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The Impacts of Low-Carbon Incentives and Carbon-Reduction Awareness on Airport Ground Access Mode Choice under Travel Time Uncertainty: A Hybrid CPT-MNL Model

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Abstract: Developing strategies to incentivize travelers towards adopting sustainable mobility options is one of the effective approaches to mitigate carbon emissions. Using Xi'an Xianyang International Airport as a case study, this study aims to explore the effects of low-carbon incentives and carbon-reduction awareness on airport ground access mode choices. In addition, to account for the complex road environment, an innovative stated preference choice experiment was designed, integrating the factor of travel time uncertainty. Then, a hybrid cumulative prospect theory–Multinomial Logit (CPT-MNL) model was also developed. The estimated results revealed that travelers increasingly prioritize emissions reduction and consciously prefer sustainable mobility options to reach the airport. Furthermore, the potential of low-carbon incentives to encourage public transport usage over private vehicles has been highlighted. Notably, travel time uncertainty had a significant impact on the choice of private cars. When the travel time to the airport is uncertain, travelers exhibit a greater inclination towards selecting public transport. The findings of this study offer nuanced insights for transportation authorities, aiding them in fostering the adoption of sustainable mobility options and achieving carbon reduction objectives.

Keywords: mode choice behavior; CPT-MNL model; stated preference choice experiment; low-carbon incentives; carbon-reduction awareness; travel time uncertainty

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1. Introduction

In recent years, the global community has confronted escalating challenges related to climate change and environmental pollution issues. The extensive literature indicates that vehicle emissions have emerged as a leading contributor to air pollution in transportation [1]. For instance, in Beijing, China, approximately 31% of air pollution is attributed to vehicle exhaust emissions [2]. In response to these pressing concerns, governments and societies have intensified their focus on implementing and encouraging sustainable travel options as a means to mitigate the adverse effects of traffic-related pollution on climate change and achieve sustainable development [3]. However, it is crucial to highlight that reducing traffic carbon emissions requires not only innovations in vehicle-related technologies but also sustaining travel behaviors of people's daily travels [4]. In this context, there is growing interest between both researchers and governments exploring strategies and policies to incentivize and encourage individuals to travel with sustainable modes.

Factors influencing transport mode choice behavior and the adoption of sustainable transport choices have been extensively explored in the literature [5–12]. Among these factors, the environmentally friendly attitude of travelers [13,14] and the government intervention policy [15,16] have received particular attention.

In the literature, the employment of incentive policies as a bonus to induce behavioral shifts and promote sustainable mobility has gained increasing attention and has been extensively investigated [17–19]. Broadly conceptualized, an incentive can be characterized as a policy measure that allocates rewards to stimulate specific behaviors in individuals. Moreover, incentives typically incur substantial costs and are administered by governmental bodies or authoritative institutions. Consequently, it becomes imperative to examine whether their impact is sufficiently affirmative to warrant their implementation [20,21]. In the context of the shared economy, incentives have demonstrated their efficacy in increasing service appeal [22]. In the field of transportation, previous studies have also demonstrated the positive impact of monetary incentives on the adoption of shared electric vehicles [23,24]. As a manifestation of environmental policy, the concept of low-carbon incentives has emerged in recent years, drawing substantial interest from both governments and researchers [25–31]. Nevertheless, these studies have mainly focused on the influence of incentives on routine travel patterns, while the potential effects on occasional travel, such as trips to airport as examined in this study, remain unclear. Therefore, this attribute is included in this study to present its potential impact on airport ground access mode choice behavior.

In addition, with the rapid expansion of urban areas, especially in developing countries, the impact of travel time uncertainty on travelers' choice decisions on routes and modes has become increasingly significant [32–34]. For instance, based on the prospect theory, Zhou et al. [32] examined the route choice behavior of travelers in the presence of travel time uncertainty. Their findings revealed that most travelers tend to avoid routes characterized by uncertain travel time. Elevated variability in travel time could extend the duration of travel mode utilization, leading to increased associated costs. Therefore, previous studies have also provided insights into the examination of the influence of travel time uncertainty on mode choice decisions [35–38]. Based on a multiple indicators and multiple causes (MIMIC) model, Tam et al. [38] quantified the effects of safety margin allowance, travel time reliability, and perceived service quality on the ground access mode choice behavior to Hong Kong International Airport. The findings of their study provide further evidence that travel time reliability is an important factor influencing airport ground access mode choices. Therefore, based on the literature mentioned above, it could be reached that travel time uncertainty is a crucial factor that should not be overlooked when studying the mode choice behaviors. Nevertheless, it is challenging to accurately represent the uncertain travel times [37]. In the literature, various methodologies have emerged to depict travel time uncertainty, including employing a range of probable travel times [39] and establishing an average travel time with equitably probable arrival scenarios [40]. Differing from existing approaches in the literature, this study introduces an innovative method to illustrate travel time uncertainty, which will be elaborated upon in later sections.

As an important component of urban transport systems, airports play a vital role in meeting the demands for interregional and international traveling. However, with the increase in airport passenger flows, the selection of efficient, convenient, and sustainable options for airport ground access has become a hot topic. Numerous studies have been dedicated to investigating the factors that may affect the mode choice behaviors when commuting to airports [6–8,41–43]. For instance, taking into account variables such as attitudes towards car usage, flight information, travel preferences, and social-demographic factors, Akar [41] examined the preferences of travelers in relation to the use of sustainable transport options when commuting to the Port Columbus International Airport. The findings revealed that business travelers, individuals who travel alone, and those who voluntarily reduce their private car usage are more inclined to use sustainable options for their airport commute.

