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# Value of travel time reliability: two alternative measures

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**Abstract**

This paper deals with the estimation of the willingness to pay for travel time reliability (*VOR*). We report on a stated preferences survey and we provide an econometric treatment of the data using a conditional logit model. Estimations are made according to two alternative approaches: The first uses a mean-variance approach and the second uses specific coefficients for the preferences function. Although the two approaches are significantly different, both yield quite similar estimations for the *VOR*.



*Keywords:* Value of Reliability ; Stated preferences ; Discrete choice model.

## Introduction

In the cost-benefit analysis of alternative transport systems, the value of travel time savings (*VTTS*) has long been recognized as the most important part of users' benefit. Traditionally in the literature on the *VTTS*, the travel time is assumed to be sure or risk-free. However, for any reason such as bad weather, accident, technical incident, strike or congestion as a result of excess demand relative to road capacity, most individuals indeed know and dislike the fact there is no risk-free transport mode exhibiting a sure travel time. Thus, nowadays, the value of travel-time reliability (*VOR*) has become a new key element.

In the present paper, we provide empirical estimations of both the *VTTS* and the *VOR* using data from a survey in stated preferences. The *VOR* is estimated for individuals choosing among various risky alternatives for a given transport mode (train) in the context of a personal intercity trip. Thus, reliability is exogenous and is captured by

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the gap between the (risky) travel time which individuals consider and the (virtually risky-free) one announced by the operator.

In a recent survey, Li et al. (2010), have identified at least three main approaches to model travel time reliability and, hence, to measure the *VOR*: (i) the mean-dispersion model (Jackson and Jucker, 1982; Small and *al*., 1999; Senna, 2004)., (ii) the scheduling model (Vickrey, 1969; Small, 1982; Noland and Small, 1995; Small and *al*., 2005; Bates and *al*., 2001; Asensio and Matas, 2009) and (iii) the mean lateness model (Batley and Ibáñez, 2009; ATOC, 2005).

Here, we compare the estimation of the *VOR* obtained using the mean-dispersion approach to the one obtained using another fourth alternative approach, namely the specific coefficients approach. In this latter approach, individuals' preferences function does not incorporate the standard-deviation of the travel time as an explicit argument. Rather, individuals' preferences function is specific to the alternative under consideration (risky or risk-free), and the *VOR* is captured by comparing differences in *VTTS*.

The paper is organized as follows. The next section presents the basic theoretical framework for the study of the *VOR*. Alternative measures of the *VOR* are exposed and discussed in section 3. The data collection from our study in stated preferences is presented in section 4. The econometric estimations of both the *VTTS* and *VOR* are given in section 5. Finally, section 6 gives concluding

## 2. Theoretical framework

Consider an individual having to make a choice among various alternatives for a given intercity trip by train. Each alternative is fully characterized by its price $p > 0$ and by the probability distribution of its random travel time $\tilde{t} > 0$. We assume that the individual's preferences over alternatives can be represented by a quasi-linear preferences function of the von Neumann-Morgenstern's expected utility form:

$$U(p,\tilde{t}) = \lambda\, p + \mathbf{E}u(\tilde{t}) \qquad (1)$$

where $u(\tilde{t})$ is a decreasing utility function defined over travel time and $\lambda$ represents (minus) the constant marginal utility of wealth of the individual. We first define the *VTTS*.

**Definition 1**. *Consider an alternative with price* $p$ *and random travel time* $\tilde{t}$*. The VTTS is the maximum additional monetary amount (above* $p$*) the individual is ready to pay to reduce the travel time by 1 unit in all states of the world. Formally, the VTTS is implicitly defined by the following identity:*

$$U(p,\tilde{t}) = U(p + VTTS, \tilde{t} - 1) \qquad (2)$$

Observe that whenever the preferences function is strictly decreasing in both the price and the travel time of each mode, i.e. $\lambda < 0$ and $u' < 0$, the *VTTS* must be strictly positive.

The following definitions essentially mimic standard ones in risk theory, adapted to the transport mode choice problem. In this context, we will define the *VOR* as a risk premium.

