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Abstract

This paper proposes to develop a latent class risky choice for interurban mode choice that we apply to SP data that were collected in the French Rhône-Alpes region. Risk is related to travel time outcomes, where its considered that travelers may arrive on-time or late with some delay probability.

We here integrate variety of attitudes to probabilities and attitudes to risky outcomes within the rank-dependent utility (RDU) framework, leaving up divergence from the latter (i.e. choice of a decision-making framework) for further research. We assume that all decision-makers behave following that theoretical framework yet considering that they may have different attitudes to risk, e.g. attitudes to probabilities and attitudes to outcomes of the risky prospect. It offers enough flexibility to characterize unobserved behavioral clusters in a sample of observed travel choices. It makes possible to elegantly consider from risky-prone behaviors to risk-adverse behaviors with risk-neutral behaviors as a balancing point in a theoretically consistent way.

Keywords

Latent Class; rank-dependent utility theory (RDUT); attitudes toward travel time

Introduction

From the implementation of a Logit, a Nested Logit or Mixture Models, many methods have been developed to understand the transport choices of decision-makers (Ben-Akiva and Lerman (1986)). It is now common to explain the choice by consumer characteristics (i.e. age, gender) or the attributes of alternatives (i.e. cost, time). At the same time, there have been tremendous progresses in applied modeling of discrete decisions under risk over the two last decades. Several competing frameworks have been proposed to determine and quantify decision-making behaviors when faced with risky prospects, mostly considering expected utility theory, rank dependent utility theory, cumulative prospect theory, regret minimization. From the empirical perspective, data collection are mostly experimental, contingent valuation experiments and SP data, hence derived statistical models relies on bracketing procedures and more widespread discrete choice modeling approaches. Surprisingly, only few applied work deals with considering that there is exists both unobserved heterogeneity of used decision rules and unobserved heterogeneity of individual sensitivities to outcomes of risky prospects when observing actual people choices.

During his choice process, each decisions-makers will be aware of the "normal" travel time of each alternative but also of a potential delay and its probability of occurrence. Therefore, they are put in a situation of risk and not of uncertainty and we make the assumption that travelers will, as in their real-life, will misrepresent the delays and probabilities of delay (and not on the perception of delays). As risk will be related to travel time outcomes and travelers will be categorized as risk-averse, risk-player or risk-neutral. The objective of this paper is to present a latent class model of under rank-dependent expected utility to emphasize these different behaviors among decisions-makers.

The rest of the article is structured as follows, Section 1 presents the literature review. Section 2 describes the mathematical framework that will be used in order to build the desired model. Section 3 proposes a description of the data used and the survey, an application of the methodology and a discussion of the main results that have been found.

1 Literature Review

The existing literature already provides studies on travel time variability in mode choice. Bhat and Sardesai (2006) show that travel time reliability is an important variable in commute mode choice decisions, Batarce and Ivaldi (2014) highlight that congestion affects individuals' transport decision and Konig and Axhausen (2019) confirm the importance of this reliability and that the influence of a high delay probability is more important than the delay itself. An elegant empirical approach of travel time variation measurement is Scheduling Models (Borjesson *et al.* (2012) and Bates *et al.* (2001)). The main limitation remains that these methods considers decision-makers as risk-neutral. Quiggin (1982) and Yaari (1987) are among the first to propose the concept of Rank-Dependent Utility Theory (RDUT), originally called anticipated utility, in economic. Applied to transportation RDUT allows decision-maker to overweight (or underweight) probability during their decision process. They are no longer categorized as risk-neutral.

Hensher *et al.* (2005) were the first to incorporate RDUT in surveys. They ask the decision-makers to report three perceived travel times for car and public transport, as well as the probability associated with each travel time. de Lapparent and Ben-Akiva (2014) propose an application of the RDUT to transportation mode choice. They show that commuters are weakly averse to small-time losses. Their results justify Yaari's dual theory of choice under risk, that the utility function is linear on outcomes but that the perception of corresponding probabilities is biased. They also highlight that, for leisure travel, the travelers are risk neutral to small losses of time.