Based on the data provided by the Airport authority for the year 2019, nearly 60% of the trips to Xi'an Xianyang International Airport (ZLXY) were made using non-public transport modes, mirroring a comparable scenario observed at Eindhoven Airport in the

Netherlands [44]. Undoubtedly, this situation poses significant challenges for the airport to achieve carbon-neutrality. Therefore, it is of utmost importance to explore strategies that can effectively promote sustainable transport options to travelers, taking into account the implementation of carbon-reduction policies (e.g., low-carbon incentives).

Despite extensive efforts, the current exploration into the effects of low-carbon incentives, carbon-reduction awareness, and travel time uncertainty on airport ground access mode choice behavior remains insufficient. First, there is a notable dearth in the examination of the impacts of monetary incentives on travel mode choice behavior. In the literature, monetary incentives are predominantly investigated to assess their potential in encouraging travelers to adopt newly introduced travel concepts, neglecting their potential as a marketing strategy to increase the mode share of existing travel options. Investigating the influence of low-carbon incentives on the adoption of sustainable choices, as a form of environmental policy, presents an intriguing avenue for research. Second, existing studies have largely incorporated carbon-reduction awareness as a latent variable in the model by employing a series of attitude indicators. It is conceivable that different combinations of attitude indicators may exert distinct effects on choice behavior [13,14]. Thus, a preferable approach could involve employing a single attribute as a proxy to represent carbon-reduction awareness. Third, while many studies have concentrated on elucidating the influence of travel time uncertainty on route choice or classical travel mode choice, the representation of travel time uncertainty often varies across these studies. Moreover, the impact of travel time uncertainty might exhibit saturation or even contradictory outcomes in the context of airport ground access mode choice due to the time pressure faced by travelers to ensure timely arrival at the airport. As such, it is necessary to examine the effects of travel time uncertainty on airport ground access mode choices.

To fill the research gaps that were identified, this study carried out a stated choice experiment with a specific focus on the ZLXY. The selection of this experimental method was prompted by the fact that low-carbon incentives had not been practically implemented in real-life scenarios. Relying on these hypothetical choice situations, this study seeks to address the following research questions: (1) How does travel behavior transform with the implementation of low-carbon incentives for sustainable travel modes? (2) To what extent does travel time uncertainty influence airport ground access mode choices? (3) Are there discernible variations in the selection of sustainable travel modes across diverse population segments?

The remainder of this study is structured as follows. Section 2 presents the survey and experiment design of this paper. Section 3 elaborates the data collection. Then, the hybrid CPT-MNL model is developed in Section 4. Section 5 analyzes and discusses the results. Finally, Section 6 concludes this paper reporting the main findings and policy recommendations of this study.

2. Survey and Experiment Design

In this study, the research focuses on the context of Xi'an City, Shaanxi Province, China. Serving as the largest air transportation hub in the Northwest region of China, and ranking as the seventh largest airport in the country (based on the passenger ridership in 2019), Xi'an Xianyang International Airport (ZLXY) airport offers direct connectivity to 171 domestic cities. Thus, for this airport, the reduction in carbon emission holds particular significance in achieving the national climate objectives. In alignment with the national strategy, the airport is actively pursuing the goal of becoming an emission-free airport, as outlined in the special plan for the green development of civil aviation in the 14th Five-Year Plan [45]. One of the main objectives of this special plan is to stimulate and realize efficient and sustainable transport options for access to and from the airport. As of 2023, the ZLXY has also been recognized as one of the eight airports in China to receive the national "Dual Carbon Airport" designation, awarded a three-star rating by the China Civil Airports Association (CCAA) [46]. However, based on the data from 2019 provided by the authority of ZLXY, the mode shares for travels to ZLXY is dominated by private cars, accounting for 60% of the trips. To contribute to its low-carbon goals, it is crucial for the airport to take actions and propose incentive policies reducing the reliance on private cars to decrease the carbon emission of ground access travels. Therefore, this study specifically aims to investigate how the incentive policies can be effectively utilized to encourage the use of sustainable public transport modes for the ground travel of ZLXY.

To examine the effects of low-carbon incentives, carbon-reduction awareness, and travel time uncertainty on airport ground access mode choice behavior, a web-based questionnaire survey using the platform, *Limesurvey*, was implemented. A total of three parts are designed in the survey. The first part includes information of the respondents' sociodemographic characteristics and historical travel patterns to the airport (e.g., preferred advance arrival time at airport). The second part presents the stated choice experiment involving three options under different policy scenarios. Finally, a set of attitude-related questions concerning driving enjoyment, facility convenience, and environmentally friendly viewpoint are investigated.

2.1. Attribute and Attribute Levels

The application of the stated choice experiment to unveil latent preferences and trade-offs among travelers concerning travel modes has a firmly established history in the field of transportation [6,7,15,16]. To ensure the realism and alignment of the choice tasks with authentic experiences, it is important to carefully determine the choice set, attributes, and attribute levels in the stated choice experiment. By assessing the existing ground access modes to Xi'an Xianyang International Airport, this study identifies three options, namely private cars (including self-driving, kiss and ride), taxis (including ride-hailing services), and public transport (including regular, customized shuttle buses, and metro), as the choice set for the experiment.

