Estimation of a regret-based model of traveler response to uncertainty and information using data from a multimodal travel simulator[1]

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Abstract

This paper presents a regret-based alternative to Expected Utility-models of traveler response to uncertainty and information provision. It allows for capturing i) a traveler's choice among uncertain alternatives, as well as ii) choice-postponement through information acquisition. The model is based on the notion of regret: travelers are assumed to minimize expected regret when choosing among uncertain alternatives. When the minimum expected regret still is higher than an individual's threshold, the individual is assumed to postpone choice and acquire additional information first. The developed model is estimated on data from a multimodal travel simulator, where participants could choose either to execute one of several travel alternatives with uncertain travel times and costs, or to postpone choice and acquire information first. Estimation results support the validity of the proposed model specification.

Keywords: Regret Theory; non-Expected Utility Theory; Choice under uncertainty

1. Introduction

Traveling is about dealing with uncertainty. When planning a trip, travelers by definition do not know the exact travel time they are about to experience should they choose a particular combination of mode, route and departure time combination. In addition to travel time, the exact values of a variety of other relevant attributes may be unknown in the eyes of the traveler at the moment of choice, such as travel costs, comfort levels, etc. One of the keys to understanding travel behavior is therefore understanding how travelers deal with the uncertainty associated with the travel alternatives they may choose from. This observation is widely acknowledged throughout the travel behavior research community, especially since the

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development and introduction of Advanced Traveler Information Services in the late 1980s. This substantial and growing interest is reflected in an abundant body of literature concerned with modeling travel choices under uncertainty. Besides a number of theoretical contributions (e.g. Noland & Small, 1995; Bonsall, 2001; Arentze & Timmermans, 2005a, b; Sun et al., 2005; Ettema et al., 2005; Chorus et al., 2006a; Batley, forthcoming), the field has recently witnessed a substantial increase in empirical studies (e.g. Bates et al., 2001; Lam & Small, 2001; Rietveld et al., 2001; Katsikopoulos et al., 2002; Denant-Boèmont & Petiot, 2003; Brownstone & Small, 2005; Avineri & Prashker, 2003, 2006; Chorus et al., 2006b).

Notwithstanding this substantial body of literature on travel choice under uncertainty, travel behavior researchers feel that there is still much scope for further work. A key issue that has recently been put on the research agenda in the travel behavior research community is the need for the development of operational[2] alternatives to the standard Expected Utility (EU) framework of choice under uncertainty (e.g. Avineri & Prashker, 2003, De Palma & Picard, 2005; Michea & Polak, 2006). This is not to say that the EU-framework has not contributed greatly to our understanding of choice under uncertainty in a normative as well as descriptive sense. However, it is felt for some years now that the development of operational alternatives to the EU-modeling approach will help increase our understanding of traveler decision making under uncertainty – perhaps especially of those observed behaviors that appear to violate the rationality principles underlying EU-theory, such as preference-intransitivity, anchoring effects, loss aversion etc.

This paper presents and empirically estimates such an operational non-EU model of (travel) choice under uncertainty. The model is rooted in Regret Theory (RT), developed in the early 1980s (Bell, 1982; Fishburn, 1982; Loomes & Sugden, 1982), which is one of the non-EU theories of choice under uncertainty most extensively studied in economics (e.g. Loomes & Sugden, 1983, 1987; Machina, 1987; Quiggin, 1994; Starmer, 2000; Hart, 2005). RT asserts that an individual facing a choice under uncertainty is aware that she may end up having chosen an alternative which turns out to be less attractive than a non-chosen alternative, causing regret. Individuals are assumed to anticipate this possibility of regret and aim to minimize expected regret when choosing from available alternatives.

It is felt that RT may provide a particularly attractive perspective on *travel* choice under uncertainty by capturing the intuition that traveling may often be about avoiding negative emotions (e.g. being late, missing a bus, getting stuck in traffic), perhaps more than about deriving some maximum level of payoff. Either way, we do wish to stress here that we do not present our operational model of RT as being in any way superior to the EU-approach: rather, this paper aims at contributing to the literature concerning modeling travel choice under uncertainty by providing a plausible and operational alternative to the well-established EU-approach. A second contribution of the work presented here is that we allow for the possibility that individuals, when faced with a choice situation where the regret associated with the minimum regret-alternative is higher than the his or her threshold, rejects the choice situation. Instead of choosing an uncertain alternative, the individual then postpones choice and acquires information first, with the aim of regret-reduction.

The remainder of this paper is structured as follows: section 2 provides a brief formal account of (non-) Expected Utility models and RT. Section 3 presents an operational, RT-based model and introduces the notion of a regret-threshold in relation to choice-

[2] The term operational refers to a model that can be directly applied to estimate behavioral parameters based on observed choices.

postponement. Section 4 describes the data-collection effort. Section 5 discusses the results of the RT-based model estimation on the dataset. Section 6 draws conclusions and discusses avenues for further research.