**Definition 2.** *The individual is 'reliability-lover' if, at any level of price* $p$*, he or she always prefers a sure travel time to any risky travel time with the same expected travel time:* $U(p,\tilde{t}) < U(p,\mathbf{E}\tilde{t})$*, i.e. the utility function* $u$ *is concave in travel time.*

**Definition 3**. *Consider an alternative with price $p$ and random travel time $\tilde{t}$. The VOR is the maximum additional monetary amount (above $p$) the individual is ready to pay to have a sure travel time equal to the expectation of the random travel time $\tilde{t}$. Formally, the VOR is implicitly defined by the following identity:*

$$U(p,\tilde{t}) \equiv U(p + VOR, \mathbf{E}\tilde{t}) \quad (3)$$

Observe that whenever $\lambda < 0$, the *VOR* is positive if and only if the individual is reliability-lover. Moreover, following Li, Hensher and Rose (2009), we can derive the reliability embedded value of travel time savings: *REVTTS=VTTS+VOR*.[†] Finally, we also consider a non-monetary measure of the *VOR* (expressed in units of time and denoted $\widehat{VOR}$).

**Definition 4.** *Consider an alternative with price $p > 0$ and random travel time $\tilde{t} > 0$. The $\widehat{VOR}$ is the maximum additional amount of travel time (above $\mathbf{E}\tilde{t}$) the individual is ready to accept to have a sure travel time, the $\widehat{VOR}$ is implicitly defined by the following identity:*

$$U(p,\tilde{t}) \equiv U(p, \mathbf{E}\tilde{t} + \widehat{VOR}) \quad (4)$$

## 3. Modeling and alternative measures

### 3.1. Mean-variance preferences

Different forms can be given to the preferences function. Assuming that $u$ is quadratic, the expectation of $u$ is a function of only the first two moments of the travel time distribution. In this case, the preferences function in *(1)* simplifies to

$$U(p,\tilde{t}) = \lambda\, p + k\mathbf{E}\tilde{t} + \gamma\mathbf{SD}\tilde{t} \quad (5)$$

where $\lambda = \frac{\partial U(p,\tilde{t})}{\partial p}$, $k = \frac{\partial U(p,\tilde{t})}{\partial \mathbf{E}\tilde{t}}$ and $\gamma = \frac{\partial U(p,\tilde{t})}{\partial \mathbf{SD}\tilde{t}}$ are negative parameters to be estimated by observing individual choices among alternatives with different prices, expectation and standard deviation. Thus, from definitions 1, 3 and 4, we have:

$$VTTS = \frac{k}{\lambda};\quad VOR = \frac{\gamma}{\lambda}\mathbf{SD}\tilde{t};\quad \widehat{VOR} = \frac{\gamma}{k}\mathbf{SD}\tilde{t} \quad (6)$$

where $\widehat{VOR} = \frac{VOR}{VTTS}$, i.e. the $\widehat{VOR}$ is equivalent to the so-called reliability ratio. Observe that the *VTTS* is independent of the mean travel time of alternatives. On the other hand, both $VOR$ and $\widehat{VOR}$ are specific to the standard-deviation of the alternative under consideration.

### 3.2. Specific coefficients approach

[†] As pointed out by a referee, it is not so straightforward to directly compare the *VTTS* and the *VOR* to the extent that they are not defined with the same unit of measurement: the *VTTS* is per unit of mean of travel time while the *VOR* is per unit of standard-deviation of travel time.

In this approach, the preferences function is supposed to be a linear function of price and mean travel time and to be specific to the alternative under evaluation. For an alternative $i$, the preferences function takes the following simple linear form:

$$U_i(p_i, \tilde{t}_i) = \lambda_i p_i + k_i \, \mathbf{E}\tilde{t}_i \quad (7)$$

where $\lambda_i$ and $k_i$ are negative parameters.