The existing literature highlights the significance of travel contexts in the decision-making of travel mode choices [47]. In this study, context variables were defined in terms of travel distance and the number of carry-on luggage. However, to precisely assess the influence of travel time uncertainty on choice decisions, this survey specifically focuses on a fixed travel distance of 30 km covering the majority of the service area of the airport. In addition, considering real situations when commuting to the airport, three scenarios were constructed for the number of carry-on luggage: 0, 1, and 2.

Furthermore, five attributes were considered for private cars in this study, namely average travel time, possible travel time advance or delay, probability of advance or delay, travel cost, and parking cost. Based on the average travel time of a 30 km distance in Xi'an, the average travel time for private cars in this study was set as 50 min. To account for incidents or unexpected events on the road, the factor of travel time advances or delays was also included in this study and was classified into three levels: (−2 min, 10 min, 22 min), (−6 min, +5 min, +16 min), and (−10 min, 0 min, +10 min). Meanwhile, the associated probabilities for these advances/delays are also provided and varied in terms of three levels: (5%, 40%, 55%), (10%, 60%, 30%), and (25%, 30%, 45%). Additionally, based on the oil price and the average fuel consumption of 100 km of fuel vehicles in Xi'an, travel cost for a 30 km distance by private car was set at three levels: 30 CNY, 40 CNY, and 50 CNY, while parking costs for private cars near the airport were proposed at three levels: 0 CNY/h, 6 CNY/h, and 12 CNY/h.

Given the similarities between taxis and private cars in offering door-to-door services, this study sets the attributes and levels of average travel time, possible travel time advance or delay, and probability of advance or delay for taxis to be the same as those for private cars. However, due to the increased operation costs and convenience associated with taxi services, the travel costs are generally higher than those of private cars. Therefore, in this study, the travel cost for taxis varies in three levels: 80 CNY, 95 CNY, and 110 CNY. In addition, compared to private cars, taxis have the potential to reduce vehicle occupancy and deadhead mileage, contributing to carbon emissions reductions. To examine the impact of carbon-reduction awareness of travelers on mode choice decisions, this study specifically included the factor of carbon-reduction percentage. Owing to data constraints regarding taxis, deliberations were held with transportation authorities and policymakers to assess the practicality of assigning carbon-reduction percentage values. Their recommendation was to designate the value as −30%. Adhering to this reference point, the carbon-reduction percentages for taxis were set at three levels: −0%, −20%, and −40%. These levels were introduced to accommodate potential discrepancies arising from distinct vehicle categories.

Compared to private cars and taxis, transit lines may exhibit lower alignment with individual travel routes, resulting in increased travel time and additional transfers for passengers. In light of this, the average travel time for public transport was set at 80 min, which is higher than that of private cars and taxis. The attribute of the number of transfers varied across three levels: 0, 1, and 2. Meanwhile, due to its fixed routes and regular service frequency, public transport demonstrates lower potential for travel time delays in contrast to private cars and taxis. For the attributes of travel time advances or delays, this study set the levels as (−3 min, +5 min, +13 min); (−8 min, 0 min, +8 min); and (−13 min, −5 min, +2 min), while the associated probabilities varied as (10%, 70%, 20%); (10%, 75%, 15%); and (10%, 80%, 10%). Moreover, acknowledging the nonprofit nature of public transport, the travel cost was accordingly reduced in this study. Finally, recognizing the greater role of public transport in energy conservation and emissions reduction relative to taxis, the carbon-reduction percentage for public transport were set at three levels of −50%, −70%, and −90% based on the survey data provided by Beijing Green Exchange [48].

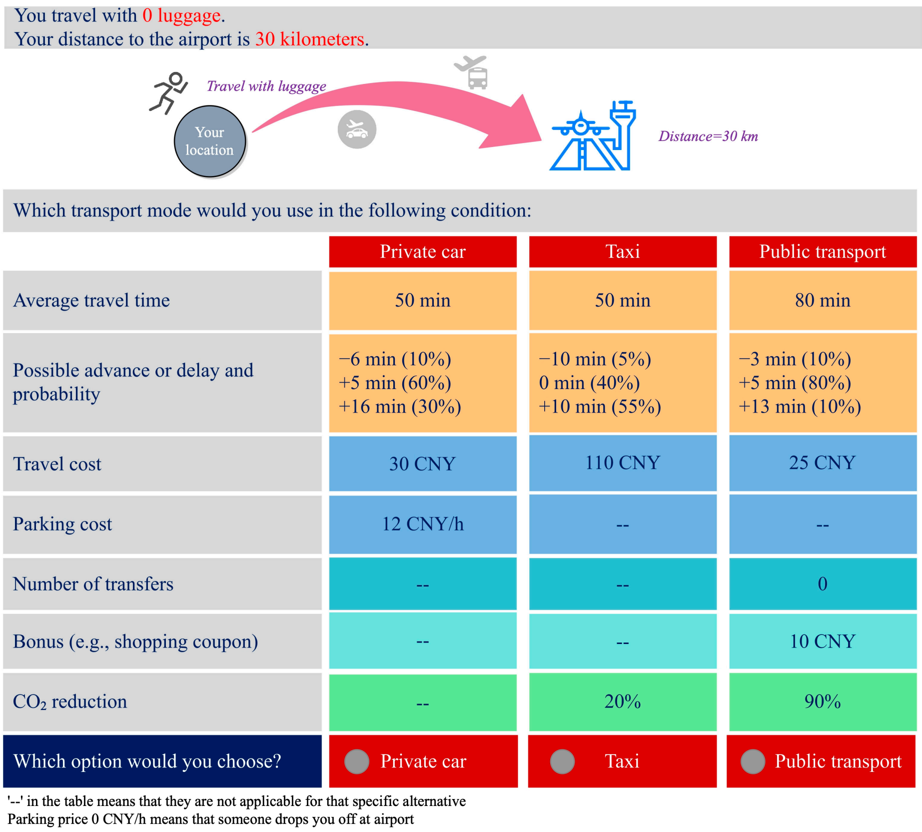
It is important to point out that the implementation of low-carbon incentives is one of the strategies usually adopted by the government to stimulate a shift in transport modes, reduce private car usage, and achieve carbon emissions reduction goals. Taking into account the average per capita income of residents in Xi'an and the average consumption level at Xi'an Xianyang International Airport, this study proposed the allocation of low-carbon incentives (e.g., retail vouchers) specifically for public transport. The levels of this attribute were established through consultations with experts from Xi'an Airport. In particular, the incentives in the experiment were varied across three levels: 0 CNY, 5 CNY, and 10 CNY. During the experiment, respondents were informed that they could receive a retail voucher upon utilizing public transport to reach the airport, which could subsequently be redeemed at any of the airport's stores within a 30-day period. The summary of the attributes and their levels in the choice experiment is presented in Table 1.

