Modelling travellers’ heterogeneous route choice behaviour as prospect maximizers

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ABSTRACT

The last decades have seen an increased interest in the use of Prospect Theory to model route choice behaviour. According to Prospect Theory, choices are based on gains and losses measured against a reference point, thus what matters is the relative gain and not the final state of wealth or welfare. Its applications, however, have been facing the main issue of how to define its reference point. For situations involving monetary outcomes, zero is the usual reference point, which can be interpreted as the status quo of wealth or welfare. But the question is: what is the value that travellers use as a reference to distinguish gains and losses in the experienced travel times in route choice behaviour? Moreover, do all travellers have the same reference point or does heterogeneity in their behaviour play an important role in the definition of the reference point?

The objective of this paper is to provide a behavioural interpretation of the reference point and in particular to account for the role of heterogeneity. With the aid of a case study we discuss the meaning of the reference point for route choice decisions and how heterogeneity plays a role and could be taken into account. Based on a model specification in which travel time is the main variable, Prospect Theory is directly applied in two distinct model frameworks and their results are compared. While one of these frameworks accounts for heterogeneity, the other considers no heterogeneity in travellers’ behaviour. Results show a significant increase in the ability of Prospect Theory to predict route choice behaviour by accounting for heterogeneity, in particular when the reference point is able to well capture travellers’ behaviour.

1. INTRODUCTION

Travel is the result of individual choice behaviour regarding (i) whether to leave home to engage in an activity, i.e. activity choice, (ii) where to perform the activity, i.e. destination choice, (iii) how to reach the destination, i.e. mode choice, (iv) when to depart, i.e. departure time choice and (v) which route to take, i.e. route choice (Bovy et al., 2006). Altogether these travel related decisions directly affect network dynamics, especially in the scenario of growth in mobility observed in most major city centres. As a result, travel characteristics such as travel times and congestion patterns, are even more severely impacted, leading to more travel time uncertainty, which is one of the main impacting factors on travellers’ behaviour (Noland and Small, 1995; Avineri and Prashker, 2003; de Palma and Picard, 2005; Henn and Ottomanelli, 2006). A proper understanding of travellers’ behaviour, therefore, is of fundamental importance to predict their behaviour and to forecast future traffic conditions on the network.

According to the literature on behavioural theories, travellers employ different criteria in the process of evaluating what the best choice is. However, the majority of existing route choice models is based on the utility maximization assumption which proposes that people act rationally in order to get the maximum utility (benefit) from the decision made. In the field of route choice under uncertainty in particular, Expected Utility Theory (von Neumann and Morgenstern, 1947) is the most widely used theory (de Palma and Picard, 2005). Situations involving uncertainty are definitely the case when dealing with routes’ travel times. For instance, irrespective of the experience someone has gathered due to frequently driving a specific route, the real travel times may vary reasonably depending on the traffic conditions.

Despite the widespread use of Expected Utility Theory, experiments in behavioural studies have found deviations from its axioms leading to the development of Non-Expected Utility Theories of which Prospect Theory (Kahneman and Tversky, 1979) is the most discussed (Starmer, 2000). Prospect Theory argues that choices are based on gains and losses measured against a reference point, i.e. values above it are perceived as gains and values below as losses. What matters, therefore, is the relative gain and not the final state of wealth or welfare as argued by Expected Utility Theory. Prospect Theory has been widely used in the field of economics, but applications in the field of transport are relatively recent (Sumalee et al., 2005; Avineri, 2006; Connors and Sumalee, 2009; Gao et al., 2010). Its application has been facing two main issues: (i) definition of meaningful reference points for a travel behaviour context and (ii) estimation of appropriate parameters for the value and weighting functions, which are respectively responsible for reflecting the subjective value of the outcome, thus measuring the deviations from the reference point into gains and losses, and how people perceive the probability of occurrence of an outcome (Avineri and Prashker, 2003; Avineri, 2006; Sumalee et. al, 2009).

The literature has largely discussed the lack of consensus about the meaning of the reference point in a route choice context. In addition, despite the importance of heterogeneity, as already shown in travellers’ behaviour analysis involving Discrete Choice models (Polak et. al, 2008; Gopinath, 1995) and car following models (Ossen and Hoogendoorn, 2010), analysis regarding heterogeneity in travellers’ reference point has not yet been performed. As intuition suggests that attitudes towards risk vary across the population, travellers may have different perceptions on
which outcomes may be characterised as gains or a losses, thus different reference points. It is therefore natural to further investigate the role of heterogeneity in the reference points. In line with the literature, we hypothesise that the reference point varies not only among the travellers but also over time, i.e. in case travellers’ route preferences change over time, such as switching to a more reliable instead of fast but unpredictable route, the reference point will also follow travellers’ new behaviour. Moreover, the reference point reflects travellers’ (risk) preferences when making route choice decisions, i.e. the reference point is aligned with the travel time distribution of the preferred route of the travellers. Thus, the reference point might vary with respect to travellers’ preferences. Besides this, in case pre-route information, such as travel time, is provided, it is expected that travellers’ might use that value as a reference point.

