A Prospect Theory approach to travel time variability

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Abstract

Travel time variability (TTV) is increasingly acknowledged to be an important concern for both the users and the providers of transport services. The correct measurement of variability and its value for the users are important in the design of transport policies.

Travel time variability is associated with risk, hence risk and its perception should be reflected in the valuation of variability. The focus of this paper is on the perception of variability and its value for the users by application of a Cumulative Prospect Theory (CPT) approach. CPT is a descriptive theory of decision making under risk that departs from Expected Value Maximization in two essential ways; the transformation of outcomes using value functions where the carriers of value are gains and losses rather than final levels, with diminishing sensitivity for both gains and losses; and the rank-dependent transformation of probabilities using probability weighting functions.

The current paper applies data from two Stated Choice experiments from a recent Norwegian value of time study (Ramjerdi, et al, 2010), which addresses variability of travel time for all modes of travel and for both long and short distance travel. In both experiments, travel alternatives differ with respect to travel time and cost, but in the first experiment, travel time is known with certainty, while in the second it is subject to variability, represented by a five-point distribution.

We model behaviour using a logit model with separate value functions for travel time and cost and a rank-dependent transformation of probabilities. We hypothesize that the resulting estimates of the value of travel time differ between the two experiments, because the value from the second experiment encompasses additional disutility due to risk. We argue that the difference between the values of time provides a measure of the value of travel time variability.

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1. Introduction

Travel time variability (TTV) is increasingly acknowledged to be an important concern for both the users and the providers of transport services. The correct measurement of variability and its value for the users are important in the design of transport policies.

The two common approaches to measure the value of TTV are the mean–variance approach and scheduling approach. The methods differ in their assumptions of how variability is perceived and interpreted by the traveller. The scheduling approach assumes that the travellers’ utility depends not only on travel time but also on scheduling considerations such as whether one arrives earlier or later than a preferred arrival time at a destination. In Vickrey’s (1969) model, the travellers have a preferred arrival time and their utility diminishes by arriving earlier or later than the preferred arrival time. Examples of this approach in the literature are Small (1982), Noland and Small (1995), Noland (1997), Noland et al. (1998), Bates et al. (2001), Hollander (2006) and Li et al. (2009): Small (1982) assumes scheduling choices are made under certainty. Noland and Small (1995) extended the approach by addressing uncertainty in scheduling. Noland (1997), Noland et al. (1998), Bates et al. (2001), Hollander (2006) and Li et al. (2009) are examples of incorporating risk in scheduling approach. In Vickrey (1973) the travellers see their utility in terms of departure and arrival times. Examples of this approach in the literature are Tseng and Verhoef (2008) and Fosgerau and Engelson (2011). Most studies on TTV in the literature assume that travellers maximise their expected utility through their choices.

The mean-variance approach (or other variations of this approach) assumes that the inconvenience travellers experience from variability to be due to uncertainty in itself, no matter if one arrives early or late. It includes the standard deviation or another measure of travel time variability directly into the utility function. While it is easy to apply, this approach lacks firm theoretical reasoning. The mean-variance approach has been widely used in many applications due to its simplicity. Examples of this approach in the literature are Lam and Small (2001), Small et al. (2005) and Brownstone and Small (2005). See Noland and Polak (2002) and Li et al. (2010) for a review of some earlier literature on empirical studies of travel time variability; scheduling and mean variance approaches.

Travel time variability is associated with risk. Hence risk and its perception should be reflected in the valuation of variability. In the current paper, we analyse travellers’ behaviour in choices with and without risky travel times based on a behavioural model derived from Cumulative Prospect Theory (CPT). Tversky and Kahneman (1992) formulated CPT by integrating Quiggin’s (1982) rank-dependent utility theory (RDUT) in their original work on prospect theory (Kahneman and Tversky, 1979). CPT is a descriptive theory of decision making under risk that departs from Expected Value Maximization in two essential ways; the transformation of outcomes using value functions where the carriers of value are gains and losses rather than final levels, with diminishing sensitivity for both gains and losses; and the rank-dependent transformation of probabilities using probability weighting functions.

