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Research Article

Sequential Route Choice Modeling Based on Dynamic Reference Points and Its Empirical Study

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Aiming at the influence of information, we investigate and analyze the sequential route choice behavior under dynamic reference points based on cumulative prospect theory in this paper. An experiment platform collecting the sequential route choices based on C/S structure is designed and four types of information are released to participants, respectively. Real-time travel time prediction methods are then proposed for travelers' decision-making. Using nonlinear regression method, the parameters of the value function and weight function of cumulative prospect theory are estimated under different types of information, respectively. It is found that travelers' behavior showed obvious characteristic of risk pursuit under the circumstance where real-time travel time information is released. Instead, when they have access to descriptive information, they tend to be more conservative.

1. Introduction

Perfect rationality theory, which assumes that the option will be chosen only with the minimum cost or maximum utility, is widely used in modeling travelers' route choice, mode choice, and travel time choice behavior [1]. Meanwhile, plenty of research shows that travelers may not be able to obtain the information of optimal route due to the uncertainty of information. In other words, the traveler may not always select the route with maximum utility.

Simon proposed that people are bounded rational during the process of decision-making [2] to make up for the deficiencies of perfect rationality. On the account of the uncertainty of traffic environment and individual cognitive diversities, it is unrealistic to find the optimal strategy every time.

Based on the bounded-rationality theory, Kahneman and Tversky put forward the prospect theory (PT) in 1979 and cumulative prospect theory (CPT) in 1992 [3, 4] on the basis of economic experiments. Instead of using the utility maximization theory, PT and CPT assume that one man will pursue risks in face of gains and avoid risks in face of losses. Moreover, one is more sensitive to loss than to gain. A large number of studies have proved that the cumulative prospect theory is more consistent with the actual travel behavior than the expected utility theory [5–8].

There are five parameters in CPT model, which denotes the sensitivity to gains and losses. Since the parameters presented by Kahneman and Tversky are calibrated according to economic behavior and cannot be applied to other fields directly, some researchers in other fields calibrated these parameters by questionnaires and experiments. Questionnaires and experiments in previous studies always provided certain information for the travelers to choose. However, traffic status may constantly change with actual travel behaviors; both accurate travel time and probability cannot be obtained in advance. Even the traffic information announced by the traffic guidance system will be dynamically updated. Therefore, traditional questionnaire survey is no longer applicable as a research tool in route choice behavior study.

In addition, these previous investigations based on individual choice behavior did not consider the characteristics under groups or take sequential choice scenarios into account, nor were the influence of different types of information revealed clearly. It is obvious that travelers exhibit different attitudes towards different types of information, and therefore the CPT parameters should be calibrated, respectively.

The paper establishes a route choice model under uncertain decision circumstances based on CPT theory scheme. A method for estimating the possibility of travel time is put forward, which can be applied to researching the traveler's route choice decision. Dynamic reference points are taken into consideration in the CPT model in which case traveler's route decision is closer to the route choice behavior in reality. The model extends the application of CPT theory and its parameters are more consistent with the characteristics of travelers in China.

The text is organized as follows. Section 2 gives a brief introduction on cumulative prospect theory and parameters calibration. In Section 3, data collection methods are conducted and experimental data is preliminarily analyzed. Section 4 presents the travel time prediction methods under historical information and descriptive information and the utility function is established under different information situations. Section 5 discusses the results of parameters calibration and compares them with other researchers' conclusions. Section 6 summarizes this paper and puts forward few suggestions for the future work.

2. Literature Review

2.1. Cumulative Prospect Theory. Cumulative prospect theory (CPT) was proposed by Tversky and Kahneman in 1992 [4]. CPT includes subjective value function and subjective probability function. Subjective value function can be described as follows:

$$v(x) = \begin{cases} x^{\alpha}, & x \geq 0; \alpha > 0, \\ -\lambda(-x)^{\beta}, & x < 0; \lambda > 0; \beta > 0, \end{cases} \tag{1}$$

where $v(x)$ is the subjective utility corresponding to option x, α is the concavity of value function for gains ($x \geq 0$), and β is the convexity of value function for losses ($x < 0$). $0 < \alpha \leq 1$ and $0 < \beta \leq 1$ indicate a progressive decrease in sensitivity. λ is loss-avoidance coefficient. $\lambda \geq 1$ denotes greater preference for gain than for the same loss, meaning that the loss region of subjective utility is steeper than the gain region.

Formula (1) indicates that the reference point of gain and loss is 0. When reference point is x_0 ($x_0 \neq 0$), the subjective value function can be described as follows:

$$v(x) = \begin{cases} (x - x_0)^{\alpha}, & x \geq 0; \alpha > 0, \\ -\lambda(-x + x_0)^{\beta}, & x < 0; \lambda > 0; \beta > 0. \end{cases} \tag{2}$$

The subjective probability function can be described as follows:

$$\pi(p) = \begin{cases} \pi^{+}(p) = \dfrac{p^{\gamma}}{\left(p^{\gamma} + (1 - p)^{\gamma}\right)^{1/\gamma}}, & x \geq 0, \\ \pi^{-}(p) = \dfrac{p^{\delta}}{\left(p^{\delta} + (1 - p)^{\delta}\right)^{1/\delta}}, & x < 0, \end{cases} \tag{3}$$

where $\pi^{+}(p)$ is the probability of subjective gains, $\pi^{-}(p)$ is the probability of subjective loss, p is the actual probability of gains and losses, and γ and δ are the sensitivity of gain and loss. $\gamma \leq 1$ and $\delta \leq 1$.

The prospect value can be described as the sum of the subjective gains and subjective loss:

$$U = \sum\left(v^{+}(t) \cdot \pi^{+}(p)\right) + \sum\left(v^{-}(t) \cdot \pi^{-}(p)\right). \tag{4}$$

There are five parameters in CPT, and researchers always assume $\alpha = \beta$ or $\delta = \gamma$.

2.2. Parameters Estimation of CPT. Kahneman and Tversky first studied the parameters using Certainty Equivalent (CE) and obtained the original parameters estimation results of $\alpha = \beta = 0.88$, $\lambda = 2.25$, $\gamma = 0.61$, and $\delta = 0.69$. For several decades, a large number of researchers applied the estimation results on the study of travel route choice [7, 9, 10], mode choice [11–13], departure time, and network equilibrium [14–16].

In terms of travel behavior, Xu et al. [17] and Liu et al. [18] designed some decision-making scenarios to conduct a questionnaire survey. Schwanen and Ettema [19] studied the behavior of picking up children from school using genetic algorithm (GA) methods. Zhang et al. [20] applied the CPT to day-to-day route choice under friends' travel information. Chow et al. [21] researched the lane-changing behavior on the basis of CPT theory. These studies all calibrated the CPT parameters using questionnaire data or estimating data and the conclusions are listed as in Table 1.