Consider two distinct alternatives: a risky alternative with random travel time $\tilde{t}_i$ and a risk-free alternative $j$ with sure travel time $t_j$. In this context, definitions 3 and 4 cannot be used to determine the *VOR*. Indeed, the parameter $k$ in the preferences function in *(7)* capture both the value of time and the value of reliability since there is no specific variable defining travel time variability. The variability is included implicitly in the mean travel time. In this context, the *VOR* is captured through the impact of variability on the *VTTS*:

$$VOR_i = VTTS_j - VTTS_i \quad (8)$$

Thus, if the individual is reliability-lover (definition 2), he or she should prefer the reliable mode $j$ to the unreliable mode $i$, and we would have $VTTS_j > VTTS_i$ and, hence, $VOR_i > 0$. According to this definition, an individual would be ready to pay a positive amount to increase reliability of travel time if and only if he or she would be ready to pay less to reduce the mean travel time of an unreliable alternative than to reduce the mean travel time of a fully reliable travel mode. This approach can be seen simply as a transposition of the results obtained by Li, Hensher and Rose (2009) in a departure time choice context to the case of modal choice between a fully reliable alternative and an unreliable one.

## 4. Study in stated preferences

We generate data through a study in stated preferences. The investigation concerns the choice between two alternatives, one with a sure travel time (reliable alternative) and another with a random travel time (unreliable alternative).[‡] To determine the different levels of price and time, we use SNCF's tariffs and travel time indicated by this train operator to Montpellier-Paris (3h20) and Montpellier-Lyon (2h40) in booking trains. To each of the two reliable travel times, we oppose five risky travel times. The levels of the price and time attributes are presented in Table 1 and 2.

The data collection proceeded during August and November 2011. We sampled the individuals according to the quota method, so the sample constitutes a photo reduction of the target population.[§] According to the literature on the empirical measurement of the *VTTS*, the selected criterion of quota is that of the taxable equivalent income per unit of consumption. Following a study conducted jointly by the Institut National de la Statistique et des Etudes Economiques (INSEE) and the Direction Générale des Impôts (DGI), we use the distribution of taxable income for the year 2007 (see table 3). The second column of Table 3 provides the characteristics of the distribution of taxable income per consumption unit of the individuals sampled.

[‡] The terms of "reliable mode" and "unreliable mode" were not used in the presentation of hypothetical choices presented to interviewed individuals.

[§] The quota method consists in building a representative sample in which the proportion of individuals in each class of equivalent income is the same as in the target population. It differs from random sampling methods, since it is not possible to assign to each individual within the target population a probability of inclusion.

Table 1. Levels of price attribute

| Mode | Price (€) | | | | |
|---|---|---|---|---|---|
| Reliable mode | 39 | 54 | 75 | 105 | 145 |
| Unreliable mode | 25 | 45 | 63 | 89 | 123 |

Table 2. Levels of travel time attribute

| Sure time | $\pi$ | $\bar{t}$ | (1-$\pi$) | $\underline{t}$ | $\mathbf{E}\tilde{t}$ | $\mathbf{SD}\tilde{t}$ (min) |
|---|---|---|---|---|---|---|
| 3h20 | 0.9 | 3h40 | 0.1 | 3h | 3h36 | 12 |
| | 0.4 | 4h05 | 0.6 | 2h50 | 3h20 | 36.74 |
| | 0.5 | 3h40 | 0.5 | 3h | 3h20 | 20 |
| | 0.25 | 3h20 | 0.75 | 3h | 3h05 | 8.66 |
| | 0.6 | 3h | 0.4 | 2h50 | 2h56 | 4.9 |
| 2h40 | 0.75 | 3h30 | 0.25 | 2h30 | 3h15 | 25.98 |
| | 0.2 | 3h45 | 0.8 | 2h30 | 2h45 | 30 |
| | 0.1 | 3h20 | 0.9 | 2h40 | 2h44 | 12 |
| | 0.1 | 3h | 0.9 | 2h40 | 2h42 | 6 |
| | 0.4 | 2h40 | 0.6 | 2h10 | 2h22 | 14.7 |