Since the origin of prospect theory, RDUT and CPT, the literature has extensively covered alternative behavioural theories of decision making under risk by applying different versions of

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1 Batley (2007) considers percentiles of travel time distribution as a third approach while Hensher et al. (2010) acknowledge mean lateness approach that was utilized by Batley and Ibáñez (2009) as a third approach. Note that percentile of travel time distribution approach can be categorised as a variation of mean variance approach and mean lateness approach as a variation of scheduling approach.
these models. See Harrison and Cox (2008) and Wakker (2010) for recent reviews of the methodologies. Li and Hensher (2011) and van de Kaa (2008; 2010) review the application of prospect theory, RDUT and CPT in transport literature.2 As these reviews suggest, the application of RDUT and CPT in transport research are limited.

It is common practice to use stated preference (SP) techniques for collecting data on preferences in valuation of travel time variability studies. The design of the SP experiments with travel time variability often consists of binary choices between travel alternatives that differ with respect to cost and the distribution of travel time. Different formats for the presentation of travel time variability have been used in different studies. See, e.g. de Jong et al. (2007) and Fosgerau et al. (2008) for reviews of these formats. de Jong et al. (2007) report that a format that has an edge is the presentation of travel time distributions given by five equally likely outcomes, as was originally used by Small et al. (1999). Figure 1 is an example that illustrates route choice tasks from a recent Norwegian valuation study (Ramjerdi, et al, 2010).

In this paper we rely on the design catered to the mean-variance approach to directly estimate a value of travel time that captures travel time variability by applying CPT. We suggest that the criticism of the lack of theoretical reasoning in presentation of travel time variability by a travel time distribution and the use of variance to capture travel time variability is circumvented by applying the approach described in this paper.

Hjorth (2011) shows that respondents in this Norwegian study indeed behave in a manner consistent with CPT. It is possible to account for reference-dependence because the design of the choice experiment provides a natural candidate for the travellers’ reference points: To set the context of the choice tasks, respondents reported the details of a recent trip before performing the route choice tasks. The emphasis on the recent trip (reference trip) justifies the assumption of the use of travel time and cost of the reference trip as reference points for the valuation of the time and cost attributes. Hjorth’s results are consistent with the behavioural premises from CPT in that she finds significant loss aversion with respect to travel time and diminishing sensitivity with respect to gains and losses in both time and cost dimensions. Loss aversion with respect to cost is negligible. Moreover, she finds significant probability weighting, in the sense that allowing for probability weighting significantly improves the explanatory power of the behavioural model. Her results indicate that respondents tend to overweight the likelihood of extreme outcomes (largest gain, smallest gain, smallest loss, and largest loss).

The current paper extends the research by Hjorth (2011) by using the same CPT model to analyse data from Figure 1 jointly with data from another experiment in the Norwegian survey, in which travel time is known with certainty. We hypothesize that the resulting estimates of the value of travel time differ between the two experiments, because the value from the experiment with risky travel times encompasses additional disutility due to this risk. We argue that the difference between the values of time provides a measure of the value of travel time variability.

The paper is organised as follows. Section 2 presents the theoretical model, section 3 the data, and section 4 our analysis. Section 5 concludes.

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2 Other examples of applications of prospect theory, RDUT and CPT in the transport literature (not covered in these reviews) are de Lapparent and Ben-Akiva (2010), Hensher et al. (2010) and Hensher and Li (2011).
2. Theoretical Model

2.1 Choices with travel time variability

We use the choice modeling framework from Hjorth (2011): The model is based on the cumulative prospect theory model in Tversky and Kahneman (1992), applied attribute-wise to travel time and cost.

Consider a traveller and a given trip, the reference trip. We assume that the traveller has a reference travel time and a reference cost for this trip, representing his normal state or his expectations regarding the trip. We analyse the situation, where the respondent chooses between two trips that are identical to the reference trip, except for the travel time and cost. The two alternatives are each characterised by a discrete travel time distribution and a monetary cost. Let \( c_k \) denote the cost and \( \{t_{ki}, p_{ki}\}_{i=1}^{n_k} \) the travel time distribution of alternative \( k \): \( t_{ki}, p_{ki} \) are distinct outcomes that occur with probability \( p_{ki} \), and \( \sum_i p_{ki} = 1 \). We normalise the reference travel time to zero, such that negative outcomes are faster than the reference (gains) and positive outcomes are slower than the reference (losses). Similarly, we normalise the reference cost to zero, such that \( c_k \) is negative when the alternative is cheaper than the reference, and positive when more expensive.