As shown as Table 1, studies of α, β, and λ are more popular. Results of Xu and Zhang are similar to each other for all the five parameters. However, for different reference points which are involved in Liu's models, the numerical distribution of parameters is very wide. Schwanen got larger α and β, while Chow came to a completely different conclusion than anyone else.

CPT is also widely put into use in behavior study of stock market. Table 2 summarizes some of the study results on the stock market.

In general, behavior of stock market is basically consistent. The results represent that behavior of stock market is obviously different with travel behavior and does not reflect significant loss-avoidance characteristic.

As for the research methods, Zeng [26] applied the same paradigm (Certainty Equivalent) used by Kahneman and Tversky in 1992 to conduct behavior experiments, using nonlinear regression to calibrate CPT parameters. It is found that α and β are both greater than 1 and the results are

Table 1: Summary of parameters calibration results of travel behavior.

References	α	β	λ	γ	δ
Xu et al. [17]	0.37	0.59	1.51	—	—
Liu et al. [18]	0.25 ~ 0.7	$\beta = \alpha$	0.7~1.3	0.68 ~ 0.74	0.7 ~ 0.9
Schwanen and Ettema [19]	1.07~1.10	$\beta = \alpha$	1.27	0.82~0.83	$\delta = \gamma$
Zhang et al. [20]	0.5	0.54	1.85	—	—
Chow et al. [21]	0.796	0.785	2.394	0.015	5.479

Table 2: Summary of parameters calibration results of stock market.

References	α	β	λ	γ	δ
Gurevich et al. [22]	0.79	0.79	1.12	0.77	0.91
Bleichrodt and Pinto [23]	0.79	0.79	—	0.674	—
Abdellaoui [24]	—	—	—	0.6	0.7
Ryan and Robert [25]	0.6~0.8	$\beta = \alpha$	1.1~1.2	0.7~0.9	0.6~0.9

incompatible with the basic idea of CPT, suggesting that Kahneman and Tversky's estimation has to be modified when CPT is applied in China. Wu and Gonzalez [27] designed a risk-prospect gradient experiment with economic benefits as reward and calibrated the parameters. Prelec [28] adopted different subjective probability function $g(p) = \exp(-(-\ln p)^{\gamma})$.

Rieger et al. [29] conducted a standardized survey on risk preferences at 53 countries around the world. The results of parameters estimation show that there are significant differences among countries and the values of parameters are related to economic and cultural differences. Rieger found that Chinese had a higher value of δ, which implies that Chinese are less worried about the small probability of loss. Rieger also found that the five parameters of CPT model were correlated.

We could summarize that CPT theory has been widely used in a variety of behavior analyses. The parameters of CPT are different in various scenarios. In current research methods, experiments were designed based on determinate probability and profit (or loss) so that all participants could know the probability and profit (or loss) of random events in advance. This premise assumption is inconsistent with the actual situation in reality. In addition, the CPT theory only investigates individual behavior and hardly involves the influence of other participants in the case of group travel. The difference between individual travel and group travel, travelers' sensitivity to gain and loss under different types of information, has not been completely revealed. Based on the two key factors above, travelers' sequential route choice behavior under different types of information has been studied in the article.

3. Data Collection

3.1. Experiment Design. First, a route choice experiment platform is established, which includes four scenarios. Suppose that the origin is Northwest Polytechnical University and the destination is Xi'an Jiao Tong University in Xi'an, Shaanxi province, China. The experiment platform provides ten sections commonly used for participants to choose.

The interfaces of the route choice experiment platform are shown in Figure 1.

There are six routes which can be chosen in the experiment platform, which is shown in Table 3.

All participants are asked to complete the experiment in a predetermined order. In each scenario, all participants are required to carry five rounds. The multiple choices are used to simulate the day-to-day travel behavior aiming to eliminate randomness and analyze continuous behavior characteristics. Four scenarios are designed as follows.

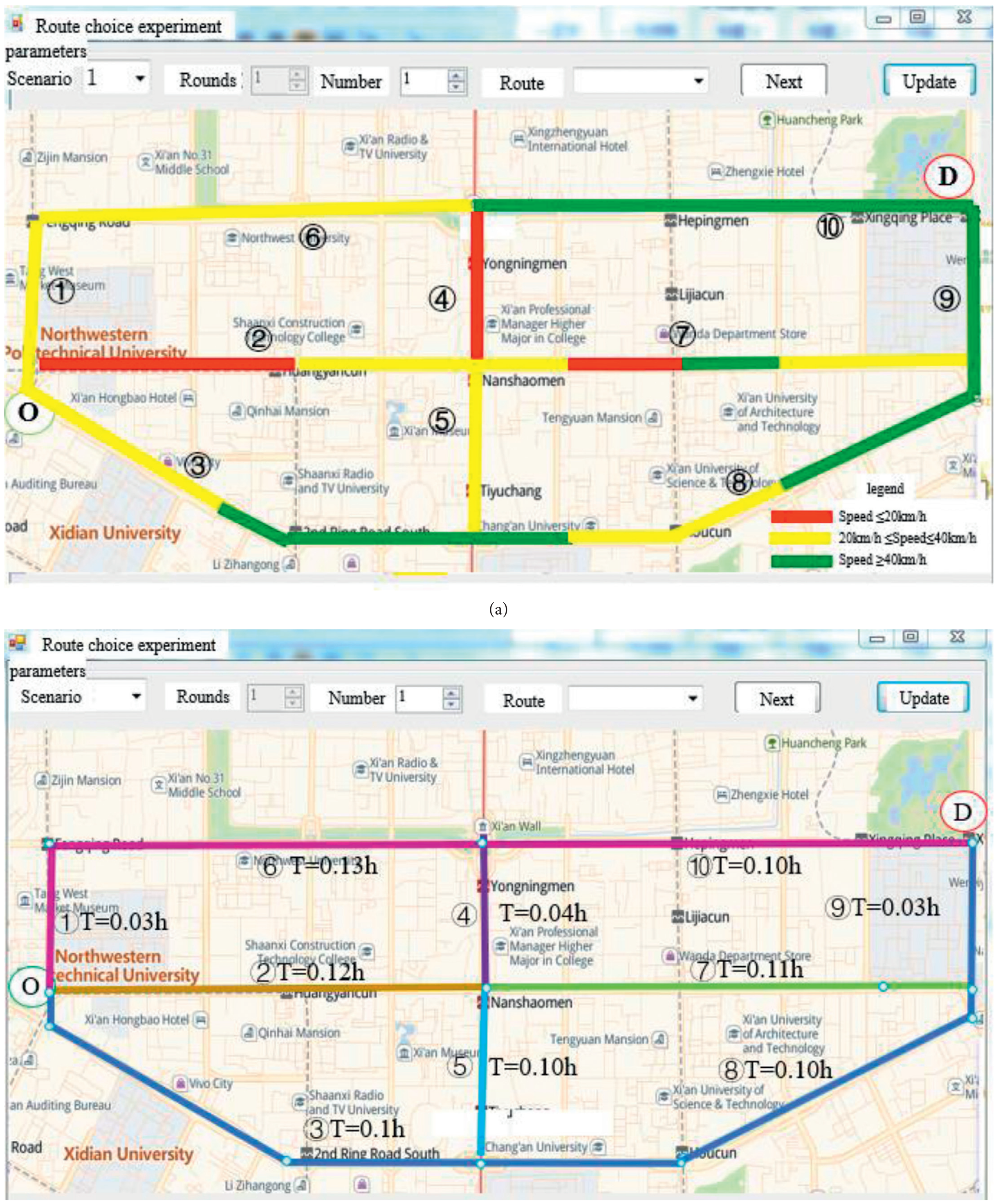
Scenario 1: historical descriptive information is released. Scenario 2: historical travel time is released. Scenario 3: real-time descriptive information is released. Scenario 4: real-time travel time information is released.

