	**-**	-	**-0.930**	-6.36
Mean travel time (***E[T]***) [hr]	**-3.04**	-4.16	**-3.37**	-3.63	**-2.33**	-1.93
Time difference (***D[T]***) [hr]	**-1.25**	-3.72	**-1.21**	-2.87	**-1.32**	-2.35
Schedule delay early (***SDE***) [hr]	**-2.03**	-16.82	**-2.05**	-12.48	**-2.01**	-11.84
Schedule delay late (***SDL***) [hr]	**-2.24**	-23.79	**-2.27**	-20.30	**-2.18**	-12.11
# observations	14365		9823		4542	
Log-likelihood	-31514.07		-21431.53		-10012.26	
Adjusted-R-sqrd	0.241		0.245		0.236	
Willingness to pay (€/hr)						
Value of time (VOT)	**9.02**		**10.03**		-	
Value of time difference (VODT)	**3.71**		**3.59**		-	
Value of schedule delay early (VSDE)	**6.02**		**6.08**		-	
Value of schedule delay late (VSDL)	**6.65**		**6.74**		-	

The estimation results of using ‘weekday-specific unweighted average of travel times’ as the expected travel time

Table A2. Final models: differentiated coefficients for ‘time difference’

Explanatory variables	All participants		Yeti participants	
	Coeff.	Robust t-stat.	Coeff.	Robust t-stat.
Standard deviation of ASC for car morning travel	**1.66**	21.74	**1.64**	12.31
ASC for car morning travel	**1.65**	10.80	**0.982**	3.81
ASC for carpool	**-2.28**	-10.81	**-2.34**	-6.36
ASC for public transport	**-0.750**	-5.03	**-0.921**	-3.69
ASC for bike	**-3.89**	-7.92	**-5.46**	-3.86
ASC for other alternatives	**-2.46**	-7.17	**-2.31**	-4.30
ASC for telework	**-1.72**	-12.34	**-1.81**	-8.24
Weather (bike) (max temperature, ***w***) [°C]	**0.121**	5.14	**0.160**	2.22
Money reward (***M***) [€]	**-0.336**	-17.49	**-**	-
Yeti_relevant credit (Y_R) (S2a)	**-2.09**	-11.87	**-2.10**	-12.12
Yeti_irrelevant credit (Y_I) (S2b)	**-1.35**	-5.40	**-1.36**	-5.66
Yeti_no credit (Y_N) (S1, S3)	**-0.927**	-6.11	**-0.935**	-6.07
E[T]	**-3.04**	-4.16	**-2.28**	-1.83
D[T] _money drivers without info.	**-1.30**	-2.94	**-**	-
D[T]_yeti drivers without info.	-1.24	-0.88	-1.66	-1.14
D[T]_yeti drivers with info.	**-1.17**	-2.01	**-1.27**	-2.25
Schedule delay early (***SDE***) [hr]	**-2.03**	-16.82	**-2.01**	-11.83
Schedule delay late (***SDL***) [hr]	**-2.24**	-23.79	**-2.18**	-12.10
# observations	14365		4542	
Log-likelihood	-31514.05		-10012.21	
Adjusted-R-sqrd	0.240		0.236	
Willingness to pay (€/hr)				
VOT	**9.05**		-	
VODT for money drivers	**3.87**		-	
VODT for Yeti drivers with info.	3.68 (insign.)		-	
VODT for Yeti drivers without info.	**3.48**		-	
VSDE	**6.04**		-	
VSDL	**6.67**		-	

Note: Bold print is used for significant values at the 90% level