Rather than claiming a higher importance of heterogeneity in the reference point to other types of heterogeneity related to risk, we intend to show based on empirical data that by accounting the heterogeneity in the reference point Prospect Theory can significantly benefit. Despite the existence of a great variety of Discrete Choice models, mostly based on the decision rule of utility maximization, that are able to quite well describe route choice behaviour, we propose to further investigate the suitability of Prospect Theory due both to its potential to better capture travellers’ behaviour as well as to the appeal of the reference point. Results from previous research developed by the authors study have suggested not only the suitability of Prospect Theory to model route choice behaviour, but also that depending on the reference point Prospect Theory can perform even better than Utility Theory (Ramos et al., 2010). These previous insights from behavioural decision research reinforced the need to further investigate the role of heterogeneity in the reference point, which are then extended in this study.

Therefore, this research discusses the behavioural appeal of the reference point and in particular accounts for the role of heterogeneity in the reference point in route choice decisions. This is done by directly applying Prospect Theory in two model specifications and comparing their results: (i) one accounting for heterogeneity and (ii) another considering no heterogeneity. The model comparison is based on data from an empirical route choice experiment in which travellers were asked to make choices among three possible routes: route 1 consisting mainly of highways, route 2 consisting mainly of rural roads and route 3 consisting partly of highway and part of urban roads. Two conditions of information provision and two travel purposes were investigated resulting in a total of four scenarios.

It is well known that information is likely to change the level of uncertainty in the choice situation. Modelling its impact thus is hardly a simple task. Additional information together with advanced technologies like GPS-based pathfinders is likely to contribute to reducing of travel time uncertainty, enabling travellers to choose efficiently among the available routes, save travel time and reduce congestion (European Commission, 2008). However, the exact impact of ATIS is likely to be sensitive to travellers’ behavioural and cognitive response to information which is much less understood. In addition, effects such as experience and learning seem also to play an important role in the decision making process (Ben-Elia and Shiftan, 2010). Although this paper focuses on the role of heterogeneity in the reference point of Prospect Theory rather than on the impact of information on travellers’ behaviour, given that two conditions of information provision is considered in the proposed case study, it is expected that travellers will present different route choice behaviour.

In the scenarios in which no information is provided we expect that at first travellers explore the routes in order to get experience about their characteristics. As a result, higher switching/exploring rates should be observed. As time evolves, however, travellers will get more experience on the routes’ travel times and the switching rate should decrease. On the other hand, when information is provided determining switching rates is not a straightforward task as this also depends on the compliance rate with the information. As a result, for travellers’ that in general do not comply with the advice the switching rate should be similar to the situation in which no information is provided. Otherwise, discussing switching rates does not make sense as travellers’ might be changing routes to comply with the advice. So, a better measure to investigate travellers’ reaction to information is switching rate from the information advice. We argue that as time evolves and travellers become more confident about the reliability of the information, switching rates from the information provision to no information decreases. The next section introduces the main distinctions between the fundamentals of Prospect Theory in relation to Expected Utility Theory. Following this, a discussion into the behavioural meaning of the reference point of Prospect Theory and the role of heterogeneity on travellers’ behaviour is presented. Afterwards two model specifications, one accounting for heterogeneity and another considering no heterogeneity are proposed and then compared based on data from an empirical route choice experiment. Finally, conclusions and recommendations for future research are provided.

2. BEHAVIOURAL FOUNDATIONS OF PROSPECT THEORY

Prospect Theory, a descriptive model of decision making under risk, was developed in 1979 as a critique to the Expected Utility Theory based on the main assumption that choices are based on gains and losses measured against a reference point (Kahneman and Tversky, 1979). The point of the critique is that due to the reference point, changing the ways in which options are presented generates predictable shifts in preferences and systematically violates the axioms of Expected Utility Theory, in particular the independence axiom. The predictable shifts in preferences are not necessarily categorized as good or bad, but instead simply reflect how people behave when facing choice decisions.

2.1 Initial developments

Considering that a prospect is a consequence associated to a probability of occurrence, the independence axiom states that for all prospects x, y, z: if x ≥ y then (x, p, z, (1-p)) ≥ (y, p, z, (1-p)). This implies that preference between two prospects is independent of the common components. Thus, in the evaluation of a prospect their common components
are perceived as if they could be cancelled (Weber and Camerer, 1987). Experiments such as the Allais Paradox (Allais, 1953) presented below have shown that the independence axiom is not necessarily applicable and that due to both the framing of options and the reference point, shifts in preferences can be observed. Contrary to the expected utility assumption that people behave as utility maximizers and have well defined preferences, Prospect Theory argues that preferences vary depending on how choices are presented.

The Allais Paradox is the first famous counter example to Utility Theory to show shifts in preferences. Allais proposed two experiments in which people had to choose between two lotteries in each of them (Table 1). A person with expected utility preferences would choose option \(b\) in both experiments because the independence axiom requires that the difference between the pairs of lotteries to be ignored. Thus, the "common consequence" of a 0.89 chance of winning \$1,000,000 in the lotteries \(a_1/b_1\), or a 0.89 chance of (winning) \$0 in the lotteries \(a_2\) and \(b_2\) would be cancelled and in both experiments the utility of the choice \((u)\) would be \(0.1 u(\$5M) > 0.11 u(\$1M)\). Allais, however, expected that when faced with these types of choices people would opt for \(a_1\) in the first situation (win for certainty) and \(b_2\) in the second (very different rewards for slightly different winning probabilities). The experiments performed confirmed this intuition, and consequently violated the independence axiom.