We assume that a subject chooses the alternative that yields the higher CPT value

\[
CPT(c_1, \{t_{1i}, p_{1i}\}_{i=1}^{n_1}) > CPT(c_2, \{t_{2i}, p_{2i}\}_{i=1}^{n_2}) + \varepsilon .
\]

(1)

We assume that the value of alternative \( k \) is additively separable in travel time and cost, such that it is given by:

\[
CPT(c_k, \{t_{ki}, p_{ki}\}_{i=1}^{n_k}) = \nu(c_k) + \sum_{i=1}^{n_k} \pi_{ki} \nu(t_{ki}),
\]

(2)

where the \( \pi \)'s are cumulative decision weights, and the \( \nu \)'s are non-increasing value functions that map cost or travel time outcomes to the set of real numbers. The value functions are normalised such that \( \nu(0) = 0 \), implying that costs and travel time outcomes equal to the reference do not contribute to the CPT value.

As Tversky and Kahneman (1992), we assume that value functions are given by two-part power functions - one power function for gains, and another for losses. We assume equal powers for gains and losses.\(^3\)

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\(^3\) The use of a power functional has been criticized (Wakker, 2010) because such functions are not differentiable at zero, and because of two unfortunate characteristics which hold whenever the gain and loss powers are not equal: First, the measured degree of loss aversion depends on the scaling of the attributes, and second, there will always be some outcome for which the gain value exceeds the loss value. Yet, the power functional is the most
where the \( \alpha \)'s and \( \beta \)'s are non-negative parameters. In the case of diminishing sensitivity, the curvature parameters (\( \alpha \)'s) will be smaller than 1. Gains are weighted by \( \beta^+ \), and losses are weighted by \( \beta^- \). Subjects exhibit loss aversion for cost if \( \beta^+_c < \beta^-_c \), and for time if \( \beta^+_t < \beta^-_t \).

The decision weights are also reference-dependent. Outcomes equal to the reference (\( t_{ki} = 0 \)) have weight zero: \( \pi_{ki} = 0 \). Using the notation from (Wakker, 2010), the decision weight for gains (\( t_{ki} < 0 \)) is given by

\[
\pi_{ki} = w^+ (p_{ki} + r^+_ki) - w^+ (r^+_ki),
\]

where \( w^+ \) is an increasing weighting function that satisfies \( w^+(0) = 0 \) and \( w^+(1) = 1 \), and \( r^+_ki \) is the gain rank of the outcome \( t_{ki} \), defined as the cumulative probability of an outcome strictly better than \( t_{ki} \):

\[
r^+_ki := \sum_j p_{kj} 1\{t_{kj} < t_{ki}\}.
\]

For losses (\( t_{ki} > 0 \)), the decision weight is given by

\[
\pi_{ki} = w^- (p_{ki} + r^-ki) - w^- (r^-ki),
\]

where \( w^- \) is an increasing weighting function that satisfies \( w^-(0) = 0 \) and \( w^-(1) = 1 \), and \( r^-ki \) is the loss rank of the outcome \( t_{ki} \), defined as the cumulative probability of an outcome strictly worse than \( t_{ki} \):

\[
r^-ki := \sum_j p_{kj} 1\{t_{kj} > t_{ki}\}.
\]

We employ the weighting functions from Tversky and Kahneman (1992):

\[
v^+_c(c) = \begin{cases} \beta^+_c (-c)^\alpha^c & \text{if } c \leq 0, \\ -\beta^+_c c^{\alpha^c} & \text{if } c > 0, \end{cases}
\]

\[
v^-_t(t) = \begin{cases} \beta^-_t (-t)^\alpha^t & \text{if } t \leq 0, \\ -\beta^-_t t^{\alpha^t} & \text{if } t > 0, \end{cases}
\]
The weighting functions have an inverted S-shape if $\gamma < 1$, and are S-shaped for $\gamma \in [1, 2]$. 

### 2.2 Choices without travel time variability

We now analyse the situation, where the respondent chooses between two trips that are characterised by a known travel time and a monetary cost. $t_k$ and $c_k$ denote the travel time and cost of alternative $k$. Again we normalise the reference travel time and cost to zero. We use the same model as above, which in the case without travel time variability reduces to alternative 1 being chosen whenever

$$v_c(c_1) + v_t(t_1) > v_c(c_2) + v_t(t_2) + \varepsilon,$$  

where the value functions have the same shape as in equations (3) and (4), but have different parameters: $\beta^+_c, \beta^-_c, \alpha_c, \beta^+_t, \beta^-_t, \alpha_t$.