2. Regret Theory

2.1. (Non-)Expected Utility models

First proposed as a model of risky choice by Bernoulli (1738, reprinted in 1954), the popularity of *Expected Utility Theory* as a model of risky choice took a flight after Von Neumann and Morgenstern's (1944) axiomatic formalization. EU-theory states that an individual, faced with a choice between two risky alternatives (that is: the exact utility of one or more of the prospects is not known at the moment of choice and depends on a future state of the world), evaluates the utility of each prospect for a given state of the world. Then, the individual multiplies this utility with the probability of occurrence of the particular state of the world. Subsequently, the individual sums these products over all possible states of the world, giving the expected utility of the alternatives. Finally, the alternative with the highest expected utility is chosen.

EU-theory, for a brief while, became *the* building block for modeling risky choice. However, starting with Allais (1953) and Ellsberg (1961) in the 1950s and early 1960s, and culminating in the 1970s (e.g. Tversky & Kahneman, 1974; Kahneman & Tversky, 1979) and beyond, an abundance of empirical evidence accumulated which showed that in real life, individuals often behaved in systematic contradiction with the premises and predictions of EU-theory. For example, individuals appeared to have great difficulty interpreting probabilities and outcomes 'correctly', and their choices turned out to be easily influenced by the formulation of the choice task at hand, leading to intransitive preferences and a wide variety of other well documented 'anomalies of choice'. McFadden (1999) provides an extensive overview of observed deviations from EU-premises and predictions. This empirical evidence did not affect EU-theory's appeal as a normative theory of risky choice, but it did cast doubt to EU-theory as a descriptive framework, describing actual behavior. Although the concept of EU-theory continued to be a widely used framework for the analysis of risky choice, the empirical evidence of deviations from EU-theory did spur the development of a number of so-called non-EU theories of risky choice (see Starmer (2000) for a well documented overview of the most widely used of these theories).

These non-EU theories aimed at providing coherent and empirically consistent descriptions of observed risky choice behavior (including 'anomalies of choice'). Of these non-EU frameworks, it appears that *Prospect Theory* (PT), (Kahneman & Tversky, 1979, 1992) is the most widely acknowledged alternative to EU. Recently, PT has been finding its way to a number of fields related to that of microeconomics and behavioral decision theory - including that of travel behavior research (e.g. Katsikopoulos et al., 2002; Avineri & Prashker, 2003; Arentze & Timmermans, 2005b). As summarized by Starmer (2000), Prospect Theory hypothesizes that "choice is modeled as a two-stage process. In the first phase, prospects are 'edited' using a variety of decision heuristics; in the second, choices among edited prospects are determined by a preference function …". This preference function is concave for gains, and convex for losses, and kinked at the status quo. Besides PT, a number of other decision theories have been developed with similar aims as the ones motivating Kahneman and

Tversky. Some of the most well known of these non-EU theories are *Generalized Expected Utility Analysis* (Machina, 1982), *Weighted Utility Theory* (Chew, 1983), *Rank Dependent Expected Utility Theory* (Quiggin, 1982) and *Regret Theory* (Bell, 1982; Fishburn, 1982; Loomes & Sugden, 1982). In the following of this paper, we will focus on the latter of these non-EU theories and present an operational version of RT that can be applied for the analysis of multiattribute risky choice from general choice sets. As mentioned in the introduction, the choice for RT is based not on a review of its particular merits in explaining behavior when compared to other non-EU models, but is rather based on the intuition that regret avoidance may play an important role in traveler decision making.

2.2. Regret Theory

RT is developed, independently, by Bell (1982), Fishburn (1982) and Loomes & Sugden (1982) as a model of pairwise choice between lotteries (Machina, 1987). That is, the situation is considered where individuals face a choice between two alternatives. These alternatives are characterized by a probability distribution and a (monetary) outcome for each probability. The crucial difference now, between EU-theory and RT, is that the latter is based on the notion that individuals base their preference structure for some state of the world not only on the anticipated 'performance' of a considered alternative for that state of the world, *but also on that of the other alternative*. More specifically, the individual is hypothesized to anticipate and take into account the possibility that the non-chosen (foregone) alternative turns out to be more attractive than the chosen one. In other words, instead of evaluating the utility of each alternative for each state of the world, RT postulates that individuals anticipate, for each state of the world, the possible regret (the chosen alternative performs worse than the non-chosen one) or rejoice (vice versa) associated with an alternative, and subsequently aggregate this regret/rejoice over all possible states of the world. Formally, RT states that an alternative *i* is chosen from the choice set containing *i* and *j* if and only if:

$$\sum_{s \in S} \left[p(s) \cdot R_{ij}(s) \right] > 0 \tag{1}$$

where *s* represents a particular state of the world, *S* gives all possible states of the world. $p(s)$ gives the probability of occurrence of state *s*, $R_{ij}(s)$ gives the regret (a negative number - in case *j* is more attractive than *i*) or the rejoice (vice versa) of alternative *i* compared to alternative *j*, given state *s*. This regret is a function of the monetary outcomes x_i and x_j of the two alternative lotteries for a given state of the world *s*: $R_{ij}(s) \equiv \varphi(x_i(s), x_j(s))$. It is assumed that $R_{ij}(s) = -R_{ji}(s)$. Note, that if $R_{ij}(s) \equiv U_i(s) - U_j(s)$, RT reduces to the expected utility model. It has been well established that particular functional forms of the regret/rejoice function $R_{ij}(s)$ give rise to models that are able to systematically describe a variety of behavioral patterns which contradict EU-theory, including preference reversals[3] (e.g. Loomes & Sugden, 1983) and some forms of preference-intransitivity (e.g. Loomes & Sugden, 1982).