Regarding the use of these models, differences between the economy and transport exist and concern the explanatory parameters of the behaviour. Economic models are mainly explained using cost attributes, while for travellers, choice is explained by cost, travel time, frequency, delay or comfort attributes (Timmermans (2010),Kemel and Paraschiv (2013)). Depending on the context or the decision-maker, their respective influences may vary and specific attributes may influence the final choice.

Finally, this work is a continuation of Bouscasse and de Lapparent (2018) work, who have investigated the intra- and inter-individual heterogeneity of mode choice, when travel time is subject to variability.

2 Methodology

This section develops the mathematical framework used in order to model attitudes toward risk related to travel time outcomes. The model integrates two components, the rank-dependant utility Theory (RDUT) presented in Section 2.1 and a latent class model Section 2.2.

2.1 Rank-Dependant Utility Theory (RDUT)

Risk-aversion or risk-seeking behaviors are taken into account in Rank-Dependant Utility Theory (RDTU). RDTU proposes to determine the weighting function of the probabilities as dependent on the rank of the outcomes. Therefore, under RDTU, the utility function that will be maximized by the decision-maker is specified as follows :

$$U_{i,m} = f_m + V_{i,m} + \varepsilon_{i,m} \tag{1}$$

Where i represent an individual, m available alternatives, $V_{i,m}$ represent the systematic part of the utility, f_m the risk component of the utility function and $\varepsilon_{i,m}$ the random part of the utility.

In the following, the hypothesis is made that, for each alternative m, the travel time t_j faced by the decision-maker can take two values : a travel time with delay $\bar{t}_m$ which is the worst outcome and occurs with probability p_m; and a travel time with no delay $\underline{t}_m$ which is the best outcome and occurs with probability $1 - p_m$. Under these assumptions, the risk component of the utility function f_m can be express as :

$$f_m = f(p_m, \bar{t}_m, \underline{t}_m) = \beta_{Time}[(1 - \omega(p_m)) \times \phi(\underline{t}_m) + \omega(p_m) \times \phi(\bar{t}_m)] \tag{2}$$

Where $\phi(.)$ is the value function and express the risk aversion of the decision-maker and $\omega(.)$ a weighting function to account for the perceptual translation of propability (here associated to the delay). $\phi(.)$ and $\omega(.)$ are functions to be defined.

Therefore, the conditionnal probability of choosing alternative m is :

$$P(y_i = m|Z_{i,m}, S_m) = \frac{e^{V'_{i,m}}}{\sum_{j=1}^{M} e^{V'_{j,m}}} = \frac{e^{f_m + V_{i,m}}}{\sum_{j=1}^{M} e^{f_m + V_{j,m}}} \tag{3}$$

With $P(y)$ the probability that an individual i choose altrnative m depending on attributes Z of the individual for an alternative and the characteristics S of an alternative, $Z_{i,m}$ attributes of the individual i regarding the alternative m and S_m characteristics of the alternative m.

2.1.1 Functionnal form of $\phi(.)$

$\phi(.)$ is the value function and expresses the risk aversion of the decision-maker. Constant relative risk aversion utility functions have been widely used in behavioral economics. With the specification :

$$\phi(t_m) = \begin{cases} \frac{t_m^{1-\alpha}}{1-\alpha} & \text{if } \alpha > 0 \text{ and } \alpha \neq 1 \\ ln(t_m) & \text{if } \alpha = 1 \end{cases} \tag{4}$$

α denotes the coefficient of relative risk aversion. $\alpha < 1$ suggest a risk-averse attitude while $\alpha < 1$ a risk-player attitude of the decision-maker.

2.1.2 Functionnal form of $\omega(.)$

The decision weight $\omega(.)$ may take different functional forms. Given the objectives of the paper, we choose a modelisation with a power transformation :

$$\omega(p_m) = p_m^{\delta} \quad , \delta > 0 \tag{5}$$

which denotes an overweighting of probabilities if $0 < \delta < 1$ and an underweighting if $\delta > 1$. δ is therefore expected to be lower than one for train trips to reflect pessimism and greater than one for car trips to reflect optimism.