### 3. Data

Our data stem from a Norwegian survey conducted to establish values of travel time, variability, and traffic safety to be used in welfare-economic evaluations of transport infrastructure policies (Ramjerdi et al, 2010). Our analysis considers car trips and distinguishes between trips less than and above 100 km.

The respondents were recruited from a representative panel, and the survey was carried out on the Internet. Incentives were offered for completed questionnaires (lottery for a number of gifts of different values). The minimum age of the respondents was 18 years old. Out of 47000 contacted 9280 responded. The response rate after two reminders was about 20 percent. The main study was conducted between 11 June and 2 July 2009. An initial data cleaning left a total of 1211 in the long distance travel by car (longer than 100 km) and 3097 in the short distance travel by car (shorter than 100 km) segments.

The structure of the questionnaire in the study is as follows:

1. Introductory questionnaire: to collect data on socio-economic and demographic characteristics of the respondents
2. Questions on reference trip (recently made trip)
3. SP experiments: to collect data on the trade-offs between attributes of interest and cost
4. Final questionnaire: control questions and to collect data further data on respondents

In order to increase the realism of the study, the attributes of the hypothetical alternatives in the choice experiments are pivoted around the corresponding values for the reference trip. The
A reference trip is a one-way domestic trip for private purpose, carried out within the last week (for the short distance segment) or within the last month (for the long distance segment). Travel time is defined as in-vehicle time without stops. For a detailed description of the survey design, see Samstad et al. (2010).

The survey contained several stated preference experiments, of which we use two: An experiment with travel time variability, consisting of six binary choices between travel alternatives that differ with respect to cost and the distribution of travel time, presented as a list of five equally likely travel times, and an experiment without travel time variability, consisting of nine binary choices, where alternatives are characterised by a cost and a known travel time. Figure 1 and Figure 2 illustrate how the alternatives are presented on the screen in the two SP experiments.

Note that in the experiment with travel time variability (Figure 1) only travel time distributions and costs of alternatives are presented. It is a common practice to use the average travel time as a further attribute. This approach was initially tried in a pilot study: There were two problems with the presentation of an average travel time. The first problem was that the pivoted distribution around the reference travel time could not be symmetrical. The travel time could be much longer than the reference travel time, but not much shorter than the reference travel time to be plausible. By taking this point into consideration a plausible distribution did not result in a significant estimation of the variance using a standard mean-variance approach. Hence only costs and distribution of travel time were used in the presentation of the alternatives.

In both experiments, all respondents are presented with both gains and losses in the time and cost dimensions. In the experiment with TTV, the five travel times presented for each alternative need not be distinct, and need not include the reference travel time. Moreover, they need not include both gains and losses.

To be able to compare behaviour in the two experiments without controlling for individual characteristics, we limit our analysis to respondents who participate in both experiments. We exclude respondents who answered side-lexographically (always chose left or right alternative), dropped out during the survey, or gave unrealistic reference values. For both the short distance and the long distance data set, these exclusions correspond to around 11% of the observations in each experiment. Moreover, since data are sparse for high values of reference time and cost, we restrict our analysis to the following samples:

- Short distance: Cost ≤ 250 NOK, time ≤ 90 minutes.
- Long distance: Cost ≤ 1500 NOK, time ≤ 900 minutes.

Table 3 in the Appendix provides summary information of the resulting samples.

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4 Unrealistic values are average speeds above 100 km per hour, cost less than 50 NOK for long distance trips, and cost per kilometre less than 0.2 NOK or higher than 11 NOK.

5 1 NOK ≈ 0.12 Euro.
4. Econometric analysis and results

To ease comparison of the preference parameters in the two experiments, we choose to normalise the cost gain parameters $\beta^+$ and $\tilde{\beta}^+$ to 1, rather than normalising the error scale. We assume that the error term $\varepsilon$ is logistic with scale parameters $\mu$ and $\tilde{\mu}$, respectively, in the two experiments (the scale parameter is inversely proportional to the standard deviation). For convenience, we assume the error terms to be independent across choices, including choices.
within the same individual, resulting in a binomial logit model. We use maximum likelihood estimation, which is carried out in Ox (Doornik, 2001), using 40 different sets of randomly generated start values to make sure we find the global optimum. The estimation results are shown in Table 1.