### Table 1: The Allais paradox

<table>
<thead>
<tr>
<th>Experiment 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>lottery</strong> (a_1) (to win)</td>
<td><strong>lottery</strong> (a_2) (to win)</td>
</tr>
<tr>
<td>$1,000,000 with certainty</td>
<td>$1,000,000 with probability 0.11</td>
</tr>
<tr>
<td>$5,000,000 with probability 0.1</td>
<td>$0 with probability 0.89</td>
</tr>
<tr>
<td>$1,000,000 with probability 0.89</td>
<td>$5,000,000 with probability 0.1</td>
</tr>
<tr>
<td>$0 with probability 0.01</td>
<td>$0 with probability 0.9</td>
</tr>
</tbody>
</table>

Following Allais, Prospect Theory was further developed by explaining choice behaviour as a two-step process: an initial phase of editing and a subsequent phase of evaluation. In the editing phase the options are organized and reformulated by the application of heuristics to simplify the evaluation. In the evaluation phase the prospect is subjectively valued. The evaluation phase is divided into two scales: a weighting function \(\omega(p)\) and a value function \(v(x)\). The probability-weighting function \(\omega(p)\) associates to each probability of occurrence \(p\) a decision weight \(\omega\) that reflects the impact of \(p\) on the overall value of the prospect. The value function \(v(x)\) reflects the subjective value of the outcome, thus measuring the deviations from the reference point. Thus, neither \(v(x)\) is perceived as valuing \(x\) nor \(\omega(p)\) as valuing \(p\).

### 2.2 Cumulative Prospect Theory

In 1992, advances were made to extend Prospect Theory to uncertain outcomes (Tversky and Kahneman, 1992), which lead to the Cumulative Prospect Theory (CPT). This extension was necessary to allow evaluation of situations involving uncertainty in which some of the outcomes or probabilities are unknown, which is also the case for situations involving travel times. Cumulative Prospect Theory employs cumulative rather than separable decision weights, it is applicable to uncertain and risky prospects and allows different weighting and value functions for gains and losses due to people’s different perception of gains and losses. Thus, there are distinct functions associated to positive and negative outcomes respectively, which are defined in terms of specific parameters that enable capturing choice behaviour (Figures 1 and 2).

![Figure 1: Illustration of the shape of the value function](image)

![Figure 2: Illustration of the shape of the weighting function](image)

The value function is defined by 3 parameters, \(\alpha\), \(\beta\) and \(\lambda\) responsible for respectively reflecting (i) the degree of diminishing sensitivity for gains and (ii) the degree of diminishing sensitivity for losses, i.e. the decrease on the marginal value of gains and losses with their magnitude, and (iii) the degree of loss aversion, i.e. the aggravation one experiences when incurring in losses. The weighting function, on the other hand, is defined in terms of 2 parameters, \(\gamma\) and \(\delta\), that capture the distortion in the perception of probabilities for gains and losses. Its reversed s-shape is derived from the (i)
overweight of small probabilities, meaning that people are risk-seekers when offered low-probability high-reward prize, (ii) overweight of moderate and high probabilities, implying that (a) people are relatively insensitive to probability difference in the middle of the range and (b) the prevalence of risk aversion in choices between probable gains and certainty, and risk seeking in choices between probable and sure losses (Tversky and Kahneman, 1992). In addition, the weighting function curve starts in zero and finishes in one ($\pi(0)=0$ and $\pi(1)=1$) and is asymmetrical with the inflection point at about 0.3 (Prelec, 1998).

Given the distinct functions for positive and negative outcomes, $V^+$ and $V^-$ respectively, the overall value of a prospect is defined by $V = V^+ + V^-: \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad 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due to the lack of consensus about the behavioural meaning of the reference point, the use of Prospect Theory to evaluate travellers’ behaviour lacks deeper conclusions.

In the context of monetary outcomes based on which Prospect Theory was developed, zero is the usual reference point meaning neither gains nor losses. In the context of route choices although some interesting researches of models based on Prospect Theory have been developed and applied, these are theoretical models that aim to illustrate its basic principles (Gao et al, 2010; de Palma et al., 2008; Avineri, 2006). In particular with respect to the reference point, however, in general values based on the travel times of the examples described, on average travel times to work as reported by transport studies, i.e. 30 minute, or free-flow travel time have been used. This is because differently from situation involving monetary outcomes in which the reference point from neither gains nor losses can be easily identified, for travel times this value may vary with respect to the decision maker, to the distances travelled, to the level of stress and to constraints regarding arrival time for instance. This raises the question of what the meaning of the reference point in a context involving route choice and travel times is. In other words, what is the value that travellers use as a reference to distinguish the experienced travel times into gains and losses? Moreover, do all travellers have the same reference point or does heterogeneity in their behaviour play an important role?

2.4 Role of heterogeneity

Over the past decade considerable progress has been made in the characterisation of unobserved taste heterogeneity in travel choice behaviour (Hess, 2007; Koppelman and Sethi, 2005; Srinivasan and Mahmassani, 2003 and Arnott et al., 1992). The term ‘taste heterogeneity’ refers to situations in which different decision makers take into account either (i) different factors or (ii) the same factors in different ways than others. Two main approaches have been used in the literature to represent the variations in preferences among individuals (Ben-Akiva and Lerman, 1985). The most common is the partition of the data into a fixed number of segments usually using demographic characteristics (exogenous segmentation) or alternatively to identify behaviourally homogeneous segments directly from the data (endogenous segmentation).