When descriptive information is published, different sections of road will be displayed to participants in different colors, which all represent various speeds of travel (shown as Figure 1(a)), and when travel time information is released, sections with specific travel time will be shown (shown as Figure 1(b)). Historical information means the actual travel time of the previous round and real-time information represents the predicted travel information of the next round.

Assume that there are N travelers and every traveler has to finish M-round experiments for each scenario in the sequential choice system. The experiment process can be shown in Figure 2.

In each scenario, all participants receive the same information and are supposed to complete all the four scenarios. The original information is the same for all scenarios. BPR impedance function is used to update travel time for routes and all scenarios.

3.2. Implementation of the Experiment. The experiment is established based on C/S (C: client; S: server) structure. The client collects the choice results of each participant and synchronizes with the server. The server calculates the travel time of each route dynamically, and travel information is pushed to client in real time. Travel times of all routes are updated in real time and pushed to the server, and participants make their next choice based on the results of the client's push.



(a)

(b)

Figure 1: Surfaces of the route choice experiment platform. (a) Scenario 1 and Scenario 3. (b) Scenario 2 and Scenario 4.

Requirements of the experiment: (1) the experiment program is sent to participants via e-mail and the installation should be completed in advance. (2) All participants are required to conduct the experiment on the appointed date and within the specified period of time. (3) All participants are numbered first, and then they should make their choice in order and follow the same sequence for all later scenarios and rounds.

3.3. Preliminary Analysis of Experimental Data. 216 participants took part in the experiment. Each scenario runs five rounds and produces 1080 pieces of data.

Each of the participants' two consecutive choices was considered as a unit to analyze sequential behavior differences.

For each traveler, assume that his/her choice is i at $(r-1)^{\text{th}}$ round and $t_{r-1,i}$ is the actual travel time for route i at

Table 3: Routes shown in the experiment platform.

Number of the routes	Sections
1	①-⑥-⑩
2	②-④-⑩
3	②-⑦-⑨
4	③-⑤-④-⑩
5	③-⑤-⑦-⑨
6	③-⑧-⑨

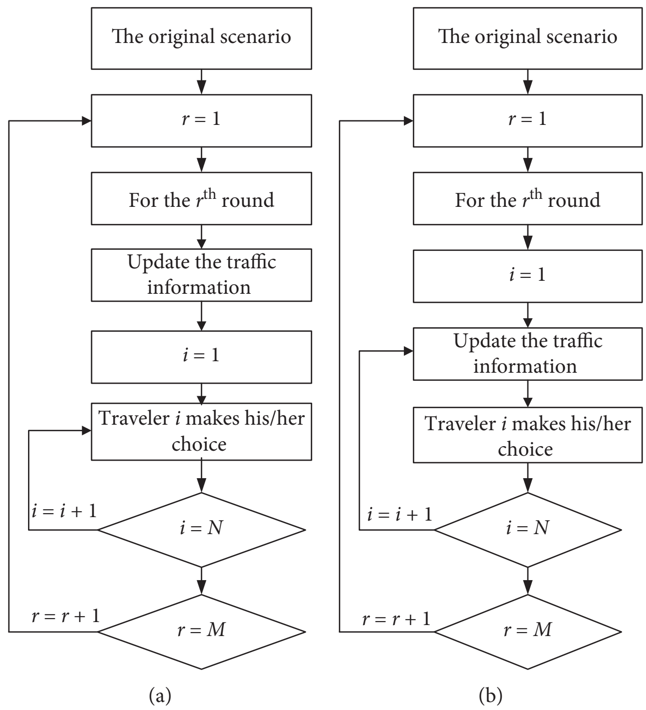


Figure 2: Experiment process. (a) Scenario 1 and Scenario 2 (historical information). (b) Scenario 3 and Scenario 4 (real-time information).

the $(r-1)^{\text{th}}$ round; assume that his/her choice is j at r^{th} round and $t_{r,j}$ is the actual travel time for route j at the r^{th} round. If $j \neq i$, we consider that the state of route choice is "switch"; else the state of route choice is "keep." If $t_{r,j} - t_{r-1,i} > 0$, we consider that the time saving is "loss"; if $t_{r,j} - t_{r-1,i} < 0$, we suggest that the time saving is "gain."

Then, travelers' behavior can be classified as four states, including switch/loss, stay/loss, stay/gain, and switch/gain. The state "switch/loss" means that traveler changes his/her route to another route in the next round and the travel time is longer than the previous round. The state "stay/gain" means that traveler keeps his/her route unchanged in the next round and his/her travel time is shorter than the previous round. Other cases can be similarly defined.

Route choice behavior under Scenario 2 and Scenario 4 is shown in Figure 3.

With the release of the historical travel time (Scenario 2), most travelers (85%) kept their route unchanged in the next round. However, only 24% of travelers received positive utility if they kept their routes the same.

With the release of the real-time travel time (Scenario 4), most travelers (65%) switched their routes in the next round. Travelers could obtain the exact current travel time; therefore, most travelers chose the relatively shorter route. Meanwhile, these travelers had no way of knowing the subsequent participants' options and not all travelers could obtain positive utility.

By comparing Figures 3(a) and 3(b), we can learn that travelers' route choice behavior is affected by the types of information. Moreover, across all participants, there are always fewer travelers in the "gain" state than in the "loss" state, regardless of the "switch" or "hold" behavior.

Evolution of route choice behavior under Scenario 2 and Scenario 4 is shown in Figures 4 and 5.

As shown in Figure 4(a), for the sequential choice behavior, probabilities of each state generally remain unchanged. The travelers in the "stay/loss" state account for the most in each round, followed by the travelers in the "stay/gain" state. This characteristic indicates that travelers' performance tends to be consistent with each turn; that is, he or she will hardly change his or her route continuously.