Table 1: Estimation results

<table>
<thead>
<tr>
<th></th>
<th>Car short</th>
<th>Car long</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Std.Err.</td>
</tr>
<tr>
<td>Experiment with TTV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_c^+$</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>$\beta_c^-$</td>
<td>0.90</td>
<td>0.04</td>
</tr>
<tr>
<td>$\beta_t^+$</td>
<td>0.60</td>
<td>0.06</td>
</tr>
<tr>
<td>$\beta_t^-$</td>
<td>0.84</td>
<td>0.07</td>
</tr>
<tr>
<td>$\alpha_c$</td>
<td>0.38</td>
<td>0.02</td>
</tr>
<tr>
<td>$\alpha_t$</td>
<td>0.77</td>
<td>0.02</td>
</tr>
<tr>
<td>$\mu$</td>
<td>0.64</td>
<td>0.04</td>
</tr>
<tr>
<td>$\gamma^+$</td>
<td>2.98</td>
<td>0.25</td>
</tr>
<tr>
<td>$\gamma^-$</td>
<td>0.80</td>
<td>0.04</td>
</tr>
<tr>
<td>Experiment without TTV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tilde{\beta}_c^+$</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>$\tilde{\beta}_c^-$</td>
<td>1.05</td>
<td>0.02</td>
</tr>
<tr>
<td>$\tilde{\beta}_t^+$</td>
<td>0.49</td>
<td>0.02</td>
</tr>
<tr>
<td>$\tilde{\beta}_t^-$</td>
<td>0.52</td>
<td>0.02</td>
</tr>
<tr>
<td>$\tilde{\alpha}_c$</td>
<td>0.46</td>
<td>0.01</td>
</tr>
<tr>
<td>$\tilde{\alpha}_t$</td>
<td>0.84</td>
<td>0.02</td>
</tr>
<tr>
<td>$\tilde{\mu}$</td>
<td>1.14</td>
<td>0.05</td>
</tr>
<tr>
<td>Log Likelihood</td>
<td>-11652.3</td>
<td></td>
</tr>
</tbody>
</table>

4.1 Discussion of the estimated parameters

The estimated value functions are roughly similar for both experiments and data sets: We observe loss aversion with respect to travel time ($\beta_t^+ < \beta_t^-$ and $\tilde{\beta}_t^+ < \tilde{\beta}_t^-$; the parameters are significantly different according to a Wald test at the 1% level). All curvature parameters ($\alpha$’s)

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6 The independence assumption is convenient, but may be unrealistic – it would be violated if, e.g., subjects have heterogeneous preferences, such that choices within a given individual are correlated.
are significantly greater than zero and less than one (z-tests, 1% level), implying diminishing sensitivity to time and cost changes. Moreover, we observe a higher degree of diminishing sensitivity for cost than for time changes.

Respondents in the short distance data set exhibit loss aversion with respect to cost in the experiment without TTV, but not in the experiment with TTV. Both effects are significant in the sense that $\beta_c^+$ and $\beta_c^-$ are significantly different from one according to a Wald test at the 1% level. In the long distance data set we observe loss aversion with respect to cost in both experiments, but the effect is only significant in the experiment without TTV.

The estimated values of $\gamma^+$ and $\gamma^-$ imply inversely S-shaped weighting functions for losses and convex weighting functions for gains. This corresponds to respondents overweighting the largest loss (relative to other losses) and overweighting the smallest gain (relative to other gains). 7

4.2 Comparison of marginal rates of substitution
To compare experiments, we look at the marginal rates of substitution (MRS) between travel time and money. These depend not only on the numerical size of the time and cost changes, but also on the signs. For each pair of time/cost changes $(t, c)$, $t, c > 0$, we therefore compute four separate measures of the MRS:

- **WTP** $(t, c)$: The MRS at a point corresponding to a time gain of size $t > 0$ and a money loss of size $c > 0$. For the two experiments, we have
  \[ \text{WTP}^{\text{With TTV}}(t, c) = \frac{\alpha_t \beta_t^+ t^{\alpha_t^{-1}}}{\alpha_c \beta_c^+ c^{\alpha_c^{-1}}}, \quad \text{WTP}^{\text{Without TTV}}(t, c) = \frac{\alpha_t \beta_t^+ t^{\alpha_t^{-1}}}{\alpha_c \beta_c^+ c^{\alpha_c^{-1}}} \]  