Route choice behaviour in particular has been widely investigated both in the presence and absence of information. It has been found that route choice behaviour varies with drivers’ familiarity and prior experience, availability and perception of alternative routes, travel times, delays, incidents and availability of information (Srinivasan and Mahmassani, 2003). Among these, the most relevant when dealing with route choice behaviour is travel time. Due to traffic congestion, travel times are usually uncertain and travellers are likely to have different perceptions of the benefits of choosing a specific route in relation to another. As proposed by Prospect Theory, choices are differently perceived depending on the reference adopted, and thus on the framing of outcomes into gains and losses. The literature, however, has argued that usually a single reference point is used when applying Prospect Theory (Zhang et al. 2010, Avineri, 2009), implying that all travellers value gains and losses similarly. In reality, however, there might be two or more reference points (Avineri and Bovy 2008; Van de Kaa, 2008) which may vary not only among travellers but also over time. For instance, experiments in psychological and social studies have shown that due to people’s different perceptions towards gains and losses, the perception of uncertainty and probabilities systematically vary (Wu and Gonzalez, 1996) and that in repeated choice tasks some people may keep on updating their reference state after experiencing the outcome of a previous choice while others might systematically choose the most rewarding probabilistic alternative after a learning period in which they assess the frequency distributions of outcomes (Schul and Mayo, 2003).

Given that travellers have different perceptions of travel times, it is natural that they also have different reference points on what may be perceived as a gain or a loss. For instance, while for a more conservative traveller a 40 minutes trip between A and B may be considered a “good” travel time, thus perceived as a gain, for a more aggressive traveller, or someone running late, the same 40 minutes between A and B may be perceived negative, and thus as a loss. Moreover in a spatially dynamic framework, such as proposed in our case study, in which travellers have to daily make route choices among three alternative routes, accounting for heterogeneity becomes particularly important as it helps capturing individual differences that persist over time. In order to capture travellers’ different perceptions of travel time variability and how this influences their route choices over time, we propose to investigate travellers’ heterogeneity in relation to their reference point.

To contribute to the establishment of meaningful reference points for the route choice context and moreover to account for the role of heterogeneity, the next section discusses these two aspects based on data from a route choice experiment. This is done by directly applying Prospect Theory in two model specifications, one accounting for heterogeneity and another considering no heterogeneity in travellers’ behaviour, and comparing their results.

3. CASE STUDY: INVESTIGATING TRAVELLERS’ ROUTE CHOICE BEHAVIOUR

This case study is based on the data from the experiment performed by Bogers (2009), in which a travel simulator was used to investigate routes’ preferences. The situations involved daily departures at 8:00 a.m. and arrivals within 1 hour at the destination for either a meeting with colleagues or a job interview. Travellers were recruited from the database of the Dutch Organization of Road Users (ANWB) and as an incentive they were informed that one of the travellers would be awarded a navigation system. The prize was randomly drawn among the participants without specifying a goal such as minimizing travel times or arriving on time which would potentially influence their behaviour. The travellers made 40 consecutive choices among 3 routes with an approximate length of 30 km and the following characteristics: (i) route 1 consisted mainly of highways, it was the fastest route, (ii) route 2 consisted mainly of rural roads, it was the most
reliable route and (iii) route 3 consisted partly of highway and partly of urban roads (going through the city centre), it was the route of intermediate performance (Figure 3).

Figure 3: Illustration of the route choice experiment

Two conditions of information provision were investigated: (i) no information provision and (ii) provision of travel time in minutes. Information was provided at the beginning of every new trip and after this travellers had to decide which route to take. Changing routes after the journey had started was not possible. The information advice was provided for all three routes and based on the true travel times. The information deviated at most 2 minutes in 85% of the days and approximately between 10 and 30 minutes in the remaining 15% of the days. The true travel times were usually underestimated. In addition, at the end of every journey, feedback information with respect to the true travel time of the chosen route was provided. The travel time distributions and scenarios investigated are depicted in Tables 2 and 3.

Table 2: Travel time distributions for each route

<table>
<thead>
<tr>
<th>Route</th>
<th>Description</th>
<th>Mean travel time (min)</th>
<th>Variance of travel time (min²)</th>
<th>10th percentile (min)</th>
<th>90th percentile (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30 draws from Gumball distribution (35, 1)*</td>
<td>44</td>
<td>233</td>
<td>34</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>10 draws from Gumball distribution (70, 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>All draws from Gumball distribution (53, 1.25)</td>
<td>53</td>
<td>1</td>
<td>52</td>
<td>54</td>
</tr>
<tr>
<td>3</td>
<td>All draws from Normal distribution (47, 12)</td>
<td>47</td>
<td>146</td>
<td>33</td>
<td>56</td>
</tr>
</tbody>
</table>

Legend: * The resulting travel times were randomly distributed over the 40 days.