Table 1. Attributes and levels in the choice experiment.

Categories	**Attributes**	**Levels**
Contexts	Travel distance (km)	fixed (30 km)
	Carry-on baggage number	0; 1; 2
Private Car (including self-driving, kiss and ride)	Average travel time (min)	fixed (50)
	Possible advance or delay (min)	(−2, 10, 22); (−6, +5, +16); (−10, 0, +10)
	Probability of advance or delay	(5%, 40%, 55%); (10%, 60%, 30%); (25%, 30%, 45%)
	Travel cost (CNY)	30; 40; 50
	Parking cost (CNY/h)	0; 6; 12
Taxi (including ride-hailing service)	Average Travel time (min)	fixed (50)
	Possible advance or delay (min)	(−2, 10, 22); (−6, +5, +16); (10, 0, 10)
	Probability of advance or delay	(5%, 40%, 55%); (10%, 60%, 30%); (25%, 30%, 45%)
	Travel cost (CNY)	80; 95; 110
	CO_2 reduction	0%; −20%; −40%
Public transport (including regular, customized shuttle buses, and metro)	Average Travel time (min)	fixed (80)
	Possible advance or delay (min)	(−3, +5, +13); (−8, 0, +8); (−13, −5, +2)
	Probability of advance or delay	(10%, 70%, 20%); (10%, 75%, 15%); (10%, 80%, 10%)
	Travel cost (CNY)	20; 25; 30
	Number of transfers	0; 1; 2
	Incentive (CNY)	0; 5; 10
	CO_2 reduction	−50%; −70%; −90%

2.2. Experiment Design

Due to the large number of attributes and their levels involved in the experiment, an orthogonal fractional factorial design approach using SAS 9.4 software was adopted in this study to retain a subset of representative profiles. Consequently, 64 profiles, characterized by favorable orthogonality and a balance in attribute levels, were reserved in the experiment design. Moreover, to further alleviate the survey burden, the 64 profiles were blocked into eight blocks, each of which contained eight choice tasks. Respondents, upon agreeing to participate in the survey, were randomly assigned one block and required to make their choices for each assigned choice tasks. An example of the choice task along with the text provided to respondents in the online survey is depicted in Figure 1.



	Private car	Taxi	Public transport
Average travel time	50 min	50 min	80 min
Possible advance or delay and probability	−6 min (10%) +5 min (60%) +16 min (30%)	−10 min (5%) 0 min (40%) +10 min (55%)	−3 min (10%) +5 min (80%) +13 min (10%)
Travel cost	30 CNY	110 CNY	25 CNY
Parking cost	12 CNY/h	--	--
Number of transfers	--	--	0
Bonus (e.g., shopping coupon)	--	--	10 CNY
CO_2 reduction	--	20%	90%
Which option would you choose?	Private car	Taxi	Public transport

'--' in the table means that they are not applicable for that specific alternative
Parking price 0 CNY/h means that someone drops you off at airport

Figure 1. An example of the choice experiment.

3. Data Collection

3.1. The Procedure of Data Collection

To define the scope of this study, individuals residing in Xi'an city, including both local and floating population, were recruited. A multi-channel approach, including social media platforms, email invitations, and face-to-face interactions, was adopted to include individuals who may have limited internet access or may not be technologically proficient. In addition, to minimize potential bias in data collection, a random sampling method was employed. To be more specific, for data collection through social media, survey information was disseminated across various platforms including Weibo, WeChat, and Post Bar, thereby obtaining responses in a random manner. Regarding email invitations, the survey details were predominantly distributed among our colleagues to facilitate survey propagation. Additionally, to ensure the reliability of responses, volunteers (mostly graduate students) were also recruited to conduct face-to-face surveys using iPads at Xi'an Xianyang International Airport. Furthermore, various controls were applied to ensure the representativeness of the sample in relation to the population of Xi'an city. Specifically, the data collection procedure involved multiple waves, with each wave followed by an analysis of the sample characteristics. The invited respondents were initially informed about the research objectives and the data protection policy. They were allowed to proceed to the formal survey after agreeing to the data policy.