Table 3. Taxable income distribution per consumption unit

| Population[a] | | Sample | |
|---|---|---|---|
| Deciles | Income declared by UC | Deciles | Income declared by UC |
| D1 | 548 € | D1 | 400 € |
| Median | 1 453 € | Median | 1 400 € |
| D9 | 2 964 € | D9 | 2 792 € |
| Average | 1 729 € | Average | 1 676 € |

[a]Source: Study "Revenus fiscaux des ménages 2007" – INSEE – DGI

The combination of the various levels of attributes[**] for both transport alternatives (reliable and unreliable) led to the *Full Factorial Design* (250 scenarios of hypothetical choice). This structure is the only one which guarantees the statistical independence of the estimation of each attribute on the answers. Unfortunately, such a structure quickly becomes non tractable. It is possible to build a reduced set of hypothetical situations, called *Fractional Factorial Design*, at the price however of a statistical efficiency loss. By the way of suitable method, we can reduce the choice set to 50 hypothetical situations. These 50 scenarios of hypothetical choices between a reliable mode and an unreliable one were then randomly partitioned into five blocks of 10 scenarios.

Table 4: Examples of choice situations

| Scenario | Mode | Price | Time | Choice |
|---|---|---|---|---|
| 14 | Mode A | 54 € | 3h20 | |
| | Mode B | 45 € | 3h40 with 50 % chance<br>3h with 50 % chance | |
| 32 | Mode A | 54 € | 2h40 | |
| | Mode B | 45 € | 3h with 10 % chance<br>2h40 with 90 % chance | |

Each of the 155 individuals sampled was faced with 10 scenarios of hypothetical choices. Finally, we obtain a database with 1550 observations. These observations correspond to the choice of a transport mode by an

[**] See Table 1 and Table 2.

individual for one of the 50 scenarios of the *Fractional Factorial Design*. Among the 1550 choices made, 693 concerned the reliable mode (sure travel time) and 857 the unreliable mode (random travel time).

Table 5. Descriptive statistics

| | Reliable mode | Unreliable mode | Sum |
|---|---|---|---|
| Choice | 693 | 857 | 1 550 |
| % | 44.71 | 55.29 | 100 |
| Average price (€) | 62.95 | 52.97 | 57.43 |
| Average time | 178.35 min | 179.44 min | 178.96 min |
| Average variability (**SD**) | | 15.74 min | 8.9 min |
| Average income (€) | 2 809 | 2 614 | 2 701 |
| Average income per UC (€) | 1 757 | 1 610 | 1 676 |

## 5. Model estimation and valuation of reliability

In the following, all models are estimated by conditional logit model realized with SAS software[††].

### *5.1. Mean-variance preferences*

We have estimated preferences function for the mean-dispersion approach. The modeling results are given in Table 6.

Table 6. Mean-variance approach

| Variables *(\|t-stat\|)* | |
|---|---|
| Price | -0.0741 *(\|18.36\|)* |
| Time | -0.0423 *(\|7.92\|)* |
| Standard-deviation | -0.0271*(\|16.081\|)* |
| Log likelihood (restricted) | -1 074 |
| Log likelihood (unrestricted) | -454.62755 |
| Pseudo-Rho$^2$ | 0.577 |
| Proportion predicted with success | 88 % |
| Size of the sample | 1 550 |

All parameters are significant at the 5 percent level. To the average point of our sample[‡‡], the choice probability of the reliable mode is 0.56, therefore the choice probability of the unreliable mode is 0.44. The model predicts correctly individual behavior in 88 % of cases.

From equation *(6)*, we have the following *VTTS* and *VOR*:

$$VTTS = 34.54\ \text{€/hour}\ ;\ VOR = 0.366\widetilde{\mathbf{SD}t}^{§§}\ ;\ \widehat{VOR} = 0.64\mathbf{SD}\tilde{t} \qquad (9)$$

According to our sample, an individual is willing to pay 34.54 € to avoid one hour in its total travel time.

[††] We also estimated the models using a Mixed Logit using uniform and normal distributions for the parameter associated with the standard-deviation of travel time (mean-variance approach) and the coefficients associated with the travel time (specific coefficients approach). The likelihood ratio test allows us to validate the choice of conditional logit model. Estimates of Mixed Logit models are available upon request from the authors.