Table 3: Scenarios investigated and number of travellers in each of them

<table>
<thead>
<tr>
<th>Travel Purpose</th>
<th>Condition of information provision</th>
<th>No Information</th>
<th>Travel time in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting with colleagues</td>
<td>Scenario 1 (20 travellers)</td>
<td>Scenario 3 (42 travellers)</td>
<td></td>
</tr>
<tr>
<td>Job interview</td>
<td>Scenario 2 (25 travellers)</td>
<td>Scenario 4 (46 travellers)</td>
<td></td>
</tr>
</tbody>
</table>

We assumed that during the first 10 route choices travellers were gaining experience with the routes and as of the 11th day, Prospect Theory was applied to predict travellers’ route choice behaviour. The travellers, however, were not informed of this. The idea behind the experience period was to enable travellers to know what to expect from the travel times of each route. Then, as of the 11th day travellers (in theory) they would start making choices following a specific route choice behaviour instead of a random route choice.

4. MODEL SPECIFICATION

For we intend to further explore the behavioural meaning of the reference point, we propose a simple model specification considering travel times as the only attribute when no information was provided, otherwise the travel information. In addition, the parameters of the value and weighting function were set equal to the originally estimated values, i.e. $\alpha = \beta = 0.88$, $\lambda = 2.25$, $\gamma = 0.61$ and $\delta = 0.69$ (Tversky and Kahneman, 1992) because we intended to focus on the role of the reference point without, at this moment, investigating other behavioural properties of Prospect Theory. In other words, we intended to investigate the ability of Prospect Theory capture travellers’ behaviour by its direct application.

Thus, by a direct application of Prospect Theory, the predicted route was determined based on the maximum prospect theoretic value (MaxPT) of travel times or information provided and then compared with the route chosen by the travellers. Then the prediction ability of Prospect Theory was determined based on the number of correct predictions for each traveller for each day in the experiment.
4.1 Considering no heterogeneity

Under this model specification, we consider that all travellers have the same reference point and this value is updated as travellers get more experience. As in the route choice experiment travellers had to make daily route choices among three alternative routes, after each route choice travellers are assumed to update their expectations and consequently their reference point. In addition, after each choice the travel time distributions were updated taking the new travel times into account. As a result, choices made on the 11th day, were based on data from the first 10 days; choices made on the 12th day, were based on data from the first 11 days and so on.

We propose the following reference points when no information was provided: (i) the mode of the fastest route, (ii) the mode of the most reliable route, (iii) the average travel time of all routes and (iv) the minimum travel time of the fastest route. In all cases, the reference point is based on the actual travel times, thus on the draws. The first reference point implies that travellers derive satisfaction from getting the best probable result while the second assumes that travellers are more conservative in their choices and tend to avoid losses, they behave thus risk averse. The third reference point, however, does not have a clear behavioural meaning and aims to explore the type of choice predicted under this circumstance. The fourth reference point is a specific group within the first and behaviourally means that travellers are (really) aggressive in their choices and only want the best possible route.

When travel time information was provided, the reference points were similar to the above mentioned, but instead of referring to routes’ travel times they referred to the information advice. Thus, instead of referring to the probabilities of occurrence of travel times in the weighting function, they refer to the probabilities of occurrence of a specific information advice. Similarly to the case in which no information was provided, the reference point is based on the actual information provided. In addition, a fifth reference point, the information advice itself, i.e. the predicted travel times, was considered in order to investigate whether travellers update their reference based on the information. Besides this, it was investigated whether people base their decisions on the real travel times and use the information solely as a reference. Under this situation, the MaxPT was determined based on the real travel times, and not on the information advice, and a sixth reference point was evaluated: the information advice_2. As a result, under this reference point, when evaluating the weighting function we refer to the probabilities of occurrence of travel times.

The MaxPT was determined based on equations 3 and 4. In the value function, $x$ measures the deviation from the reference point (RP) and values $x=RP-TT$ or $RP-info$ depending on whether information is provided. $TT$ is the real travel time and $info$ the information advice of a specific route. In the weighting function, $p$ is the probability of occurrence of travel times or information advice.

4.2 Accounting for heterogeneity

Under this model specification, we argue that travellers’ route choice behaviour varies across the population and as a result each traveller has its own reference point depending on their different behavioural characteristics. In addition, similarly to the situation in which no heterogeneity is taken into account, after each route choice travellers are assumed to update expectations and consequently their reference point.

In order to reflect travellers’ usual behaviour, and thus capture more risky and more conservative route choice behaviour, when no information is provided we propose that the reference point on day $d$ is defined as: (i) the travel time of the most chosen route up to the previous day and (ii) the travel time of the most chosen route in the previous five days. Otherwise, the reference point on day $d$ is defined as (i) the information advice of the most chosen route up to that day and (ii) the information advice of the most chosen route in the previous five days. In addition, in this case the calculation procedure follows both rules as defined above for the information advice and for the information advice_2, i.e. the weighting function respectively accounts for the probabilities of occurrence of travel times and information advice.

The main difference between the conditions in which we consider travellers’ heterogeneity to the one without is that in the first case each traveller is considered as a unique individual with different behavioural characteristics. Consequence of this is that we are able to model travellers’ preference individually and thus consider the preference of each of them in all days of the experiment, in the previous five days or in other situation that could have been defined. In all these situations, the reference point is responsible to capture travellers’ preference. However, the same does not apply when no heterogeneity is considered. Under this condition all travellers are assumed to behave similarly and as such only their general behaviour can be captured, i.e. the behaviour of the majority. As a result, it does not make sense to propose a reference point that reflects short term switches in preferences such as the ones under condition ii above.