2.2 Latent Class and model

Based on the observations made during the qualitative analysis, the wollofing suppositions are formulated :

- Inter-individual heterogeneity : people are different in terms of attitude toward risk
- Intra-individual heterogeneity : the behavior may be different even when performed by the same individual when faced with a different transport mode

To test those hypothesis we propose to use a latent class model with two classes where each individual i belong to class k with a probability π.

$$Pr(i \in class1) = \pi \quad ; \quad Pr(i \in class2) = 1 - \pi \tag{6}$$

By generalizing we have the probability of belonging to a class (π^k) express as :

$$\pi_i^k = \frac{e^{\theta_k X_i^*}}{\sum_{j=1}^{2} e^{\theta_j X_i^*}} \tag{7}$$

Where X_i^* are socio-economic characteristics of a respondent and θ_k are parameters to estimate.

Using the results obrained in Section 2.1 we can generalize the risk component of the utility function for a class k :

$$f_m^k = \beta_{Time}^k[(1 - \omega(p_m)) \times \phi(\underline{t}_m) + \omega(p_m) \times \phi(\bar{t}_m)] \tag{8}$$

And finally the probability that an individual choose alternative m of the class k as :

$$P^k(y_i = m|Z_{i,m}, S_m) = \frac{e^{f_m^k + V_{i,m}}}{\sum_{j=1}^{M} e^{f_m^k + V_{j,m}}} \tag{9}$$

Under RDUT and for a latent class model, the individual contribution to the likelihood function is given by the following expression:

$$L_i^* = \sum_{k=1}^{K} \left[\pi_{i,k} \prod_{m=1}^{M} P^k(y_i = m)^{y_i} \right] \tag{10}$$

And the Log likelihood function :

$$L = \sum_{i=1}^{N} ln(L_i^*) \tag{11}$$

3 Case Study

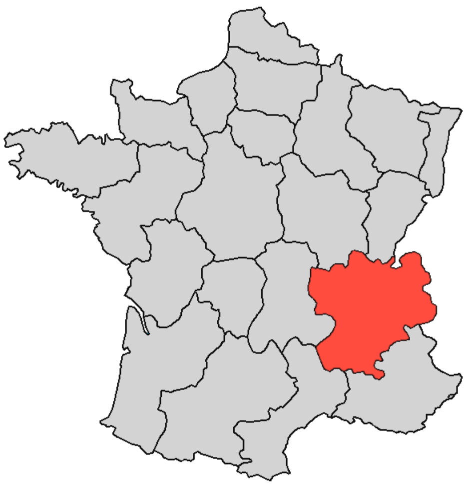
This section provides a description of the data used, an implementation of the mathematical framework proposed in the previous section and a discussion on the results obtained.

3.1 Data description

The data used has been collected between January and April 2015 in the Rhône-Alpes Region (France) (Figure 1).

Getting a representative sample is a main issue. In order to achieve this, some responses were removed thanks to the screening part of the survey. For example, minor, respondents without a car or a driving licence. This survey includes stated and revealed preference questions but also questions about attitudes to and perceptions of public transport modes.

Figure 1: Survey origin : Rhône-Alpes Region (France)



During the SP survey, each respondent had to choose between three travel modes, described in terms of travel mode, delay, frequency, travel time and travel cost (Figure 2).

Travel cost includes public transport ticket or pass, gasoline, parking cost and toll. Travel time is defined from origin to destination (including access time, egress time, waiting time and in-vehicle time). The delay time has one of the following values: 10, 15 or 30 minutes.

Figure 2: Survey example : SP questions

	Option A	Option B	Option C
Travel mode			
Delay	Delay of 15 minutes 2 trains out of 10 (20%)	Delay of 30 minutes 1 train out of 10 (10%)	Delay of 15 minutes 1 train out of 10 (10%)
Frequency	1 train per hour	2 trains per hour	Departure whenever you want
Travel time	54 minutes	1h21	1h30
Travel cost	€23 / trip	€18 / trip	€21 / trip
Choose your option:			

The delay probability has one of the following values: 5%, 10% or 20%, which reflect what is actually observed for trains in the Rhône-Alpes region. The frequency of trains is one every two hours, one every hour, two every hour and four every hour.

Respondents had to answer to five choices questions, leading to a database with 8,933 observations, since a few respondents did not answer all five questions. The choice questions are personalized with the data collected for the reference journey.