[3] The notion of preference reversal is defined as the situation where an individual prefers lottery (or alternative) *i* over *j* , but places a higher certainty equivalent value (the amount of money she wishes to receive in order to forego executing a lottery) on lottery *j* than the one placed on *i*.

This consistency with real behavior in combination with its relatively simple formal structure have made RT a relatively popular candidate for the analysis of choice under uncertainty in such areas as psychology (e.g. Zeelenberg, 1999; Crawford et al., 2002), marketing (e.g. Simonson, 1992; Taylor, 1997; Inman et al., 1997) and finance (e.g. Stoltz & Lugosi, 2005). Its application in the travel behavior domain is to the authors' knowledge virtually non-existing (but see a theoretical study by Chorus et al. (2006a)). It should be noted here that many of the applications of RT in other fields than decision theory are based on the general notion of regret as a determinant of choices, rather than being based on the full formalism of the regret/rejoice structure presented above.

3. An operational RT-based model allowing for choice-postponement

3.1. An RT-based formalization of choice under uncertainty

Although the analysis of observed pairwise choices between monetary lotteries may provide useful building blocks for theories of choice under uncertainty such as RT, the analysis of *travel* choice under uncertainty needs a more general perspective: first, the average travel choice set contains considerably more than two alternatives and second, the average travel alternative is characterized by considerably more than one attribute. This is evident for example in the situation where a traveler may consider a variety of mode-route-departure time alternatives, each determined by travel times, costs and comfort levels which may or may not be exactly known by the traveler at the moment of choice. Therefore, in order to successfully apply RT in a travel behavior context, two forms of generalizations need to be made: one towards general choice sets, another towards multiattribute decision making.

To start with the first of these, we may build on work done by Quiggin (1994) who derived a functional form of RT for general choice sets, based on the requirement of *Irrelevance of Statewise Dominated Alternatives* (ISDA). This requirement states that a choice from a given choice set should not be affected by adding to or removing from this set an alternative that is dominated by the other alternatives for every state of the world. This requirement turns out to imply that "the regret associated with a given action *i*, assuming state *s* to occur, depends only on the actual outcome $x_i(s)$ and the *best possible outcome* that could have been attained in state *s* " (Italics added and notation adapted). There are two fundamental consequences to this generalization: firstly, it states that regret associated with an alternative does not depend on other alternatives that are (for some state of the world) better, but not the best one available. Secondly, by only considering regret with respect to the best available alternative, Quiggin's general form removes from RT the notion of rejoice, and with that its symmetrical or compensatory nature. As Quiggin puts it, the first consequence is not unreasonable from the viewpoint of psychology of choice (regret may be assumed to particularly felt with respect to the best of the foregone alternatives)[4]. The second consequence, he argues, is consistent not only with the ISDA-requirement, but also with the notion that RT has always been more about regret, than it has been about rejoice. For the remainder of this paper, we adopt Quiggin's notion of *regret with respect to the best*

[4] However, as Bell (1982) suggests, it is also not unreasonable to hypothesize that regret with respect to second best alternatives may play a role in decision making - see Chorus et al. (2006a) for a model of travel choice where this thought is formalized.

alternative for a given state of the world as a generalization of RT towards general choice sets. Note that, also in the general form, RT reduces to EU-theory when regret is defined as the difference, for a state of the world, *in terms of utility* between a considered alternative and the best alternative available.

The second generalization that is needed to obtain an operational RT-based model of travel choice is one towards the case where the (anticipated) performance of an alternative is based on more than one attribute. A literature search provided no building blocks for this generalization, which led the authors to develop a notion of multiattribute regret that can be put as follows: regret associated with alternative *i*, when compared to alternative *j* is the sum of the regret that is associated with alternative *i*'s first attribute, when compared to alternative *j*'s first attribute, and the regret associated with alternative *i*'s second attribute, when compared to alternative *j*'s second attribute, etc. That is, we assume that individuals evaluate the alternatives in terms of the *associated regret on an attribute by attribute basis*. Consistent with Quiggin's (1994) suggestion to apply a regret-function, rather than a regret/rejoice function, we hypothesize that the regret associated with alternative *i*, due to a comparison with alternative *j* based on a particular attribute equals zero in case alternative *i* scores equal or better than *j* on the particular attribute. Otherwise, the regret associated with the attribute comparison is a non-decreasing function of the difference in attribute-values.