- **WTA** $(t, c)$: The MRS at a point corresponding to a time loss of size $t > 0$ and a money gain of size $c > 0$.
  \[ \text{WTA}^{\text{With TTV}}(t, c) = \frac{\alpha_t \beta_t^- t^{\alpha_t^{-1}}}{\alpha_c \beta_c^- c^{\alpha_c^{-1}}}, \quad \text{WTA}^{\text{Without TTV}}(t, c) = \frac{\alpha_t \beta_t^- t^{\alpha_t^{-1}}}{\alpha_c \beta_c^- c^{\alpha_c^{-1}}} \]  

- **EG** $(t, c)$: The MRS at a point corresponding to a time gain of size $t > 0$ and a money gain of size $c > 0$.
  \[ \text{EG}^{\text{With TTV}}(t, c) = \frac{\alpha_t \beta_t^+ t^{\alpha_t^{-1}}}{\alpha_c \beta_c^+ c^{\alpha_c^{-1}}}, \quad \text{EG}^{\text{Without TTV}}(t, c) = \frac{\alpha_t \beta_t^+ t^{\alpha_t^{-1}}}{\alpha_c \beta_c^+ c^{\alpha_c^{-1}}} \]  

- **EL** $(t, c)$: The MRS at a point corresponding to a time loss of size $t > 0$ and a money loss of size $c > 0$.
  \[ \text{EL}^{\text{With TTV}}(t, c) = \frac{\alpha_t \beta_t^- t^{\alpha_t^{-1}}}{\alpha_c \beta_c^- c^{\alpha_c^{-1}}}, \quad \text{EL}^{\text{Without TTV}}(t, c) = \frac{\alpha_t \beta_t^- t^{\alpha_t^{-1}}}{\alpha_c \beta_c^- c^{\alpha_c^{-1}}} \]  

7 However, it is likely that the high end of the estimated weighting function is determined largely by the fitting of the assumed functional form to the low end, since only around 20% of non-reference outcomes in the experiment with TTV are associated with $w$ evaluated in 0.6 and 0.8. We therefore expect the estimated weighting of high ranks (smallest gain/loss) to be less reliable. We refer to Hjorth (2011) for a discussion.
We consider the ratios $\frac{\text{WTP}^{\text{WithTTV}}}{\text{WTP}^{\text{WithoutTTV}}}$, $\frac{\text{WTA}^{\text{WithTTV}}}{\text{WTA}^{\text{WithoutTTV}}}$, $\frac{\text{EG}^{\text{WithTTV}}}{\text{EG}^{\text{WithoutTTV}}}$, and $\frac{\text{EL}^{\text{WithTTV}}}{\text{EL}^{\text{WithoutTTV}}}$. Note that all four ratios are proportional to $f(t,c) = t^{\alpha_0 - \bar{\alpha}_i} c^{-(\alpha_i - \bar{\alpha}_i)}$, with the proportionality constant depending on the $\beta$'s. We have

$$f(t,c) = t^{-0.07} c^{-0.08}$$  \hspace{1cm} \text{for the short distance data set, and} \hspace{1cm} (13)$$

$$f(t,c) = t^{0.07} c^{-0.11}$$  \hspace{1cm} \text{for the long distance data set.} \hspace{1cm} (14)$$

Interestingly, this implies that while the ratios for the short distance data set attain their lowest values in points corresponding to large time changes and small cost changes, the ratios for the long distance data set attain their lowest values in points corresponding to small time changes and large cost changes.

Figures 3-10 in the Appendix show the level curves of the estimated ratios, for the range of $(t,c)$ where we have data (time changes short/long distance: $[1, 36]/[5, 230]$; cost changes short/long distance: $[1, 73]/[5, 450]$, cf. Table 3). Table 2 reports the minimum and maximum values of the ratios over the range. For the short distance data set, the ratios range from 1.07 to 2.99, indicating that respondents consistently value travel time higher in the experiment with TTV than in the experiment without. For the long distance data set the range is 0.85-3.13: It exceeds one for the majority of the data, but is less than one for points that correspond to small time changes and large cost changes (this corresponds to the upper left corner in Figures 7-10; note, however, that data are sparse here and in the lower right corner).