3.2 Application

We performed a multinomail logit model (mnl) with a mixture panel effect estimated only with 50 draws due to limitied power calculation.

The objective is to observe the differences of behavior between classes according to the model specification. Thus, we chose include few alternative characteristics. Those alternatives, presented in (Table 1) are included in all classes.

Regarding our datas we model the risk component of the utility function as :

$$f_m^k = \beta_{Time}^k \Big[TT^{\alpha^k} + Prob_{Delay}^{\delta^k}[(TT + Delay)^{\alpha^k} - TT^{\alpha^k}]\Big] \tag{12}$$

Table 1: Specification table of latent class models

Coefficient	Variable	Variable description
β_{Cost}	$Travelcost$	Travel cost for each alternative
β_{Freq}	$Frequency$	Frequency of each alternative for public transportation
β_{Time}	$Traveltime$	Travel time for each alternative

With TT the travel time of the alternative, $Prob_{Delay}$ the probability of the alternative and $Delay$ the estimated delay.

Using these simple variables we aim to observe respondent behavior when faced to risk, related to travel time outcomes. First we performed a simple logit model with no latent class model to verify that signs are consistent with expectations ($\alpha_1 = \alpha_2 = 1$). Then, we performed several latent class model :

- model with only risk aversion $\phi(.)$: $\delta = 1$, α to be determined
- model with only decision weight $\omega(.)$: $\alpha = 1$, δ to be determined
- model with both risk aversion $\phi(.)$ and decision weight $\omega(.)$: α and δ to be determined

Finally, we must mention that for this first implementation, belonging to a class is a constant to be estimated and not directly dependent on an individual (π^k and not π_i^k).

3.3 Discussion

The parameter estimates for the logit models are robust and consistent with expectations and existing litterature (Table 2).

The higher the frequency of train, the higher the probability of choosing a train alternative. At the same time, more the the cost or travel time increase, less the alternative is likely to be chosen.
Then, we tried to study the risk behaviour related to travel time (α) and delay probability (δ) as express in Equation (12). To do so we have built two distinct latent class models for which results are presented in Table 3 and Table 4.

The parameter estimates for the latent class models remain aligned with our initial expectations. Except some variations in the obtained values or the t-test robustness, the signs obtained for the risk aversion model and decision weight model are consistent with our initial model.

Table 2: Model 0 : Logit model with no latent class

Name	Value	t-test
β_{COST}	-0.245	-18.73
β_{FREQ}	0.520	19.20
β_{TIME}	-0.0390	-20.18
Final log likelihood :	*-4651.659*	

Estimated separately, the alphas parameters specific to the risk component of our utility function, offer quite different results. Concerning the model dealing with risk aversion $\phi(.)$, two distinct classes can be observed (Table 3). The first being risk averse ($\alpha^2 = 0.631$) and the second being risk player ($\alpha^1 = 1.86$).

Despite the fact that the Betas estimations are significantly different, the model dealing with the decision weight $\omega(.)$ proposes almost identical deltas (δ 0.431 vs. 0.402) (Table 4). This result suggests that there is no difference in behaviour in terms of decision weight function. Both classes tend to overweight probabilities.

The final log-likelihood of these two models are lower than that of our initial model: respectively -4567.329 and -4574.330 vs. -4651.659. This first result confirms part of our initial hypothesis: attitudes are heterogeneous when confronted with the risk associated with transportation time.

Table 3: Model 1.1 : Latent Class with risk aversion $\phi(.)$

Name	Value	t-test
β_{COST1}	-3.18	-2.49
β_{COST2}	-0.144	-9.89
β_{FREQ1}	1.82	2.51
β_{FREQ2}	0.483	15.15
β_{TIME1}	-0.00153	-0.79
β_{TIME2}	-0.301	-1.82
α^1	1.86	8.37
α^2	0.631	6.99
π^1	0.22	
π^2	0.78	
Final log likelihood :	*-4567.329*	