[‡‡] The average point of our sample is characterized by $(\bar{p}; \bar{t}; \overline{\mathbf{SD}}) = (57.43\ €;\ 178.96\ \text{min}\ ; 8.9\ \text{min})$.

[§§] Estimating the *VOR* at the average point of our sample leads to a value of 3.26 € (=0.366*8.9). This value represents the individual's willingness to pay for removing all travel time uncertainty (8.9 min of standard deviation).

For the VOR, the coefficient that determines the willingness to pay is constant; however, the VOR is proportional to the travel time variability. Consider a risk of one hour of variability ($\mathbf{SD}\tilde{t} = 60$ minutes), while an individual is willing to pay 21.96 € for removing all uncertainty and having a sure travel time.

According to the value of the non-monetary $\widehat{VOR}$, an individual is willing to accept at most 0.64 minute of additional travel time to eliminate 1 minute of standard-deviation on total travel time.

Table 7. Specific coefficients approach

| Variables (\|*t-stat*\|) | |
|---|---|
| Intercept | 1.02 *(\|1.33\|)* |
| Price mode 1 | -0.0712 *(\|13.72\|)* |
| Time mode 1 | -0.0509 *(\|8.7\|)* |
| Price mode 2 | -0.0729 *(\|13.77\|)* |
| Time mode 2 | -0.0468 *(\|8.56\|)* |
| Log likelihood (restricted) | -1 074.378 |
| Log likelihood (unrestricted) | -462.37 |
| Pseudo-Rho$^2$ | 0.565 |
| Proportion predicted with success | 89 % |
| Size of the sample | 1 550 |

### 5.2. Specific coefficients approach

We have estimated preferences functions for both reliable (alternative 1) and unreliable (alternative 2) modes defined as equation *(7)* by a conditional logit model. The modeling results are given in Table 7.

All parameters are significant at the 5 percent level, with the exception of *intercept*. Despite the small difference between the estimated coefficients, the likelihood ratio test confirms the validity of the specific coefficients approach (against generic coefficients). To the average point of our sample, the probability of choosing the reliable alternative is 0.59, therefore the probability of choosing the unreliable alternative is 0.41. The model predicts correctly individual behavior in 89 % of cases. From definition 1, we have for the two alternatives, the following VTTS:

$$VTTS_1 = 42.89 \text{ €/hour} \; ; \; VTTS_2 = 38.52 \text{ €/hour}. \qquad (10)$$

For the reliable alternative, an individual is willing to pay *42.89 €* to avoid an one hour in its total travel time. While for the unreliable alternative, an individual is willing to pay *38.52 €* to avoid an one hour in its total travel time. The *VTTS* is higher for the reliable alternative as observed under the mean-variance approach. From equation *(8)*, we have:

$$VOR_2 = VTTS_1 - VTTS_2 = 42.89 - 38.52 = 4.37 \text{ €} \qquad (11)$$

An individual is willing to pay 4.37 € to increase reliability with this approach, i.e. for removing all travel time uncertainty (8.9 minutes of standard-deviation) at the average point of the sample.

## Conclusion

This paper has used data from a survey in stated preferences to provide empirical estimations of both the *VTTS* and the *VOR*. Hence, we have compared the estimation of the *VOR* obtained using the mean-dispersion approach to the one obtained using the specific coefficients approach.

From a statistical viewpoint, we observed that the proportion predicted with success and the pseudo-$R^2$ are quite similar for both econometric models, although the likelihood ratio test reveals statistically significant differences.

Moreover, while the mean-dispersion approach and the specific coefficients approach lead to different values for the *VTTS*, 34.54€ for the former versus 42.89€ (reliable alternative) and 38.52€ (unreliable alternative) for the latter.

On the other hand, at the average point of the sample, both approaches yield quite similar values for the *VOR*. We get that individuals' willingness to pay for removing all travel time uncertainty (i.e. 8.9 minutes of standard deviation) is around 3.26€ using the mean-dispersion approach, compared with 4.37€ using the specific coefficient approach.

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