Formally, consider a traveler *n* that faces a choice between alternatives *i*, *j* and *k*. The alternatives are fully defined in terms of uncertain attributes x_i, x_j, x_k and y_i, y_j, y_k, and intrinsic preferences z_i, z_j, z_k (one may, for example, envisage *x* and *y* representing travel times, respectively travel costs of a car-, bus- and train-option, and *z* representing the individual's intrinsic preferences for different travel modes). The individual is assumed to believe that both the *x* and *y* attributes will depend on the state of the world *s*, and that *x* and *y* are independent from one another. This latter assumption is not critical for the model developed here, and may be replaced by more complex assumptions including covariances between beliefs for different attributes within and between alternatives. She has some ideas about the probability that *x* and *y* will take on particular values. Let us assume that these beliefs may be represented by a multi-dimensional probability density function:

$$f(s) = f(x_i, x_j, x_k, y_i, y_j, y_k) = f(x_i) \cdot f(x_j) \cdot f(x_k) \cdot f(y_i) \cdot f(y_j) \cdot f(y_k) \qquad (2)$$

Now consider the occurrence of a particular state of the world *s*, reflected through a draw from the density function given by equation (2). Given this draw, the individual faces three alternatives, characterized as follows: $i^s = \{x_i^s, y_i^s, z_i\}$, $j^s = \{x_j^s, y_j^s, z_j\}$ and $k^s = \{x_k^s, y_k^s, z_k\}$. In this particular state of the world *s*, she associates regret with each of the three alternatives *i*, *k* and *j*. Following Quiggin, this regret equals the regret associated with the comparison of the alternative with the *best* of the other two alternatives:

$$R_i^s = \max\{R_{ij}^s, R_{ik}^s\}, R_j^s = \max\{R_{ji}^s, R_{jk}^s\}, R_k^s = \max\{R_{ki}^s, R_{kj}^s\} \qquad (3)$$

Note that this specification implies that, where for one state of the world the regret associated with, say, alternative *i* equals the regret associated with the comparison of *i* with *j*, it is well possible that for another state, *i*'s regret stems from a comparison with *k*.

Each of the binary regrets entering equation (3) is a sum of the regrets associated with comparing the alternatives on an attribute by attribute base, take for example the binary regret between alternative *i* and *j* for state *s*, R_{ij}^{s} :

$$R_{ij}^{s} = \varphi_x\left(x_i^s, x_j^s\right) + \varphi_y\left(y_i^s, y_j^s\right) + \varphi_z\left(z_i, z_j\right) \tag{4}$$

Although many, more complex than the linear, specifications may be appropriate for the attribute-regret functions φ_x, φ_y and φ_z, we will for now define them as follows:

$$\begin{cases} \varphi_x\left(x_i^s, x_j^s\right) = \max\left\{0, \beta_x \cdot \left(x_j^s - x_i^s\right)\right\} \\ \varphi_y\left(y_i^s, y_j^s\right) = \max\left\{0, \beta_y \cdot \left(y_j^s - y_i^s\right)\right\} \\ \varphi_z\left(z_i, z_j\right) = \max\left\{0, \beta_z \cdot \left(z_i - z_i\right)\right\} \end{cases} \tag{5}$$

That is, either alternative *i* performs better than *j* in terms of an attribute, in case there is no attribute-regret, or alternative *i* performs worse than *j*, in case the regret associated with this attribute comparison is a linear function of the difference in attribute values. The non-symmetrical nature (based on the behavioral assumption that only regret with respect to the best alternative, not rejoice with respect to other alternatives, plays a role in decision making) implies that non-fully compensatory decision making is assumed at the attribute level: bad performance of an alternative with respect to one attribute is not compensated by a good performance with respect to another attribute. Parameters β are now to be estimated from observed choices, the sign of the estimate signaling whether an increase in a particular attribute adds to or does not add to the formation of regret.

Now that the regret associated with each alternative for a given state of the world is derived, we proceed by defining expected regret as the sum of the regret associated with every possible state of the world, weighed by their probability of occurring. For the case of alternative *i*, we thus write:

$$ER_i = \int_s R_i^s \cdot f\left(s\right) ds \tag{6}$$

The individual is subsequently assumed to choose the alternative with the lowest expected regret. However, it is possible that the preferred travel alternative’s expected regret is still too high for the individual to be acceptable. In that case, where the expected regret of the most attractive alternative is above the individual’s regret-threshold π, (s)he chooses to postpone choice and acquire information first – with the aim of reducing the uncertainty (resulting in expected regret) of the choice situation.

3.2. Econometrical aspects

Together, the above sub-section defines choice under uncertainty at the individual level. In order for the model to become operational, we now take the perspective of an analyst that is facing a sample of individuals *n*. Let us start by assuming that the analyst is unable to exactly assess an individual's intrinsic preferences β_z, assuming these are not constant across the sample. Capturing this intrinsic preference-heterogeneity implies that an error vector is added to the vector of constants *Z*. Let us denote this vector as $\eta_n \sim N\left(0, \sigma_{\eta_n}\right)$. Subsequently, we add an i.i.d. error component ε to *ER*, in order to reflect the analyst's measurement errors in combination with his failure to capture all attributes that are relevant to the decision maker, as well as the 'mistakes' and idiosyncrasies that travelers may display when choosing. Furthermore, we assume that an individual's regret-threshold consists of a deterministic part, an individual-specific random component $\delta_n \sim N\left(0, \sigma_{\delta_n}\right)$, and an i.i.d. random component. Now, the above presented choice structure can be formalized econometrically as the following multinomial logit-models for travel alternatives *i and j, k,* and for choice postponement:

$$P_{in} = \int_{\eta_n, \delta_n} \left(\frac{\exp\left(-RER_{in}\left(\eta_n\right)\right)}{\sum_{l \in \{i,j,k\}} \exp\left(-RER_{ln}\left(\eta_n\right)\right) + \exp\left(-\pi\left(\delta_n\right)\right)} \right) f\left(\eta_n, \delta_n\right) d\left(\eta_n, \delta_n\right) \tag{7}$$

$$P_n^{\text{postpone}} = \int_{\eta_n, \delta_n} \left(\frac{\exp\left(-\pi\left(\delta_n\right)\right)}{\sum_{l \in \{i,j,k\}} \exp\left(-RER_{ln}\left(\eta_n\right)\right) + \exp\left(-\pi\left(\delta_n\right)\right)} \right) f\left(\eta_n, \delta_n\right) d\left(\eta_n, \delta_n\right) \tag{8}$$

Note that, in line with intuition, a higher regret-threshold, or a lower expected regret of a travel alternative, results in a lower probability that choice is postponed, and in a higher probability that the travel alternative is executed.

4. Data-collection

4.1. A multimodal travel simulator with information provision

The constructed simulator is geared towards the study of decision making under incomplete knowledge in multimodal networks, in the presence of highly functional travel information services. A dynamic stated preference travel and information simulator is used in order to study in a controlled environment hypothetical ATIS-technology without requiring expensive field trials, and without being limited by more basic stated preference surveys. It stands in a long tradition of computer-based travel simulator tools of varying levels of sophistication (See Koutsopoulos et al. (1995) and Bonsall (2004) for useful overviews). See Chorus et al. (2007) for an extensive introduction and validation of the simulator as a data-collection tool. Figure 1 shows the screen plot of an arbitrary travel situation that a participant may be confronted with. The workings of the simulator will be discussed based on this example. The screen consists of 4 parts: lower left presents the trip context, upper-left shows the transport network, upper right presents the information service and lower right shows a visual aid.

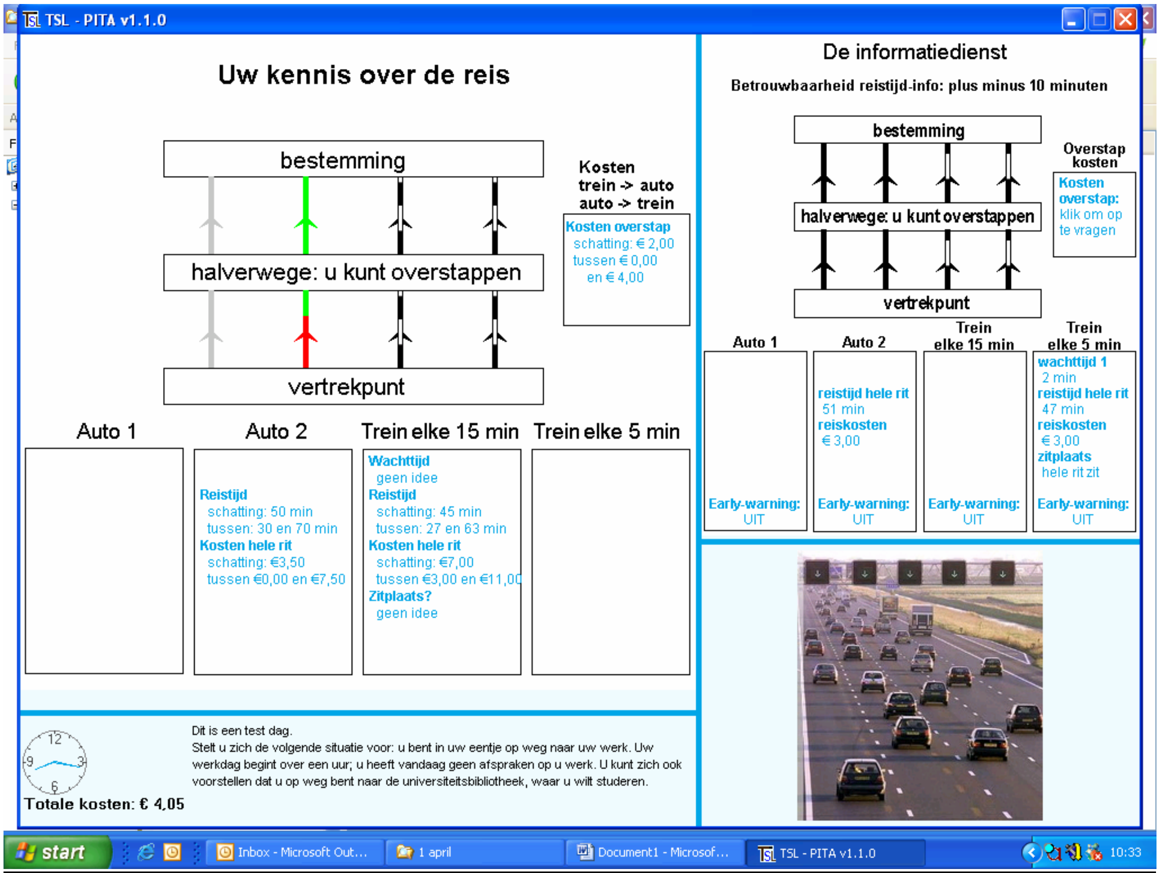

Figure 1: screen plot of the simulator *(in Dutch)*

Trip purpose

The trip purpose consists of a story line describing trip purpose (business, commute, social visit and leisure) and possibly preferred arrival times, generated at random for each trip from a set of predefined options. These story lines were presented at the beginning of each new trip through pop-up windows, after which they were located at the lower left of the screen during the completion of the trip. Next to the story line, the trip context displays a clock, presenting accelerated time. It ticks away one minute waiting time or in-vehicle time per actual second, after a travel alternative is executed. Finally, beneath the clock, a money counter registers the amount of money spent so far on a given trip, including both travel costs and costs of information acquisition.