As can be seen from Figure 4(b), the states of "switch" and "stay" are basically stable, with slight fluctuation on the whole. While the possibility of "loss" decreases gradually, the possibility of "gain" increases gradually. It is apparent that

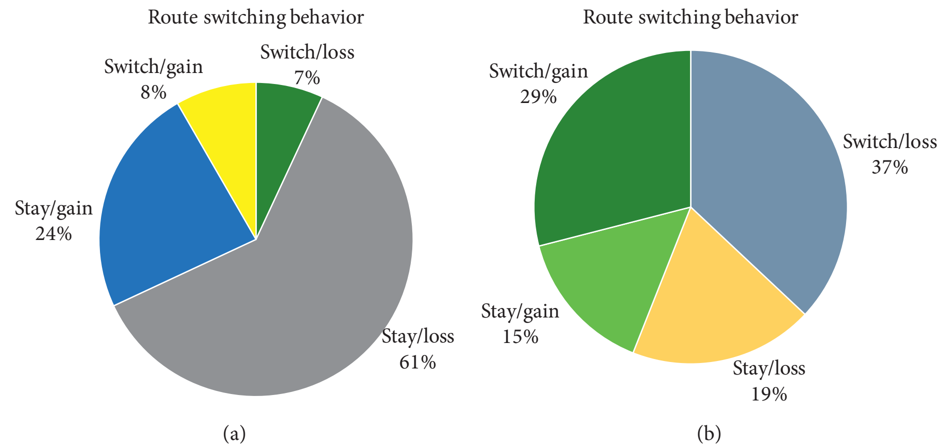


FIGURE 3: Route choice behavior under Scenario 2 and Scenario 4. (a) Scenario 2 (b); Scenario 4.

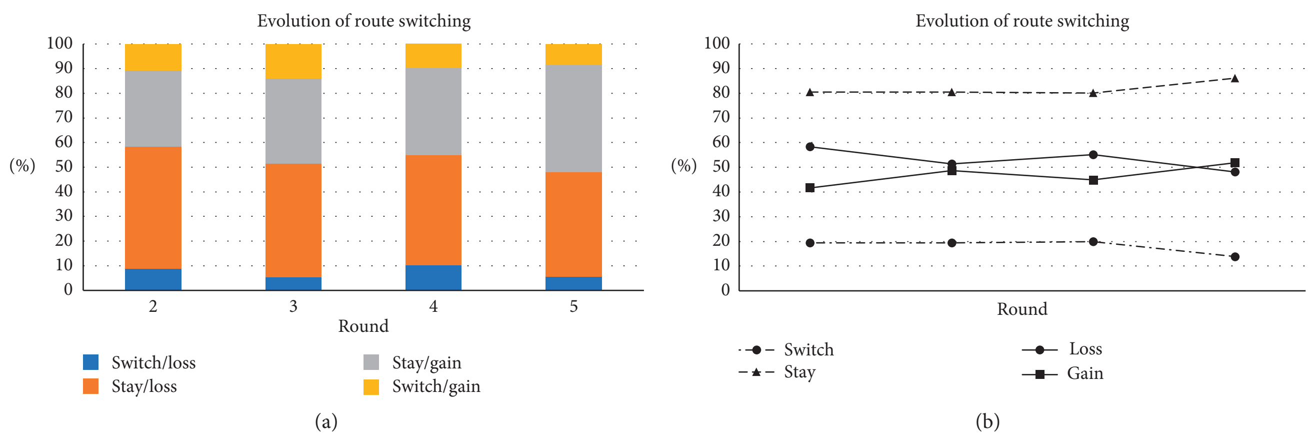


FIGURE 4: Evolution of route choice behavior under Scenario 2. (a) Probability of each state. (b) Propensity of each state.

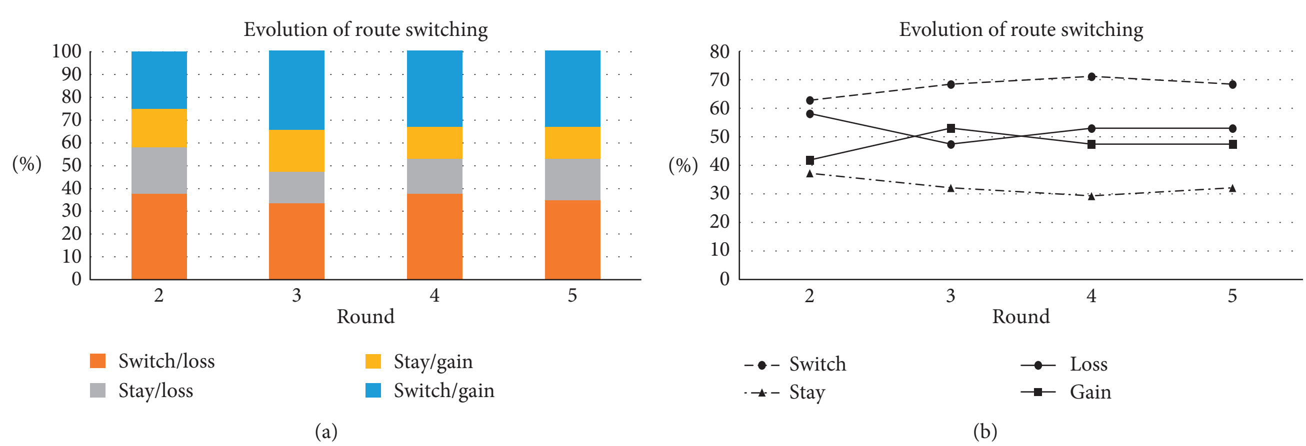


FIGURE 5: Evolution of route choice behavior under scenario 4. (a) Probability of each state. (b) Propensity of each state.

more and more travelers can reduce their travel time through multiple exploratory choices.

The probability and evolution propensity of travelers' route choice behavior are described in Figure 5. In Figure 5(a), the probability of each state generally remains unchanged during the sequential choice process, which is the same as the characteristics shown in Figure 4(a).

As shown in Figure 5(b), each state fluctuates slightly during the sequential choice progress. Travelers who switch their routes still outnumbered travelers who keep their routes the same. The amounts of travelers who obtained positive utility are almost equal to the number of travelers who received negative utility, about 50% each.

By comparing Figures 4 and 5, it can be concluded that travelers are more inclined to pursue risks and utility when faced with real-time information. Precisely because the travel time under real-time travel time information is available, more people choose to switch their route to the shortest route in order to obtain objective utility. Inversely, when historical information is published, the manifestation of behavior of travelers tends to be conservative on account of the fact that they cannot get an accurate prediction travel time.

Moreover, the trend each stage presents in Scenario 2 and Scenario 4 indicates that the traveler's behavior exhibits a high degree of consistency in the route choice process. Then, all the data recorded in the experiment would be applied to the modeling.