Table 4: Model 1.2 : Latent Class with decision weight $\omega(.)$

Name	Value	t-test
β_{COST1}	-0.151	-9.09
β_{COST2}	-1.55	-4.59
β_{FREQ1}	0.483	13.70
β_{FREQ2}	0.938	4.56
β_{TIME1}	-0.0363	-15.19
β_{TIME2}	-0.0852	-5.19
δ^1	0.431	3.12
δ^2	0.402	2.25
π^1	0.77	
π^2	0.23	
Final log likelihood :	*-4574.330*	

Afterwards, we tried to study the differences in behaviour when we had both types of risk in the same latent class model. To do this, we have built two models with two latent classes:

- With two supposed behaviors for risk related to travel time (one specific α per class) and only one behavior for weighting function of probability for delays (one generic δ for the two classes) : model with 3 alplhas
- With two supposed behaviors for the risk related to travel time and two for the weighting function : model with 4 alphas

Results are presented in Table 5.

At first, we notice that the Beta values are almost identical for both models. Signs are still in line with our initial expectations and the results obtained in the first models.

Then, we can observe that results of α related to the risk aversion of the travel time are consistent with model 1.1 in both situations. We still have two distincts behaviors, one risk averse ($\alpha^2 = 0.432 \quad or \quad 0.517$) and one risk player ($\alpha^1 = 2.10 \quad or \quad 2.18$).

Finally, the results that deserve the most discussion are the risk related to delay. In the case where only one behaviour is evaluated across the 2 classes, the obtained value alpha is substantially identical to Model 1.2 ($\delta^1 = \delta^2 = 0.418$). However, when alpha becomes specific for each class, the obtained values are significantly different ($\delta^1 = 0.992 \quad vs. \quad \delta^2 = 0.333$). These values indicate that class 1, who is strongly risk player ($\alpha = 2.18$) almost does not change the associated probabilities ($\delta = 0.992$). At the same time, class 2, which is a risk ($\alpha = 0.517$), overestimates probabilities ($\delta = 0.333$). These results seem intuitively consistent

Table 5: Model 2 : Latent Class with risk aversion $\phi(.)$ and decision weight $\omega(.)$

	3 alphas		**4 alphas**	
Name	Value	t-test	Value	t-test
β_{COST1}	-4.47	-2.34	-4.10	-2.88
β_{COST2}	-0.139	-9.41	-0.152	-10.08
β_{FREQ1}	2.57	2.25	2.42	2.74
β_{FREQ2}	0.506	15.87	0.474	14.96
β_{TIME1}	-0.000664	-0.98	-0.000340	-0.64
β_{TIME2}	-1.14	-1.65	-0.665	-1.65
α^1	2.10	13.48	2.18	7.12
α^2	0.432	4.83	0.517	5.50
δ^1	0.418	4.57	0.992	1.69
δ^2			0.333	3.94
π^1	0.36		0.24	
π^2	0.64		0.76	
Final log likelihood :	*-4579.834*		*-4570.872*	

From these results we will produce tables for value of time, willingness to pay for time distribution and the value of reliability. These additional results will allow us to compare the different types of profiles (risk-averse, neutral or risk player).

4 Conclusion

This paper presents a model capable of evaluating the decision-maker behavior when facing risk relating to travel time and potential delay. Based on the existing literature a latent class model under rank-dependent utility theory was developed. The data used were collected between January and April 2015 in the Rhône-Alpes Region (France).

The results confirmed our first assumptions of the fact that decision-makers do have different attitudes to risk. Concerning the associated risk to travel time, results highlight two distinct classes. The first being risk-averse and the second a risk-player. Within these 2 classes, the results indicate that risk-averse travelers tend to overweigthing probabilities (of delay), while risk-player travelers almost not modify these probabilities.The decision weight function being more subject to interpretation it will be worth to be explored in the future.

As future work, an important issue will be to confirm those results when increasing our power calculation. Afterwards, we will developp the present model by :

- the incorporation of new variables, especially consumer characteristics (i.e. gender, age, income),
- investigating about nonlinear specifications as Box-cox or picewise linear transformations,
- studying the impact when increasing the number of class and varying the number of variables (α and/or δ) inside the risk component of the utility function for the different classes,
- expressing the class membership (π) as related to an individual and not only to a class.

This future work will allow us to identify more precisely the behaviour of travellers belonging to different classes.

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