The transport network

A purely fictive O-D pair was created, connected by four paths displayed as arrows and an interchange facility halfway. As our current analyses do not deal with in-trip choice adaptation, we will not discuss here the interchange possibilities. The two left arrows symbolize two car-options, i.e. highway routes. The two routes are equivalent except that they may differ in terms of travel times and costs. Next to these two car-options, two intercity train options exist which are also equivalent, except that they may also differ in travel time and cost, as well as seat availability. Furthermore, the left one of the two trains departs once every 15 minutes, the right one once every 5 minutes, thus inducing a lower expected and maximum waiting time. The number of a priori alternatives 'known' to the traveler varies per trip.

'Unknown' alternatives are marked grey instead of black, and the traveler initially has no knowledge concerning their characteristics. These alternatives are inactive, and cannot be executed by the traveler. For the trip displayed in Figure 1, one car-option and the 15 minute train option are known a priori. The other train alternative is activated by the information service. The participant's initial knowledge of the alternatives (i.e., before acquiring any information) is presented in the boxes below the black arrows. The following a priori knowledge is provided to the traveler for the known alternatives: for both car and train options, i) *best guesses* for travel times and travel costs[5] are provided, as well as ii) *certainty intervals*, i.e. ranges of times and costs within which the participants are told (correctly) that actual values will fall almost certainly. A priori, train travelers do not know the exact departure times (although they do know the service’s frequency), neither do they know whether or not a seat is available for them. A participant may start his journey by clicking one of the arrows, and subsequently confirming his choice in the appearing pop-up window. By confirming his or her choice, there is no possibility of adaptation until the interchange point is reached. Directly after confirmation, the traveler is confronted with the actual costs of the alternative, and train travelers were also informed whether or not they had a seat. As the trip commences (Figure 1 shows the situation where a car option is chosen), the clock starts ticking and the arrow that represents the chosen alternative incrementally turns red, indicating the amount of distance traveled so far. These actual travel costs were drawn from a normal distribution, having the best guess as mean, and a quarter of the length of the ‘confidence’ interval as standard deviation, so that 95% of the drawn actual values would indeed fall within the ‘certainty’ interval. The same applies to the generation of actual travel times. On the other hand, seat availability was randomly drawn from a discrete distribution (50% chance of having a seat), waiting times from a uniform distribution between 0 and the headway (either 5 or 15 minutes).

The information service

Instead of choosing to execute one of the known alternatives, based on its uncertain characteristics, the traveler may choose to postpone choice and acquire information first, before eventually executing a travel alternative. As can be seen in Figure 1, the information service's layout is an exact copy of the transport network. In the sample used for our current analyses all provided information was fully reliable, meaning that every received message corresponds to the actual value of that particular attribute. Participants were told about this complete reliability.

The service presents three ways of acquiring information. Firstly, a traveler may acquire information concerning one or more particular attributes of a known alternative, be it travel times and/or costs for a car or train option, and/or waiting times and seat availability for train options. This is done by first clicking on the arrow of a 'known' alternative and subsequently checking the boxes for those attributes for which information is needed (the information price is listed at every box, and varies between .15, .30, .45 eurocents). After the boxes are checked, the service displays the information in the information box. Figure 1

[5] Travel times were framed as door to door for car-trips, and door-to-door minus waiting times for train-trips. All ‘best guess’ travel times were randomly varied beforehand and could take the values of 50 and 60 minutes for the car-option and 45 and 55 minutes for the train option (since to the latter also waiting times had to be added to get the total travel time). Travel costs were framed as fuel expenditures + parking costs for car-trips, and ticket tariffs for train-trips. Travel costs were randomly assigned beforehand the values of 3.5 euro or either 7 euro.

presents the situation where for one of the car-options, both travel time and costs are informed about by the information service. Secondly, a traveler can ask the service to generate or activate one or more alternatives that are currently 'unknown' to him or her. This is done by clicking on an arrow within the information service screen that corresponds to an unknown alternative in the transport network. After this is done, a pop-up window appears that states the price of the information acquisition (being varied between .45, .60 and .75 eurocents) and asks for a confirmation. After confirmation, the alternative is made active, that is, its color turns black in the transport network, and the alternative can be executed from then on. Furthermore, the information service provides estimates for all the alternative's characteristics. These estimates are displayed in the box below the activated alternative in the information service screen part. Figure 1 presents such an information acquisition for the 5 minute train option. Thirdly, a traveler may activate the so-called early-warning function. This function notifies a traveler when an alternative that is about to be chosen has an actual travel time that is substantially larger than the traveler's best guess (no strict level of travel time differences that triggers these messages is mentioned to the travelers). This type of information is acquired by clicking on a known alternative and checking the early warning box. Note that all these types of information can be acquired either pre-trip, as well during the trip, which makes the information service 'mobile'.