The data were collected from February 2020 to March 2020, a period during which China was experiencing the impact of the COVID-19 outbreak. To mitigate the influence of pandemic-related policies and impacts on the collected data, respondents were explicitly informed before the formal survey that they should not consider the effects of the COVID-19 pandemic on their travel decisions. In other words, the choices made by the respondents in this survey were based on a non-pandemic scenario. A total of 583 respondents were invited to engage in the survey, out of which 409 surveys were completed. It should be noted that a pilot survey was administered to the recruited volunteers prior to the formal data collection in this study. The feedback received from these volunteers indicated an average questionnaire completion time of 8.2 min. Considering the distribution of completion times during the formal data collection, the decision was made to exclude the last 5% of surveys. In other words, responses with completion times of less than 5 min were regarded as unreliable. Therefore, after excluding those surveys with short response times (less than 5 min) or exhibiting logical inconsistencies, 382 surveys were regarded as valid and used for the following analysis. In accordance with the literature addressing the determination of sample size requirements, the sample employed in this study was deemed acceptable [49].

3.2. Socio-Demographics of the Sample

The descriptive statistics of the socio-demographic characteristics of the sample are presented in Table 2. It is observed that males account for 44% of the total samples, while the remaining 56% are females. Regarding age distribution, approximately 28.1% of the respondents are younger than the age of 25. The majority of the respondents (69.7%) fall within the age range of 26 to 55, while those aged 56 and above constitute a relatively small share of 2%. In addition, 60.5% of the respondents have received a Bachelor's degree or higher education. In terms of income, 34.2% of the respondents' report incomes below 4000 CNY/month, whereas the remaining 65.8% have an income above 4000 CNY/month.

Table 2. The socio-demographic characteristics of the respondents.

Characteristic	Level	Percent (%)	Xi'an Census (%)
Gender	Male	44	48.83
	Female	56	51.17
Age	≤25	28.1	[0,14]: 7.33 [15–59]: 63.46 ≥60: 13.32
	[26,40]	41.3	
	[41,55]	28.4	
	≥56	2.2	
Education level	Bachelor's degree of above	60.5	18.4
	Others	39.5	81.6
Income	<4000	34.2	-
	[4000, 8000)	26.2	-
	[8000, 10,000)	11.5	-
	≥10,000	28.1	-
Driving license	Yes	83.1	-
	No	16.9	-
Transport mode for the last trip to the airport	Public transport	39.6	-
	Taxi	23.7	-
	Private car	16.4	-
	Kiss and ride	13.7	-
	Others	6.6	-

To assess the representativeness of the sample for studying airport ground access mode choice behaviors in Xi'an, a comparison is made between the demographic attributes of the sample and the seventh population census of Shaanxi Province. The results indicate a relatively balanced representation in terms of gender, but a lower representation of the elderly population and individuals with lower levels of education. However, it is important to note that this study specifically focuses on air travelers, and previous studies suggest that individuals with higher incomes and higher levels of education tend to prefer air transport for long-distance travel [50]. Therefore, despite the slight under-representation in certain demographic groups, this sample is considered feasible in representing airport travelers in Xi'an city and can be used to study their airport ground access mode choice behaviors.

Finally, information regarding the mode choices of the respondents for their last arrivals at the airport was also collected in this survey. The results show that 30.1% of the respondents selected private cars (including kiss and ride) as their mode to the airport. This finding clearly illustrates that the respondents tend to select modes with convenience and efficiency when commuting to the airport.

4. Methodology

Given the dynamic and intricate nature of traffic conditions, there is a possibility of travel time delays or advancements when commuting to the airport. In addition, this attribute inherently entails uncertainty as its values cannot be predicted in advance. Hence, it is of utmost importance to develop a model that can effectively incorporate risk assessment and decision-making under uncertainty. The existing literature suggests that expected utility theory, regret theory, and (cumulative) prospect theory are all effective theories for modeling decision-making under uncertain contexts [37]. However, compared to the rational behavior assumption in the expected utility theory, (cumulative) prospect theory offers a more reasonable explanation for choice behavior in uncertain environments. Therefore, this study aims to investigate the ground access mode choice behavior under travel time uncertainty by integrating the concepts of cumulative prospect theory into the discrete choice model.

4.1. Uncertain Attributes under the CPT Model

In this study, the attributes influencing airport ground access mode choice decisions could be categorized into two types: deterministic attributes and uncertain attributes. To model the uncertain attribute considered in this paper, the concept of cumulative prospect theory (CPT) is introduced. The concept provides a reasonable explanation for decision-making behavior under uncertainty. In the CPT model, the relative value, $x_{nisk}^{un}(k \in K)$, of the uncertain attribute (i.e., possible travel time advances/delays) for alternative i chosen by individual n in choice situation s can be evaluated with respect to a reference point, which is defined as follows:

$$\Delta x_{nisk}^{un} = x_{nisk}^{un} - \tau_{nis} \quad (1)$$

where, τ_{nis} represents the reference point of individual n regarding travel time advances/delays, and Δx_{nisk}^{un} is the relative value of the travel time advances/delays. Depending on its values, Δx_{nisk}^{un} can be categorized into gains and losses. In this study, the reference point is defined as the maximum acceptable delay time stated by the respondents. Therefore, a smaller actual travel time delay represents a higher gain for the traveler ($\Delta x_{nisk}^{un} \leq 0$), whereas a larger actual travel delay leads to a greater loss ($\Delta x_{nisk}^{un} > 0$).