Since descriptive information is published in Scenarios 1 and 3, the accurate travel time could not be obtained from the platform, so the traveler's behavior is not analyzed.

4. CPT Model Establishment

4.1. Dynamic Reference Point. The actual travel time in the previous round could be regarded as the reference point in the process of establishing CPT model, which is x_0 mentioned in formula (1). Then, the reference point $\widetilde{t}_{i-1,j}$ on behalf of the travel time of route j in round $i-1$ can be specifically expressed as

$$\widetilde{t}_{i-1,j} = t_{j,0}\left(1 + 0.15 \cdot \left(\frac{\widetilde{q}_{i-1,j}}{C_j}\right)^4\right). \tag{5}$$

$\widetilde{q}_{i-1,j}$ means the number of travelers choosing route j at round $i-1$, which can be collected by the experimental platform. $t_{j,0}$ is the free-flow travel time for route j, which is constant given by the platform before the experiments. C_j is the capacity of route j.

The value function is

$$v(t) = \begin{cases} v^+(t) = \left(\widetilde{t}_{i-1,j} - T_{i,k,j}\right)^{\alpha}, & T_{i,k,j} \le \widetilde{t}_{i-1,j}; \alpha > 0, \\ v^-(t) = -\lambda\left(T_{i,k,j} - \widetilde{t}_{i-1,j}\right)^{\beta}, & T_{i,k,j} > \widetilde{t}_{i-1,j}; \lambda > 0; \beta > 0. \end{cases} \tag{6}$$

$T_{i,k,j}$ is the travel time of route j in round i predicted by k^{th} traveler. Then, $v^+(t)$ means the subjective obtained, because the actual travel time decreases compared with the last round for traveler k. Similarly, $v^-(t)$ means the subjective loss. α, β, λ are the parameters needed to be calibrated.

In the next step, travel time $T_{i,k,j}$ will be elaborated in detail first, and utility function may be established for every scenario, respectively. Calculating methods of travel time under the certain traffic information is different from others; then the actual travel time $T_{i,k,j}$ is redefined as $t_{1,i,k,j}$ (historical information), $t_{2,i,k,j}$ (real-time descriptive information), and $t_{3,i,k,j}$ (real-time travel time information).

4.2. Historical Information (Scenario 1 and Scenario 2)

4.2.1. Travel Time Calculation. Before making a decision, each traveler can forecast the choice of other travelers according to the decision of all travelers in the previous round and the choice of the travelers before him in order in the current round. Suppose that there are N travelers in the system.

Step 1. The traveler forecasts other travelers' choice results in the i^{th} round according to the actual choice results in the $(i-1)^{\text{th}}$ round, using Markov method.

(1) Divide the status. The system contains six routes, each representing a state.

(2) Establish the state transition probability matrix:

$$G_{i,k} = \begin{bmatrix} g_{11}(i,k) & \cdots & g_{16}(i,k) \\ \cdots & \cdots & \cdots \\ g_{61}(i,k) & \cdots & g_{66}(i,k) \end{bmatrix}, \tag{7}$$

where $G_{i,k}$ is the state transition probability matrix of the k^{th} traveler in $i-1$ rounds, $g_{j,j'}(i,k)$ is the state transition probability from j^{th} state to j'^{th} state in all the $i-1$ rounds ($j = 1, \ldots, 6$; $j' = 1, \ldots, 6$, $j \neq j'$), and $g_{11}(i,k)$ is the probability that traveler k chooses route 1 twice in succession in $i-1$ rounds. One has

$$g_{j,j'}(i,k) = \frac{M_{j,j'}(i,k)}{M_j(i,k)}, \tag{8}$$

where $M_{j,j'}(i,k)$ is the transition time of traveler k from state j to state j' in $i-1$ rounds and $M_j(i,k)$ is the number of times that traveler k belongs to the state j in all the $i-1$ rounds. Therefore, $M_1(i,k)$ represents the number of times that traveler k chooses route 1 in all the $i-1$ rounds.

(3) Forecast the choice results at round i:

$$R_{i,k} = v_{i-1,k} \times G_{i,k}. \tag{9}$$

$R_{i,k}$ is choice probability matrix of traveler k in round i, $R_{i,k}(1,j)$ is the probability that traveler k chooses route j in round i, and $v_{i-1,k}$ is the choice vector matrix of traveler k in $(i-1)^{\text{th}}$ round. If traveler k chooses route 1, $v_{i-1,k} = (1, 0, 0, 0, 0, 0)$.

The probability that traveler k chooses route j in round i is $\widetilde{g}_{i,j,k} = R_{i,k}(1,j)$. Assume that the number of times travelers choose route j in round i is $q_{i,j} = \sum_{k=1}^{N} \widetilde{g}_{i,j,k}$ and the corresponding probability is $g_{i,j}(q_{i,j}) = (\sum_{k=1}^{N} \widetilde{g}_{i,j,k})/N$.

Step 2. Traveler k forecasts the decision results of others based on the current choices of some travelers. For traveler k, when he/she makes the choice, there are $k-1$ travelers who have made their decision. Traveler k can infer others' decision results according to the actual choices of the previous $k-1$ travelers.

For traveler k, the probability of choosing route j in all the $i-1$ rounds can be expressed as

$$\widetilde{h}_{i,k,j} = \frac{w_{i,k-1,j}}{k-1}. \tag{10}$$

$w_{i,k-1,j}$ means the number of travelers who choose route j among all $k-1$ travelers in all the $i-1$ rounds.

Then, the number of travelers choosing route j at round i that traveler k infers is

$$m_{i,k,j} = \widetilde{h}_{i,k,j} \cdot N. \tag{11}$$

And the probability corresponding to $m_{i,k,j}$ is $h_{i,k,j}(m_{i,k,j}) = \widetilde{h}_{i,k,j}$.

Step 3. Considering the prediction results of previous all $i-1$ rounds and the current round i, traveler k could infer that the number of travelers choosing route j and their corresponding probability are $\{q_{i,j}, g_{i,j}(q_{i,j}); m_{i,k,j}, h_{i,k,j}(m_{i,k,j})\}$. We can construct two sets to represent the number of travelers $Q_{i,k,j} = \{q_{i,j}, m_{i,k,j}\}$ and the corresponding probability distribution $P_{i,k,j=}\{g_{i,j}(q_{i,j}) h_{i,k,j}(m_{i,k,j})\}$, respectively.

Traveler k forecasts the actual travel time of route j at i^{th} round as

$$t_{1,i,k,j}(p) = t_{j,0}\left(1 + 0.15 \cdot \left(\frac{q_{i,k,j}(p)}{C_j}\right)^4\right), \quad q_{i,k,j}(p) \in Q_{i,k,j}, p \in P_{i,k,j}. \tag{12}$$

$t_{1,i,k,j}(p)$ is the travel time of route j at round i predicted by k^{th} traveler, of which corresponding probability is p. $q_{i,k,j}(p)$ is the number of travelers choosing route j, of which corresponding probability is p. Other variables are defined as before.