4.2. The experiment

Participants were recruited through placement of advertisements in a campus newspaper and another free newspaper. Also a mail was sent out to ± 500 students. A 20 euro reward was offered for participation. All participants were required to have had some experience with both car and train travel. In total, 264 individuals were recruited this way, of which 31 were randomly assigned to the experimental conditions on which we focus here (i.e. fully reliable information conditions). Table 1 presents response group characteristics, and shows a rather heterogeneous group in terms of socio-economic characteristics.

Before commencing with the simulator experiment, an extensive web survey was filled out by the participants concerning among other things their actual travel behavior. Following this, participants performed a brief binary mode-choice experiment. Subsequently, they were given a rather extensive introduction in the simulator. Participants were asked very explicitly to not regard the experiment as some form of a game (e.g. by trying to travel as fast as possible, or spending as much or as little money as possible), but rather to try to identify with the travel situations presented and make choices that they would make, would they be confronted with such a situation in real life. It is known that in simulated travel situations like the ones presented in this experiment, the issue of motivation is a difficult one (see Carson et al. (2000) and Bonsall (2002) for overviews of possible incentive-caveats). In order to increase the motivation of participants to put effort in identifying themselves with the simulated travel environment, the following approach was chosen: participants were told during the introduction that they could win a 7,5 euro bonus, to be awarded to about half of the respondents, based on the success of their identification effort. It was mentioned that the correspondence of their choice-behavior as observed in the simulator experiment with the choice-behavior observed in the stated mode choice experiment and the answers to web-survey questions concerning revealed behavior would be used to measure the degree of identification. It was made clear to the participants that they would probably be most likely to obtain the bonus by simply making a real effort to identify with each of the travel situations presented. After the introduction, about 50 minutes were left. In these 50 minutes, participants made two test-rides, during which they were encouraged to try out all possible types of traveling and information acquisition. These trips were not saved in the database, as was told to the participants.

Table 1: response group characteristics (N=31)

Variable	**Frequency**
Gender	
female	14
male	17
Age	
< 25	16
< 40	10
< 65	5
Completed education	
lower education	0
secondary school	21
higher education	10
Main out-of-home activity	
paid work	9
education	18
other	4

The first two trips after the trials were performed without information being available. Subsequently, a number of trips (maximum 25) were to be made in the presence of information services. In total, the 31 participants made 559 trips (excluding the test-trips and the trips without information service available), on average equaling about 18 trips per participant. Some 30% of trips made fell under trip purpose of an important business trip. Although most observed trips consisted of a sequence of decision stages (consisting of one or more information acquisitions followed by one travel choice), we are currently only interested in the choice the individual makes directly at the outset: either she chooses to acquire some form of information (and postpone choice), or else she decides to execute one of the available travel alternatives. For this paper's analyses, the information acquisition alternatives are therefore aggregated into one alternative. See table 2 for the observed choice frequencies at the outset of each trip.

Table 2: Choice frequencies for information acquisition and travel choices

Choice alternative	**Availability at the outset (# trips)**	**Freq. (N=559)**	**Rel. Freq. (100%)**
Choice postponement	559	413	74 %
Execute car 1	367	31	5 %
Execute car 2	390	29	5 %
Execute train 1	355	64	11 %
Execute train 2	213	22	4 %

5. Model estimation

5.1. Model operationalization and parameters to be estimated

Table 2 shows the dataset available for analysis: 559 choices made by 31 individuals at the outset of trips where either a choice is made for choice-postponement (information acquisition) or for one of the available travel alternatives, the latter being uncertain in terms of their attributes. We estimate the average regret-threshold. Also, the standard deviation of the individual-specific threshold-component σ_{δ_n} is estimated, allowing for different individuals to have different regret thresholds - and associated inclinations to acquire information before executing a travel alternative. We estimate a constant for traveling by car, and the standard deviation of the random component reflecting the individual-specific intrinsic preference for traveling by car. Note that the standard deviations were estimated acknowledging the panel structure of the data. That is, the unit of observation is the full sequence of all choices that are made by the same individual. A travel time parameter is estimated, as well as an additional travel time valuation for business trips, and a travel cost parameter. Since there was no variation in seat availability for train options at the outset of the trip, no parameter is estimated for this attribute. Note that the model of choice under uncertainty presented in section 3 assumes that individuals perceive uncertain attributes of alternatives in terms of a multidimensional probability density function (pdf). Since the alternatives were presented in terms of best guesses and certainty intervals, additional assumptions are needed with respect to their translation towards a multi-dimensional pdf that may be used for our analyses. i) We assume mutual independence of attributes within and between alternatives. Given the set up of the experiment (where independency was assured) and the provided meaning of the attributes, see footnote 10, this is a reasonable assumption. ii) The following assumptions were made to arrive at an operational multidimensional pdf. Travel times and costs, presented to the participant through a best guess and a certainty-interval, are assumed to be perceived in the form of a normal distribution around this ‘best guess’ with a standard deviation that equals one-quarter of the length of the certainty interval, implying that 95% of draws from this density function are within the certainty-interval. Perceptions of waiting time for trains, presented to participants through a headway (“a train departs every *x* minutes”), are assumed to consist of a uniform distribution between 0 and *x*. Note that these distributions match those that are used to generate actual travel times, waiting times and costs – that is, we assume that participants’ beliefs concerning uncertain attributes contain no structural bias.