5. RESULTS AND DISCUSSION

Results regarding travellers’ route choice behaviour in scenario 1 show that during the experience period, i.e. during the first 10 days, routes 1, 2 and 3 were respectively chosen 62%, 18.5% and 19.5% of the times, while after this period, i.e. between the 11th and the 40th days, route 1 was chosen 40.5% of the times, route 2 was chosen 48.8% and route 3 was chosen 10.7%. This implies that after getting experience about the routes’ travel times, travellers tend to be more conservative (risk averse) in their choices, preferring the most reliable route. Travellers’ behaviour in Scenario 2, however, tended to favour the most reliable route since the beginning of the experiment. During the experience period, route 1 was preferred 50.86% of the times, route 2 was preferred 28.8% and route 3 was preferred 20.4%. During the remaining days, route 1 was chosen 34.5% of the times, route 2 was chosen 52.0% of the times and route 3 was chosen 13.5% of the times. The observed pattern behaviour implies that the more serious the purpose is the more conservative people tend to be in their choices. Therefore, when the travel purpose changed from meeting with colleagues to job...
interview, route 2 was more preferred from the 1st day already. In addition, it is possible to observe that the route of intermediate performance was the least preferred irrespective of the travel purpose. Figures 4 and 5 depict travellers’ route choice behaviour in scenarios 1 and 2.

Regarding travellers’ reaction and adaptation to information the following was observed. The observed behaviour under no information was similar to what we argued in the introduction, i.e. at first travellers explored the routes to get experience about their travel times; as time evolved, however, switching rates decreased as they became more aware of what their best route choice was (Figure 6). For sake of clarity, the reader should consider that a route switch is observed only if the traveller did not choose the same route as in the day before (exploring routes) or as two days before (back to usual behaviour).

When information was provided, 3 groups regarding compliance rate with information were identified: group 1 with compliance rate above 60%, group 2 with compliance rate between 30% and 60% and finally group 3 with compliance rate lower than 30%. We hypothesized that travellers that in general do not comply with the advice (group 3) should behave similar to the group without information. Figure 7 shows that the exploration rate tended to decrease up to 2/3 of the experiment and then tended to increase again. This is not entirely aligned to our expectations as it seems that travellers restart exploring the routes. It is possible that although in general group 3 does not comply with the advice, they might have felt intrigued about it and decided to explore the routes to investigate the effectiveness of the information. As a result a mixed behaviour aroused at the end of the period, i.e. at time travellers complied with the advice and in other occasions they trusted in their own experience.

In addition, for groups 1 and 2 we argued that as time evolves and travellers become more confident about the reliability of the information, switching rates from the information should gradually decrease. Our expectations did not resemble the observed behaviour. For group 1 the switching rate from the advice was about 15%, but peaks were also observed (in general) after advices favouring route 3 (Figure 8). This is due to the fact that route 3 was the travellers’ least preferred route. For group 2, no pattern can be identified (Figure 9). Due to the fact that in order to make their route choice decisions travellers’ neither resemble on the travel information nor on their own experience, it seems they need a longer learning period in order to figure out what to expect from each route. It has to be noted, however, that the observed behaviour is also consequence of the design of the experiment in which the information neither was always
correct nor always precise. In addition, at times the information deviated between 10 and 30 minutes from the true travel times.

Nevertheless, in the scenarios in which information was provided, travellers tended to follow it (Figure 10). In Scenario 3, route 1 was recommended the most, followed by route 3 and finally route 2, and this was the observed route choice pattern (Figure 10a). Overall, the compliance rate with the information was around 63% during and after the experience period. In Scenario 4, although the information provided was almost the same as in scenario 3, the compliance rate was around 55%, thus significantly inferior. In addition, the route choice pattern did not fully resemble the pattern of the information provided as route 2 was chosen more often than route 3 (Figure 10b).

**Figure 8:** Travellers’ switching rate from the advice in Scenarios 3 and 4 (group 1)

**Figure 9:** Travellers’ switching rate from the advice in Scenarios 3 and 4 (group 2)

**Figure 10:** Travellers’ route choice in reaction to information day by day in Scenarios 3 and 4.

Top part of each figure: the route which the advice favoured (1, 2 or 3) day by day. Bottom part of each figure: travellers’ route choice. Route 1 in black (bottom), route 2 in lilac (middle) and route 3 in dark grey (top)
Similarly to the scenarios in which no information is provided, there is a tendency to be more conservative in the choices when the seriousness of the travel purpose increases. Moreover, due to travellers’ preference for some of the routes, when the information favoured these, the compliance rate was significantly higher. For instance, route 3 was the least preferred route and even when the advice favoured solely this option, the compliance rate was (relatively) small compared to the other routes (Table 4).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Travellers’ route choice</th>
<th>Compliance rate with the advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No info + Meeting colleagues</td>
<td>Route 1 40.5%</td>
<td>Route 2 48.8%</td>
</tr>
<tr>
<td>2. No info + Job interview</td>
<td>Route 1 34.5%</td>
<td>Route 2 52.0%</td>
</tr>
<tr>
<td>3. Info in minutes + Meeting colleagues</td>
<td>On average</td>
<td>54.7% 22.0% 23.3%</td>
</tr>
<tr>
<td>Information favoured route 1</td>
<td>67.1% 17.1% 15.8%</td>
<td>67.1%</td>
</tr>
<tr>
<td>Information favoured route 2</td>
<td>3.6% 82.1% 14.3%</td>
<td>82.1%</td>
</tr>
<tr>
<td>Information favoured route 3</td>
<td>32.0% 19.4% 48.6%</td>
<td>48.6%</td>
</tr>
<tr>
<td>4. Info in minutes + Job interview</td>
<td>On average</td>
<td>45.4% 28.4% 26.2%</td>
</tr>
<tr>
<td>Information favoured route 1</td>
<td>55.5% 24.3% 20.1%</td>
<td>55.5%</td>
</tr>
<tr>
<td>Information favoured route 2</td>
<td>1.1% 87.0% 12.0%</td>
<td>87.0%</td>
</tr>
<tr>
<td>Information favoured route 3</td>
<td>31.3% 23.9% 44.8%</td>
<td>44.8%</td>
</tr>
</tbody>
</table>