### Table 2: Minimum and maximum of estimated ratios of values of travel time with and without TTV and their confidence limits

<table>
<thead>
<tr>
<th>Car</th>
<th>Min (lower conf limit)</th>
<th>Max (upper conf limit)</th>
<th>Min (lower conf limit)</th>
<th>Max (upper conf limit)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Car short</td>
<td>Car long</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WTP ratio</td>
<td>1.24</td>
<td>2.25</td>
<td>0.96</td>
<td>3.02</td>
</tr>
<tr>
<td>WTA ratio</td>
<td>1.42</td>
<td>2.57</td>
<td>1.22</td>
<td>3.30</td>
</tr>
<tr>
<td>EG ratio</td>
<td>1.07</td>
<td>1.93</td>
<td>0.83</td>
<td>2.55</td>
</tr>
<tr>
<td>EL ratio</td>
<td>1.65</td>
<td>2.99</td>
<td>1.42</td>
<td>3.92</td>
</tr>
</tbody>
</table>

We compute 95% confidence limits for the ratios by simulating draws from the asymptotic distribution of the estimated parameters and computing the corresponding distributions of the ratios (using 10,000 draws). For the short distance data set, the lower confidence limit generally exceeds one, indicating that travel time is valued significantly higher in the experiment with TTV. The only exception is for WTP and EG ratios for points corresponding to large time changes and small cost changes (this corresponds to the lower right corner in Figures 3-6; note, however, that data are sparse here and in the upper left corner). For the long distance segment, the ratios are not in general significantly higher (or lower) than one, so travel time is rarely valued significantly higher in one experiment than the other.
5. Conclusion

The design of SP experiment for the accommodation of the “mean-variance” approach to measure the value of TTV calls for presentation of a distribution of travel time. The analyst assumes that the respondents maximise their (expected) utility, trading an average time against the variability measured by the variance (or other measures of variability of travel time). We deviate from this assumption and propose that the respondents integrate their perception of the assigned probabilities to transform the travel time distribution to a likely travel time given the TTV and hence the value of travel time derived by such assumption includes VTT.

We compare SP experiments with and without travel time variability for short and long car trips. In the case of short distance car trips, where we have observations from more than 1500 individuals, we find that travel time is valued significantly higher in the experiment with TTV than in the experiment with known travel times. In the case of long distance car trips, where we ‘only’ have observations from 543 individuals, we also find that travel time is valued higher in the experiment with TTV for most attribute levels, but not significantly so.

The results from our study, the differences between values of travel time with and without TTV, can be interpreted as a “reliability premium”, cf. Batley (2007), who theoretically derives a reliability premium, i.e. the cost of bearing unreliability, in a scheduling setup.

Another study similar to ours is by Hensher et al. (2010), where SP data for short distance travel is used for the estimations of values travel time with TTV and without TTV. Their study is however different from ours in several aspects. A major difference is that they rely on only one experimental design to address values of travel time without TTV and with TTV, implicitly assuming that the respondents ignore TTV when they estimate the value of travel time without TTV. They also rely on Extended CPT by assuming the reference point can be updated in the experiments (see Harrison and Ruström, 2008; van de Kaa, 2010). They do not address the differences between WTP, WTA, EG and EL. They only apply value functions to cost, while in this study we observe loss aversion with respect to travel time and higher degree of diminishing sensitivity for cost than for time. They report the ratio of value of travel time with TTV and value of travel time without TTV to be 18.04/16.65 or 1.083 using a logit model.
References


## Appendix

### Table 3: Summary statistics of the sample

<table>
<thead>
<tr>
<th></th>
<th>Car long</th>
<th>Car short</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample size</strong></td>
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</tr>
<tr>
<td>- individuals</td>
<td>543</td>
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<tr>
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<tr>
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Note: Travel times are in minutes, costs are in NOK.
Figure 3: Level curves of WTP ratio (car short)

Figure 4: Level curves of WTA ratio (car short)
Figure 5: Level curves of EG ratio (car short)

Figure 6: Level curves of EL ratio (car short)
Figure 7: Level curves of WTP ratio (car long)

Figure 8: Level curves of WTA ratio (car long)
Figure 9: Level curves of EG ratio (car long)

Figure 10: Level curves of EL ratio (car long)