In the decision-making procedure, travelers have distinct attitudes towards gains and losses, even when faced with the same magnitudes [51]. The existing literature suggests that the impact of losses on decision-making is significantly higher than that of gains of equal magnitude. Therefore, taking this into account, this study adopts the segmented value function proposed by Tversky and Kahneman to transform gain and loss values [51]. The expressions are presented as follows:

$$V(\Delta x_{nisk}^{un}) = \begin{cases} \left(-\Delta x_{nisk}^{un}\right)^{\alpha}, \Delta x_{nisk}^{un} \leq 0 \\ -\lambda \cdot \left(-\Delta x_{nisk}^{un}\right)^{\beta}, \Delta x_{nisk}^{un} > 0 \end{cases} \quad (2)$$

where, $V\left(\Delta x_{nisk}^{un}\right)$ represents the perceived value associated with gains and losses. α and β, ranging from 0 to 1, are unknown parameters representing the sensitivity of the traveler to gains and losses, respectively. A larger value of α or β indicates a higher sensitivity towards travel time uncertainty. $\gamma(\gamma > 1)$ is the loss aversion coefficient, used to capture the fact that individuals tend to be more sensitive to losses.

In addition, individuals also exhibit variations in their perception of probabilities. Previous studies indicate that individuals tend to pay more attention to events with low probabilities while underestimating events with high probabilities [51]. To account for this phenomenon, a probability weighting function, which involves a nonlinear transformation of objective probabilities, is employed. By incorporating the preference-ranking-dependent weighting decision mechanism from the rank-dependent utility theory into the classical prospect theory, the rank-dependent probability weighting function which is an essential component of the CPT model is developed [52–54]. The associated mathematical expressions are shown as follows:

$$\pi^{+}_{nsic} = \omega^{+}(p^{un}_{nsic}) \quad (3)$$

$$\pi^{+}_{nsid} = \omega^{+}(p^{un}_{nsid} + \cdots + p^{un}_{nsic}) - \omega^{+}(p^{un}_{nsi,d+1} + \cdots + p^{un}_{nsic}) \quad (4)$$

$$\pi^{-}_{nsi,-q} = \omega^{-}(p^{un}_{nsi,-q}) \quad (5)$$

$$\pi^{-}_{nsid} = \omega^{-}(p^{un}_{nsi,-q} + \cdots + p^{un}_{nsid}) - \omega^{-}(p^{un}_{nsi,-q} + \cdots + p^{un}_{nsi,d-1}) \quad (6)$$

where, $\pi^{+/-}_{nisk}$ represents the non-linear transformation of the objective probabilities associated with travel time advances/delays. The subscripts c, d, q denote the numerical rankings obtained by ordering all possible values of travel time advances/delays from the worst to the best. Here, c represents the worst case value, while q represents the best case value. $\omega^{+}(\cdot)$ and $\omega^{-}(\cdot)$ are functions used to nonlinearly transform the cumulative objective probabilities. It is important to note that this function might take on different forms, and in this study, the commonly used linear-in-log-odds expression is used, which is defined as follows:

$$\omega^{+}(p^{\text{un}}_{nsik}) = \frac{(p^{un}_{nsik})^{\gamma}}{\left((p^{un}_{nsik})^{\gamma} + (1 - p^{un}_{nsik})^{\gamma}\right)^{\frac{1}{\gamma}}} \quad (7)$$

$$\omega^{-}(p^{\text{un}}_{nsik}) = \frac{(p^{\text{un}}_{nsik})^{\delta}}{\left((p^{\text{un}}_{nsik})^{\delta} + (1 - p^{un}_{nsik})^{\delta}\right)^{\frac{1}{\delta}}} \quad (8)$$

where, p^{un}_{nsik} represents the objective probability associated with the k-th possible travel time advances/delays value when individual n chooses alternative i in choice situation s. γ and δ are the parameters to be estimated. Based on the defined perceived value and the rank-dependent probability weighting function, the utility value related to uncertain attribute (i.e., travel time advances/delays) can be calculated by the following equation. In other words, the subjective value of travel time advances/delays is equivalent to the accumulation of the cumulative prospect values of all possible advance/delay times.

$$V^{un}_{nsi} = \sum_{k \in K} \pi_{nsik} \cdot V(\Delta x^{un}_{nsik}) \quad (9)$$

4.2. Hybrid CPT-MNL Model

In addition to the uncertain attribute discussed above, deterministic attributes also play a significant role in influencing the ground access mode choice behavior. Based on principles of the multinomial logit model, this study develops a hybrid CPT-MNL model that incorporates the notion of extended deterministic utility. The mathematical formulation of the utility function is presented as follows.

$$V_{nsi} = ASC_i + V^{\text{var}}_{nsi} + \beta^{un}_{n} \cdot V^{un}_{nsi} \quad (10)$$

where, V_{nsi} represents the extended deterministic utility perceived by traveler n for alternative i in choice situation s. ASC_i is the alternative-specific constant. V_{nsi}^{var} is a linear combination function (as shown in Equation (11)), formed by the context variables x_{nst}^{con}, the deterministic tributes x_{nsih}^{det}, and their corresponding parameters (β_t^{con} and β_h^{det}). β_n^{un} is the parameter associated with the variable V_{nsi}^{un}.