With respect to the prediction ability of Prospect Theory, in line with the literature, results reinforce the importance of establishing meaningful reference points. Moreover, they show the need to align the reference point to travellers’ observed behaviour, thus accounting for heterogeneity. Discussion regarding the role of the reference point in situations accounting and not accounting for heterogeneity in travellers’ behaviour is respectively presented in sections 5.1 and 5.2.

5.1 Considering no heterogeneity

In scenarios 1 and 2, in which no information was provided, travellers’ were more conservative in their choices and tended to choose route 2 the most. As a result, when the reference point was set equal to the mode of the most reliable route, the prediction ability of Prospect Theory was the highest. On the other hand, the lowest performance was observed when the reference point was equal to the average travel time of all routes (Figure 11a). Under this condition route 3 was predicted the most making it possible to infer that when the reference point is not based on a specific type of behaviour, but on average values, routes of intermediate performance benefit from this. In addition, no differences between setting the reference point as the mode of the fastest route or the minimum travel time of the fastest route. We believe, however, this happened mostly due to the characteristics of the experiment for which there was not much difference between the values of the minimum and mode of travel times for the fastest route.

In scenarios 3 and 4, in which information was provided, the role of the reference point is more subtle because its variability is smaller. Prospect Theory performed best when the reference point was equal to the information advice2 allowing inferring that people tend to rely on actual travel times and use the information solely as a reference of how good the choice is (Figure 11b). In addition, because route 2 was not often recommended, the worst performance occurred when the reference point was equal to the mode of the most reliable route. Somewhat disappointing are the results of scenario 4 because the prediction ability Prospect Theory was only slightly better than in Scenario 2, in which no information was provided, and inferior to that observed in Scenario 3, in which only the travel purpose was different. This makes it possible to infer that information provision does not necessarily lead to improvement in the prediction ability of Prospect Theory. Nevertheless, these results were somewhat expected due to the fact that the route choices in scenario 4 were more homogeneous allied to the fact that route 1 was predicted as the route choice experiment progressed. For instance, as of the 20th day advice favouring route 1 was provided 75% of the times (15 out of 20 times) while travellers chosen it only 49% of the times.

![Graph showing prediction ability of Prospect Theory in relation to the reference point in scenarios 1 and 2](image-url)
Accounting for heterogeneity

Results make clear that by considering each traveller as unique individual (as it is naturally the case) and thus allowing each of them to have his/her own reference point, the prediction ability of Prospect Theory (substantially) increases. This is particularly true when no information is provided (scenarios 1 and 2). Figure 12 depicts the comparison between the best performances of each scenario considering no heterogeneity and the performance of both reference points when accounting for heterogeneity. Under the condition of the reference point as defined in ii, i.e. the travel times or information advice of the most chosen route in the previous five days, the improvements are definitely significant. It may be questioned, however, the real benefit of accounting for heterogeneity given that under the condition of reference point as defined in i, i.e. the information advice of the most chosen route up to day d-1, improvements in scenarios 3 and 4 were not so significant. Although in these scenarios the average amount of correct predictions remained the same, increase in the minimum amount of correct predictions per traveller from 2 to 8 was ascertained, contributing thus to the robustness of the model.

The underlying reason for the better performance of the reference point as defined in ii rather than as defined in i is that the former allows a quicker adaption of the reference point to a new route preference. For instance, as we considered that the reference point referred to the travellers’ choice in the previous 5 days, after 3 days driving a new route, the reference point would shift to the new route preference. Otherwise, this would be the case only if the traveller had driven on a new route for a period longer than on the previous preferred route. In addition, the data analysis allows inferring that for travellers who appear to have a clear route choice behaviour rather than random route choices, i.e. route switches are observed, but not such that every other day a different route is chosen, to account for heterogeneity in their behaviour is of no doubt the reason for significant improvements.