Given these assumptions, the equations in section 3 are used to calculate regret for each travel alternative: for each observed choice. The regret associated with each alternative is calculated by comparing it, for a given parameter setting, to all other travel alternatives in terms of travel times, travel costs, and intrinsic preferences for traveling by car, rather than train. Subsequently, the expected regret of the travel alternative with lowest expected regret is compared to the individual’s threshold, leading to choice-postponement or else choice for the minimum-regret travel alternative.

5.2. Model estimation and results

The model was coded in GAUSS 7.0. Note that, from the analyst’s point of view, the computation of the sample likelihood involves evaluating two multidimensional integrals: one two-dimensional integral captures the intrinsic individual-specific preference for traveling by car as well as the individual-specific component of the regret-threshold. A second multidimensional integral reflects that travelers do not know beforehand what state of the world they will encounter when executing one of the available travel alternatives. Since the four travel alternatives have been characterized in terms of uncertain travel times (consisting of a waiting-time draw added to a travel-time draw for train options) and costs, this latter integral has 2+2+3+3=10 dimensions. Note the crucial difference in terms of interpretation between the two sets of integrals: where the error component integral reflects the *lack of knowledge from the side of the analyst* with respect to the traveler's intrinsic preference and her regret threshold, the state-of-the-world integral reflects the *traveler's lack of knowledge* with respect to what travel time and cost she will encounter when choosing a particular travel alternative. Both multidimensional integrals were evaluated through simulation, using 400 Halton draws per individual per dimension for the individual-specific car-preference and regret-threshold component, and 1000 Halton draws per dimension for the 10-dimensional state-of-the-world integral. That is, for each individual-specific two-dimensional draw for the error components, 1000 draws are made to simulate states of the world. Sensitivity analysis with a varying number of draws (up to 2000 state-of-the world draws and 800 error-component draws) showed that the numbers used where sufficiently large. Table 3 shows the estimation results. Concerning the performance of the model as a whole, it appears that the parameters are generally highly significant and all have the expected sign. Furthermore, the large increase in Log-Likelihood signals that a substantial part of the variation in travelers' choices is captured with our seven-parameter regret-based model. Together, the model fit in combination with the significance and expected sign of the parameters suggest validity of the proposed methodology in terms of the regret-based model specification, the assumptions made to operationalize the model, and the data gathered through the simulator-experiment.

Table 3: estimation results

Variable	**Parameter**	***t*-Statistic**
Car constant	-1.123	-3.917
Sigma (car constant)	0.934	1.624
Travel time (minutes)	-0.175	-6.305
Business * Travel time (to be added to Travel time)	-0.414	-6.561
Travel costs (euros)	-0.485	-5.117
Regret threshold	1.723	3.411
Sigma (regret threshold)	1.677	5.109
Model statistics		
0-Log-Likelihood	-652	
Log-Likelihood at convergence	-332	
Number of cases	559	

Looking at the parameter estimates in more detail, it appears that there is an intrinsic preference for traveling by train, rather than by car. Heterogeneity concerning modal preferences (*Sigma(car constant)*) remains insignificant. On average, individuals maintain a substantial and significant regret-threshold, and a substantial level of heterogeneity exists concerning its magnitude (*Sigma (regret threshold)*). The latter signals that individuals may differ widely concerning the level of expected regret they are willing to incur from a given travel choice situation. Travel time- and cost-parameters are of the expected sign, but note that, as mentioned in section 3, their interpretation is not equivalent to time- and cost-parameters in a random utility model. The estimated values imply that a cost-difference between alternatives of one euro adds, for the average traveler, almost three times as much regret to the considered alternative as does a time-difference of one minute. The fact that our model does not assume fully compensatory decision-making implies that a positive three minute time difference does not necessarily make up for a negative one euro cost difference. Finally, for business trips, high travel times appear to cause a very substantial extra amount of regret (*Business * travel time*).

6. Conclusions

This paper presents a regret-based alternative to Expected Utility-models of travel choice under uncertainty and information provision, that allows for choice-postponement in case the expected regret associated with a choice situation exceeds an individual's regret threshold. The model is rooted in Regret Theory (RT), one of the leading alternatives for the EU framework. RT asserts that an individual making a choice under uncertainty is aware that she may end up having chosen an alternative which turns out to be less attractive than a non-chosen alternative, causing regret. It is subsequently asserted that the individual anticipates this possibility of regret and aims to minimize expected regret when choosing from available alternatives. The RT-based model of travel choice is estimated on data from a multimodal travel simulator, where participants could choose between travel alternatives with uncertain travel times and costs. Estimation results, i.e. a good model fit in combination with significance and expected sign of the parameters, can be regarded a first suggestion of the validity of the proposed RT-based model specification.

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