$$V_{nsi}^{\text{var}} = \sum_{t \in T} \beta_t^{con} \cdot x_{nst}^{con} + \sum_{h \in H} \beta_h^{\text{det}} \cdot x_{nsih}^{\text{det}} \tag{11}$$

It is worth noting that Equation (10) is a deterministic expression that ignores the unobservable utilities within the choice set. Examination of the relevant literature suggests that incorporating a random error term into the utility function is a direct and effective way to account for the influences of unobservable utilities in choice decisions [55]. Therefore, in this study, it is assumed that the random error term, ε_{nsi}, follows an independently and identically distributed extreme value Type I distribution. Then, the probability of traveler n selecting alternative i in choice situation s can be calculated as follows:

$$P_{nsi} = \frac{\exp(V_{nsi})}{\sum_{i \in I} \exp(V_{nsi})} \tag{12}$$

The log-likelihood function for Equation (13), denoted as $LL(\beta)$, can also be derived as follows:

$$LL(\beta) = \ln\left(\prod_{n \in N} \prod_{s \in S_n} \prod_{i \in I} (P_{nsi})^{y_{nsi}}\right) = \sum_{n \in N} \sum_{s \in S_n} \sum_{i \in I} y_{nsi} \cdot \ln(P_{nsi}) \tag{13}$$

where, N denotes the total number of respondents. S_n is the set of choice situations faced by respondent n. I represents the set of alternatives presented to respondent n in choice situation s. y_{nsi} is a binary variable that takes the value of 1 if respondent n selects alternative i in choice situation s, and 0 otherwise.

5. Results and Analysis

5.1. Ground Access Mode Choice Behavir under Different Number of Carry-on Luggage

The results from the choice experiment could be primarily analyzed to determine the potential mode share under different numbers of carry-on luggage. As discussed in Section 3, a total of 3056 observations (i.e., 382 surveys $\times$ 8 choice tasks) were collected. Then, based on the collected data, the general mode choice patterns observed in the sample could be depicted in Figure 2. It is evident that the number of carry-on luggage items when commuting to the airport significantly influences mode choice behavior. Specifically, when travelers do not carry any luggage, public transport is a preferred choice. However, as the number of carry-on luggage items increases, travelers gradually shift towards more convenient options such as taxis or private cars. The mode share of public transport reaches its lowest point when the number of carry-on luggage items is at its highest level. In addition, it is interesting to note that the mode share of taxis is consistently higher than that of private cars in all scenarios. This result is also in line with the common knowledge that taxis offer comparable convenience to private cars, but without the additional cost of parking fees. Consequently, taxis are perceived as a more flexible and convenient travel service for travelers commuting to the airport compared to private cars. Based on the aforementioned analyzes, it could be inferred that, for trips to the airport, greater attention should be given to the enhancement of services related to the convenience of carrying luggage. Improving the convenience of carrying, picking up, and storing luggage, as well as reducing the number of transfers, can make travelers be more inclined to use the public sustainable transit modes.

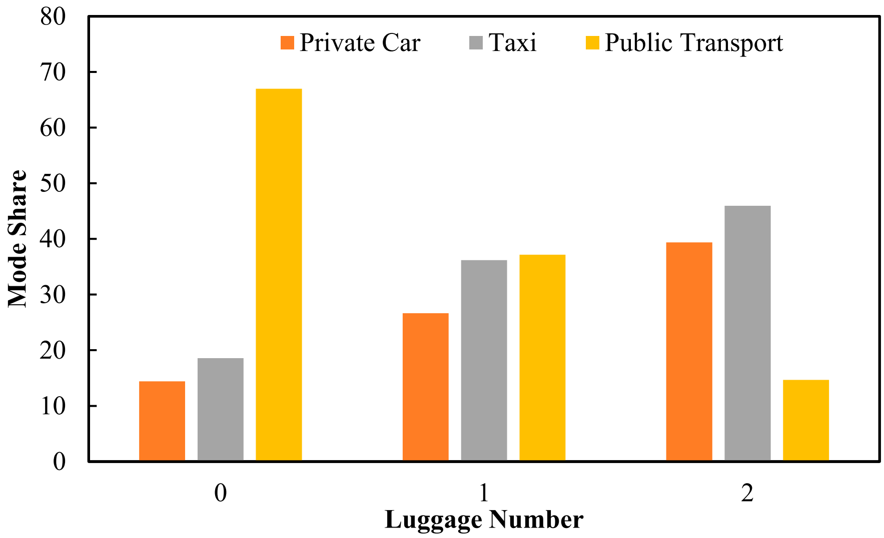


Figure 2. Choice of the sample with different luggage amount.

5.2. Estimation Results of the MNL Model Part

The hybrid CPT-MNL model presented in this paper is estimated based on Biogeme and Python self-coding. Specifically, this study introduces a hybrid estimation approach that combines the genetic algorithm (GA) and the CFSQP algorithm. In this procedure, GA is applied to estimate the parameters related to the CPT model part, whereas the CFSQP algorithm is employed for estimating the remaining parameters involved in the log-likelihood function. The estimated results of the model are summarized in Table 3. First, concerning the context variables, it is observed that the number of carry-on luggage has a significant impact on the airport ground access mode choice. As the number of carry-on luggage increases, the probability of choosing public transport for commuting to the airport decreases. The utilization of public transport exhibits its minimum share when the number of carry-on luggage reaches its maximum level. This finding aligns with conventional understanding and is in accord with the existing literature [7,56,57] which indicate that passengers are disinclined to use public transport to the airport due to challenges associated with transporting luggage.