The value function can be written as

$$v(t) = \begin{cases} v^{+}(t) = \left(\widetilde{t}_{i-1,j} - t_{1,i,k,j}(p)\right)^{\alpha}, & t_{1,i,k,j}(p) \le \widetilde{t}_{i-1,j}; \alpha > 0; p \in P_{i,k,j}, \\ v^{-}(t) = -\lambda\left(t_{1,i,k,j}(p) - \widetilde{t}_{i-1,j}\right)^{\beta}, & t_{1,i,k,j}(p) > \widetilde{t}_{i-1,j}; \lambda > 0; \beta > 0; p \in P_{i,k,j}. \end{cases} \tag{13}$$

4.2.2. Subjective Probability Function. The probability function is

$$\pi(p) = \begin{cases} \pi^{+}(p) = \dfrac{p^{\gamma}}{\left(p^{\gamma} + (1-p)^{\gamma}\right)^{1/\gamma}}, \\ \pi^{-}(p) = \dfrac{p^{\delta}}{\left(p^{\delta} + (1-p)^{\delta}\right)^{1/\gamma}}, \\ p \in P_{i,k,j}. \end{cases} \tag{14}$$

4.2.3. Utility Function Establishment. The utility function can be described as

$$\begin{aligned} U_{i,k,j} &= \sum\left(v^{+}(t) \cdot \pi^{+}(p)\right) + \sum\left(v^{-}(t) \cdot \pi^{-}(p)\right) \\ &= \sum v^{+}\left(t_{1,i,k,j}(p) \cdot \pi^{+}(p)\right) + \sum v^{-}\left(t_{1,i,k,j}(p) \cdot \pi^{-}(p)\right). \end{aligned} \tag{15}$$

4.3. Real-Time Descriptive Information (Scenario 3)

4.3.1. Travel Time Calculation. It is assumed that the maximum travel time of route j is $\widetilde{T}_{dj}$ and the minimum travel time is $\widetilde{T}_{uj}$. The actual travel time t_j obeys uniform distribution $t_j \sim U(\widetilde{T}_{dj}, \widetilde{T}_{uj})$, the probability density function is $f(t_j) = 1/(\widetilde{T}_{uj} - \widetilde{T}_{dj})$, and the cumulative distribution function is $F(t_j) = (t_j - \widetilde{T}_{dj})/(\widetilde{T}_{uj} - \widetilde{T}_{dj})$.

Assume that the maximum speed and minimum speed of a certain route are v_u and v_d, respectively. For the sections displaying red information, $v_{ru} = 20$ and $v_{rd} = 5$. For the sections displaying yellow information, $v_{yu} = 40$ and $v_{yd} = 20$. For the sections displaying green information, $v_{gu} = 60$ and $v_{gd} = 40$. For route j, the lengths of the sections showing red, yellow, and green information in the round i before traveler k makes his/her decision are $L_{r,j,i,k}$, $L_{y,j,i,k}$, and $L_{g,j,i,k}$, respectively.

The minimum travel time of the route j in round i for traveler k is $T_{d,j,i,k} = (L_{r,j,i,k}/v_{ru}) + (L_{y,j,i,k}/v_{yu}) + (L_{g,j,i,k}/v_{gu})$. The maximum travel time of the route j in round i for traveler k is $T_{u,j,i,k} = (L_{r,j,i,k}/v_{rd}) + (L_{y,j,i,k}/v_{yd}) + (L_{g,j,i,k}/v_{gd})$. The travel time $t_{2,i,k,j}$ of route j perceived by traveler k at the i^{th} round can be randomly selected during $[T_{d,j,i,k}, T_{u,j,i,k}]$, of which probability is $f(t_{2,i,k,j}) = 1/(T_{u,j,i,k} - T_{d,j,i,k})$ and cumulative distribution function is $F(t_{2,i,k,j}) = (t_j - T_{d,j,i,k})/(T_{u,j,i,k} - T_{d,j,i,k})$.

4.3.2. Utility Function Establishment. By the analysis of travel time, it can be seen that the perceived travel time of route j is $t_{i,k,j}$ when traveler k makes his/her choice at round I and its probability density function and distribution function are $f(t_{2,i,k,j})$ and $F(t_{2,i,k,j})$, respectively. The utility of route j can be expressed as

$$U_{i,k,j} = \sum \left(v^{+}(t) \cdot \pi^{+}(p)\right) + \sum \left(v^{-}(t) \cdot \pi^{-}(p)\right)$$
$$= \int_{-\infty}^{\widetilde{t}_{i-1,j}} -\frac{d\pi\left(1 - F\left(t_{2,i,k,j}\right)\right)}{dt_{2,i,k,j}} v^{+}\left(t_{2,i,k,j}\right) dt_{2,i,k,j}$$
$$+ \int_{\widetilde{t}_{i-1,j}}^{\infty} \frac{d\pi\left(F\left(t_{2,i,k,j}\right)\right)}{dt_{2,i,k,j}} v^{-}\left(t_{2,i,k,j}\right) dt_{2,i,k,j}. \quad (16)$$

4.4. Real-Time Travel Time Information (Scenario 4). Real-time travel time is published before each traveler makes a choice. In the i^{th} round, when the k^{th} traveler makes a choice, $t_{3,i,k,j}$ is the travel time of route j accessible to the traveler, which can be obtained from the platform record.

When traveler k makes his/her choice at round i, travel time of route j is $t_{3,i,k,j}$, which would be released by the system. If $t_{3,k,i,j} \leq \widetilde{t}_{i-1,j}$, the probability obtaining positive utility is $p = 1$; that is, $\pi^{+}(p) = 1$; else, the probability obtaining negative utility is $p = 1$; that is, $\pi^{-}(p) = 1$. The total utility of route j is expressed as

$$U_{i,k,j} = \sum\left(v^{+}(t) \cdot \pi^{+}(p)\right) + \sum\left(v^{-}(t) \cdot \pi^{-}(p)\right)$$
$$= \sum v^{+}(t) + \sum v^{-}(t)$$
$$= \begin{cases} \left(\widetilde{t}_{i-1,j} - t_{3,i,k,j}\right)^{\alpha}, & t_{3,i,k,j} \leq \widetilde{t}_{i-1,j}, \\ -\lambda\left(t_{3,i,k,j} - \widetilde{t}_{i-1,j}\right)^{\beta}, & t_{3,i,k,j} > \widetilde{t}_{i-1,j}. \end{cases} \quad (17)$$

5. Results and Discussion

5.1. Methods of Parameters Evaluation. Methods of Sum-Square Error (SEE) are used to estimate the parameters of CPT:

$$\Pr\left(U_{i,k,j} > U_{i,k,j'}\right) = \frac{1}{1 + \exp\left(U_{i,k,j} - U_{i,k,j\prime}\right)},$$
$$\mathrm{SSE}(\alpha, \beta, \lambda, \gamma, \delta) = \sum_{i=1}^{M} \sum_{k=1}^{N} \left(r_{i,j,k} - \Pr\left(U_{i,k,j} > U_{i,k,j\prime}\right)\right)^{2},$$
$$(j = 1, \ldots, 6), \quad (18)$$

where $\Pr(U_{i,k,j} > U_{i,k,j'})$ is the probability that the prospect value of route j is greater than that of route j' for traveler k and $r_{i,j,k}$ is the actual probability for traveler k to choose route j at round i. If the difference between the probability of prospect value and the actual probability for all the travelers is closer to 0, then the parameters calibration is more accurate. The goal of the parameter estimation is minimizing the SSE.