The data analysis allows indentifying the following groups regarding routes’ preferences: group 1 with strict preference for one route, group 2 with moderate preference for one route and group 3 of indifferent travellers. In the first group, travellers rarely switched from the preferred route; in the second, a predominance for the preferred route was observed, despite a consistent route switch, i.e., although travellers switched routes, this was not done every (other) day; in the third group, travellers’ route choice decisions did not seem to follow a behavioural pattern, i.e. travellers changed routes almost daily seeming to be making random choices. Figures 13 to 16 depict the percentage of correct predictions in scenarios 1 to 4 for each traveller. In addition, the group to which each of them belongs to are depicted above the figures: group 1 is illustrated by green squares; group 2 by yellow circles and group 3 by the purple triangles.
Figure 13: Prediction ability of Prospect Theory for each traveller in scenario 1

Figure 14: Prediction ability of Prospect Theory for each traveller in scenario 2

Figure 15: Prediction ability of Prospect Theory for each traveller in scenario 3
When investigating the role of heterogeneity in the reference point, in general it suffices that travellers make choices following a behavioural pattern (groups one and two) rather than random route choices. If travellers do present a “route choice behaviour”, good results regarding the prediction ability of Prospect Theory can be obtained as it is possible to capture the behaviour of each group of travellers with the reference point. Under this condition, the hypothesis about the reference point raised in the introduction that (i) it varies among travellers, (ii) it varies over time, (ii) it reflects travellers’ (risk) preferences were confirmed by the data analysis. Nevertheless, it is possible to observe that in some situations, such as in scenario 3 for travellers 18 and 39 for instance, despite the fact that the travellers present a clear behavioural pattern (in this case belonging to group 1) the percentage of correct predictions was quite low. These were mainly situations in which travellers’ preferred route was route 3, whose characteristics were not so well defined. As a result, in spite of the reference point being aligned to the travel times and traffic information of route 3 low prediction rates were observed. This implies that not only the reference point should be aligned to the observed behaviour but as well as that the observed behaviour should be a good reflection of the routes’ characteristics. On the other hand, when heterogeneity is not taken into account good results are obtained only if we align the reference point to behaviour of the majority. Thus, irrespective of travellers’ different preferences for reliable and slower route on the one hand or unreliable and faster on the other, only the behaviour of the majority can be captured. Finally, irrespective of accounting for heterogeneity, for obvious reasons, random choices cannot be properly captured.

For the important role of the reference point, both its behavioural appeal and the role of heterogeneity should be further investigated with the support of more empirical experiments.

6. CONCLUSIONS AND FUTURE RESEARCH

The behavioural meaning of the reference point of Prospect Theory and the role of heterogeneity in travellers’ behaviour were discussed in this paper. This was done by providing a behavioural interpretation of the reference point in the travel behaviour context and, with the support of a case study, comparing the results regarding the prediction ability of Prospect Theory under different reference points.

Results show that despite the potential of information to influence travellers’ behaviour, they are not willing to fully comply with the advice. Nevertheless, travellers’ route choices are more clustered when information is provided, in particular when the information is aligned with travellers’ preference for a specific route. The main issue underlying the compliance rate is determining the extent to which this impacts network dynamics. For instance, given the higher compliance rates in certain situations, the impact of information provision may lead travellers to completely switch to alternative routes which would then significantly impact network dynamics. Further conclusions should be drawn carefully as other aspects that might affect the compliance rate, such as traveller’ familiarity with the routes and distance between the origin and destination, need to be investigated. These are topics left for future research.

The use of Prospect Theory to model travellers’ behaviour is relatively new and the literature has made clear the lack of empirical experiments to validate its use on route choice behaviour in particular due to the need to better understand the reference point. This case study is one of the first attempts to propose a behavioural interpretation to the reference point in a route choice context and to further investigate the role of heterogeneity on it. In line with literature, results show that the reference point considerably influences the prediction ability of Prospect Theory, thus reinforcing the need of establishing meaningful values. Moreover, by accounting for heterogeneity in travellers’ behaviour, thus considering that each individual traveller has its own reference point, significant improvements are observed. As in this study the same parameters as originally estimated were used, the prediction ability of Prospect Theory can be further improved by using appropriate parameters. Whether appropriate parameters will lead to improvement in the prediction ability of Prospect Theory is not clear. Nevertheless, they will be more coherent with the type of behaviour studied.
The data analysis allows indentifying the following groups of travellers: group 1 with strict preference for one route, group 2 with moderate preference for one route and group 3 which is made of indifferent travellers. In the first group, the travellers almost did not switch from the preferred route; in the second, a predominance for the preferred route, even if it consistently changed over time, was observed, i.e. although travellers switched routes, this was not done every (other) day; in the third group, travellers’ route choice decision did not seem to follow a behavioural pattern, i.e. travellers change routes almost daily seeming to be random choices. When investigating the role of heterogeneity in the reference point, it suffices that travellers make choices following a behavioural pattern (groups one and two) rather than random route choices. If travellers do present a “route choice behaviour”, good results regarding the prediction ability of Prospect Theory can be obtained as it is possible to capture the behaviour of each group of travellers with the reference point. Under this condition, the hypothesis about the reference point raised in the introduction that (i) it varies among travellers, (ii) it varies over time, (ii) it reflects travellers’ (risk) preferences were confirmed by the data analysis. On the other hand, if we do not account for heterogeneity good results are obtained only if we align the reference point to the largest group in terms of routes’ preference. In other words, only the behaviour of the majority can be captured. Irrespective of accounting for heterogeneity, for obvious reasons, random choices cannot be properly captured. For the important role of the reference point, both its behavioural appeal and the role of heterogeneity should be further investigated with the support of more empirical experiments.

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References