Levenberg-Marquardt method is used to estimate the parameters. Parameters estimation step can be described as follows. Assume that the actual choosing probability $r_{i,j,k}$ is expressed as matrix R.

Step 1. Give initial value of all the parameters, which can be recorded as vector X_0 and control constant vector E. The initial value of E is $E_0 = \|R - \mathrm{SSS}(P_0)\|$. Other control parameters can be given as $k = 0$, $\lambda_0 = 10^3$, $v = 10$ (or other values larger than 1).

Step 2. Calculate the Jacobian matrix J_k. Construct incremental equation $\overline{N}_k \cdot G_k = J_k^T \cdot E_k$, where $\overline{N}_k = J_k^T \cdot J_k + \lambda_k \cdot I$ and I is unit matrix.

Step 3. Obtain the vector G_k through solving the incremental equation.

(1) If $\|R - \mathrm{SSE}(X_0 + G_k)\| < E_k$, then $X_{k+1} = X_0 + G_k$. If $\|G_k\| < E$, stop iteration and output the results; else, $\lambda_{k+1} = \lambda_k / v$ and return to Step 2.

(2) If $\|R - \mathrm{SSE}(X_0 + G_k)\| \geq E_k$, then $\lambda_{k+1} = v \cdot \lambda_k$ and resolving the incremental equation to obtain G_k, return to Step 1.

For the experiment of the article, $M = 5$ and $N = 216$.

5.2. Results of Parameters Evaluation. Consulting the methods and hypothesis of other researchers, we assume that $\alpha = \beta$ and $\gamma = \delta$ with the purpose of simplifying the calculation, which is congruent with the original hypothesis of Kahneman and Tversky.

The estimated results of three parameters are shown in Table 4.

For all scenarios, $\alpha(\beta) < 1$, $\gamma(\delta) < 1$, and most $\lambda > 1$. It can be seen that $\alpha(\beta)$ under which travel time information is available (Scenario 2 and Scenario 4) is always larger than that under descriptive information (Scenario 1 and Scenario 3). This could be expounded as that the value function is steeper in the case of travel time information releasing than in other cases. In other words, travelers' sensitivity to profit and loss declines faster. In addition, the value of $\alpha(\beta)$ under real-time travel information is larger than that under the historical travel information situation, which indicates that when the real-time travel time is learned, travelers are more adventurous when facing a single risk.

Under the situation of real-time travel time information ($\lambda < 1$), traveler's subjective utility is smoother in loss domain than in the profit domain, which indicates that travelers hardly show the characteristic of loss avoidance.

Under the situation of the uncertain information such as historical or descriptive information, travelers may underestimate the probability, which is concluded from the fact that the value of $\gamma(\delta)$ in Scenario 1 and Scenario 2 is less than that in other scenarios.

6. Discussion

Results of some typical studies are shown in Table 5.

The values of γ and δ are basically consistent with each other. $\gamma(\delta)$ in Scenario 1 and Scenario 2 (which release descriptive information) is larger than that in Table 2. The phenomenon indicates that travelers are more sensitive to losses and gains in the face of uncertain information.

The values of λ, α, and β in this paper differ greatly from those of other researchers' study.

Table 4: Estimation results.

Scenarios	$\alpha(\beta)$	λ	$\gamma(\delta)$
Scenario 1 (historical descriptive information)	0.48	1.32	0.63
Scenario 2 (historical travel time information)	0.63	1.21	0.71
Scenario 3 (real-time descriptive information)	0.68	1.19	0.85
Scenario 4 (real-time travel time information)	0.74	0.78	—

Table 5: Results of some other typical studies.

Researchers	α	β	λ	γ	δ
Kahneman/Tversky	0.88	$\beta = \alpha = 0.88$	2.25	0.61	$\delta = \gamma = 0.61$
Xu	0.37	0.59	1.51	—	—
Wu/Gonzalez	0.52	$\beta = \alpha = 0.52$	—	0.74	$\delta = \gamma = 0.74$
Liu	0.25–0.72	$\beta = \alpha$	0.69–1.3	0.68–0.74	$\delta = \gamma$

Comparing the current study achievement with the results in this article, it is clear that travelers are more prone to pursue risk (i.e., larger α and β) when real-time information is published. Travelers have limited ability to perceive subjective probability (minimum value of $\gamma(\delta)$) under the context of historical descriptive information. In the case conducted in the article, smaller λ means that travelers are less inclined to avoid loss. It is accounted from the fact that there is no incentive mechanism established for participants in the experiment in this paper; travelers will not be confronted with real loss. All travelers completed the experiments due to their professionalism.

7. Conclusions

In this paper, an experiment platform is constructed and four types of information about travel are released to four groups severally. Next, we propose travel time calculations method under the circumstance of descriptive information and historical information. Then, CPT model is established based on sequential route choice behavior and the parameters are calibrated. It can be concluded that decision-makers exhibit different behavioral characteristics when faced with various decision-making scenarios, as well as facing route choice. Route selection behaviors tend to be more diversified and the attitude about risk of decision-makers mainly depends on the experiment methods and the scheme provided.

It is convinced that travelers embody differentiated propensity of risk pursuit and risk avoidance. Specifically, compared with descriptive information, travelers are more inclined to pursue risks in the face of travel time information and they are more inclined to pursue risks in the face of real-time information compared with historical information. Meanwhile, when real-time travel time information is accessible, travelers hardly express the characteristic of loss avoidance. The behaviors of travelers have few such feature as risk aversion when real-time travel time information is accessible.

The five parameters indicate the degree of travelers' bounded rationality. Calibration of parameters further consummates the CPT theory and the achievement can be directly applied to traffic guidance. Travelers' route choice can be forecasted based on CPT theory under different guidance mechanism, which could supply more accurate traffic information for travelers and allocate traffic resources reasonably.

Nevertheless, only two routes are involved in the experiment and route choice behavior under complicated network has not been thoroughly revealed. More effort is supposed to be devoted into actual daily travel behavior.

Data Availability

The supplementary material data used to support the findings of this study are included within the supplementary information file.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

The supplementary material comprises the experimental data of Scenario 3 and Scenario 4, which release the travel time information. The data contains the travel time of each section and each participant's route choice result at every round. Parameters of CPT model are calibrated based on the choice results of all the four scenarios. (*Supplementary Materials*)

References

[1] Y. Sheffi, *Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods*, Prentice-Hall Englewood Cliffs, New York, NY, USA, 1984.

[2] H. A. Simon, *Models of Man: Social and Rational; Mathematical Essays on Rational Human Behavior in a Social Setting*, Wiley, Hoboken, NJ, USA, 1957.

[3] D. Kahneman and A. Tversky, "Prospect theory: an analysis of decision under risk," *Econometrica*, vol. 47, no. 2, pp. 263–291, 1979.

[4] A. Tversky and D. Kahneman, "Advances in prospect theory: cumulative representation of uncertainty," *Journal of Risk and Uncertainty*, vol. 5, no. 4, pp. 297–323, 1992.

[5] G. Song, F. Emma, and B.-A. Moshe, "Adaptive route choices in risky traffic networks: a prospect theory approach," *Transportation Research Part C: Emerging Technologies*, vol. 18, no. 5, pp. 727–740, 2010.

[6] G. Wang, S. Ma, and N. Jia, "A combined framework for modeling the evolution of traveler route choice under risk," *Transportation Research Part C: Emerging Technologies*, vol. 35, no. 11, pp. 156–179, 2013.

[7] W. Zhang, Z. B. He, Z. He, W. Guan, and G. Qi, "Day-to-day rerouting modeling and analysis with absolute and relative bounded rationalities," *Transportmetrica A: Transport Science*, vol. 14, no. 3, pp. 256–273, 2018.

[8] Y. Y. Liu, W. M. Liu, and J. W. Wu, "Route choice model of traveler based on cumulative prospect theory," *Journal of South China University of Technology (Natural Science Edition)*, vol. 38, no. 7, pp. 84–89, 2010.

[9] L. Zhou, S. Zhong, S. Ma, and N. Jia, "Prospect theory based estimation of drivers' risk attitudes in route choice behaviors," *Accident Analysis & Prevention*, vol. 73, pp. 1–11, 2014.

[10] X. Di and H. X. Liu, "Boundedly rational route choice behavior: a review of models and methodologies," *Transportation Research Part B: Methodological*, vol. 85, pp. 142–179, 2016.

[11] S. X. Liu, W. S. Chen, and H. Yan, "Network traffic flow evolution considering departure time choice based on bounded rationality," *Journal of Transportation Systems Engineering and Information Technology*, vol. 17, no. 3, pp. 127–135, 2017.

[12] H. Xu, H. Yang, J. Zhou, and Y. Yin, "A route choice model with context-dependent value of time," *Transportation Science*, vol. 51, no. 2, pp. 536–548, 2017.

[13] S. Jang, S. Rasouli, and H. Timmerman, "Tolerance and indifference bands in regret–rejoice choice models: extension to market segmentation in the context of mode choice behavior," *Transportation Research Record*, vol. 2672, no. 47, pp. 23–34, 2018.

[14] C. Sun, L. Cheng, and J. Ma, "Travel time reliability with boundedly rational travelers," *Transportmetrica A: Transport Science*, vol. 14, no. 3, pp. 210–229, 2018.

[15] T. Li, H. Z. Guan, and K. K. Liang, "Day-to-day dynamical evolution of network traffic flow under bounded rational view," *Acta Physica Sinica*, vol. 65, no. 15, pp. 11–21, 2016.

[16] X. Di, H. X. Liu, X. X. Ban, and J. W. Yu, "Submission to the DTA 2012 special issue: on the stability of a boundedly rational day-to-day dynamic," *Networks and Spatial Economics*, vol. 15, no. 3, pp. 537–557, 2015.

[17] H. Xu, J. Zhou, and W. Xu, "A decision-making rule for modeling travelers' route choice behavior based on cumulative prospect theory," *Transportation Research Part C: Emerging Technologies*, vol. 19, no. 2, pp. 218–228, 2011.

[18] S. X. Liu, L. D. Guo, and W. S. Chen, "Two reference points' route choice model and its empirical study," *Journal of Transportation Systems Engineering and Information Technology*, vol. 17, no. 6, pp. 108–114, 2017.

[19] T. Schwanen and D. Ettema, "Coping with unreliable transportation when collecting children: examining parents' behavior with cumulative prospect theory," *Transportation Research Part A: Policy and Practice*, vol. 43, no. 5, pp. 511–525, 2009.

[20] C. Zhang, T.-L. Liu, H.-J. Huang, and J. Chen, "A cumulative prospect theory approach to commuters' day-to-day route-choice modeling with friends' travel information," *Transportation Research Part C: Emerging Technologies*, vol. 86, pp. 527–548, 2018.

[21] J. Y. J. Chow, G. Lee, and I. Yang, "Genetic algorithm to estimate cumulative prospect theory parameters for selection of high-occupancy-vehicle lane," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2157, no. 1, pp. 71–77, 2010.

[22] G. Gurevich, D. Kliger, and O. Levy, "Decision-making under uncertainty—a field study of cumulative prospect theory," *Journal of Banking & Finance*, vol. 33, no. 7, pp. 1221–1229, 2009.

[23] H. Bleichrodt and J. L. Pinto, "A parameter-free elicitation of the probability weighting function in medical decision analysis," *Management Science*, vol. 46, no. 11, pp. 1485–1496, 2000.

[24] M. Abdellaoui, "Parameter-free elicitation of utility and probability weighting functions," *Management Science*, vol. 46, no. 11, pp. 1497–1512, 2000.

[25] O. M. Ryan and H. W. B. Robert, "Hierarchical maximum likelihood parameter estimation for cumulative prospect theory: improving the reliability of individual risk parameter estimates," *Management Science*, vol. 64, no. 1, pp. 308–326, 2018.

[26] J. M. Zeng, "An experimental test on cumulative prospect theory," *Journal of Jinan University*, vol. 28, no. 1, pp. 44–47, 2007.

[27] G. Wu and R. Gonzalez, "Curvature of the probability weighting function," *Management Science*, vol. 42, no. 12, pp. 1676–1690, 1996.

[28] D. Prelec, "The probability weighting function," *Econometrica*, vol. 66, no. 3, pp. 497–527, 1998.

[29] M. O. Rieger, M. Wang, and T. Hens, "Estimating cumulative prospect theory parameters from an international survey," *Theory and Decision*, vol. 82, no. 4, pp. 567–596, 2017.