For the socio-demographic variables, the results indicate that males are more inclined to select private cars or taxis when commuting to the airport. Meanwhile, individuals with a moderate-income level (4000–8000 CNY/month) and high-income level (>=10,000 CNY/month) are more likely to choose private cars or taxis as their preferred modes to the airport. Interestingly, a significant effect of redundant time preference for the ground access mode choice behavior is observed. Travelers who prefer to arrive at the airport 1.5 to 2 h in advance are more likely to select public transport, while those who prefer to arrive 2.5 to 3 h in advance tend to choose private cars or taxis. This finding can be attributed to the psychology of risk aversion. Travelers who choose a longer buffer time are more sensitive to travel time and thus less inclined to select public transport due to the extended travel duration. In contrast, the perception of time for travelers who choose to arrive 1.5 to 2 h in advance is not significant, and using public transport offers the advantage of cost reduction. Furthermore, the results indicate that travelers who prefer to arrive at the airport 1 to 1.5 h in advance show a higher probability of choosing private cars or taxis, potentially due to the urgency of boarding time. In comparison to public transport, private cars or taxis provide a fast and convenient transport to the airport.

Table 3. Results of the hybrid CPT-MNL model.

Attribute			**Transport Mode**	**Parameter**	***t*-Value**
Context variables	Carry-on baggage number		Public transport	−0.676 ***	−7.91
Socio-demographic variables	Gender		Private Car/Taxi	0.149 **	2.41
	Income (CNY/Month)	<4000	Private Car/Taxi	−0.271	-
		[4000–8000)	Private Car/Taxi	0.389 ***	3.54
		[8000–10,000)	Private Car/Taxi	−0.0198	−0.141
		>=10,000	Private Car/Taxi	0.00217	0.0203
	Advance arrival time	[1–1.5) h in advance	Private Car/Taxi	0.2724	-
		[1.5–2) h in advance	Private Car/Taxi	−0.821 **	−2.07
		[2–2.5) h in advance	Private Car/Taxi	0.0766	0.337
		[2.5–3) h in advance	Private Car/Taxi	0.472 ***	2.82
Alternative-specific attributes	Travel cost (CNY)		Private Car	−0.0239 ***	−2.84
			Taxi	−0.00158	−0.319
			Public transport	0.0175	1.17
	Parking cost (CNY/h)		Private Car	−0.0284 **	−2.07
	Number of transfers		Public transport	−0.0472	−0.64
	Average Travel time (min)		All modes	−0.00233	−0.0994
	Possible travel time advance or delay (min)		Private Car	−0.0481 **	−2.16
			Taxi	−0.00996	−0.628
			Public transport	−0.0125	−0.627
	Carbon-reduction		Taxi	0.188 *	−1.711
			Public transport	0.0445	−0.118
	Low-carbon incentives		Public transport	0.191 *	1.818
Alternative-specific constant			Private Car	0.264 **	2.417
Goodness-of-fit	Log-likelihood value at zero			−1347.997	
	Log-likelihood value at convergence			−1042.569	
	ρ^2			0.226	
	Adjusted ρ^2			0.211	

*** significant at 99% confidence level; ** significant at 95% confidence level; * significant at 90% confidence level.

Regarding the alternative-specific attributes, the results indicate that increases in both travel costs and parking fees would discourage travelers from using private cars. These results are in line with earlier observations reported in the existing literature [37,58]. As expected, the travel time associated with each alternative also has a significant impact on the airport ground access mode choice. It is important to note that the concept of travel time advances/delays is also introduced in this study to capture the effects of uncertainty on mode choice decisions. The results reveal that travel time advances/delays have a more significant impact on the choice of private cars. Specifically, when the travel to the airport experiences congestion, travelers are more inclined to choose public transport. Furthermore, although the effect of the number of transfers is found to be statistically insignificant in this study, the negative sign suggests that an increase in the number of transfers would decrease travelers' willingness to choose public transport. This result is consistent with findings of previous studies [59].

To investigate the effect of environmentally friendly awareness and the influence of policy incentives on the airport ground access mode choice behavior, this study incorporated the concepts of carbon-reduction awareness and low-carbon incentives as alternative-specific attributes for public transport. Examining the effects of these attributes could provide valuable theoretical support for airport operators and governmental entities in developing low-carbon support policies and effectively working towards achieving carbon neutrality targets. The estimation results demonstrate that the carbon-reduction attribute has a positive impact on the use of sustainable transport modes when commuting to the airport. Specifically, a higher carbon-reduction percentage is associated with a stronger inclination towards taxis or public transport, suggesting that individuals actively opt for sustainable modes in response to the promotion of green travel. This conclusion is also consistent with previous literature findings that demonstrate the significant influence of pro-environmental attitudes on the travel mode choice behavior [37,58]. Moreover, the estimation also reveals that higher levels of low-carbon incentives are associated with a greater propensity among travelers to choose public transport. Drawing from these findings, it can be concluded that when encouraging green travel, transportation authorities should emphasize the role of incentives and the achievements in carbon reduction. By doing so, they can guide travelers towards making mode choices that align with the objective to reduce carbon emissions [60,61].

5.3. Estimation Results of the CPT Model Part

Regarding the issue of risk perception for travelers in uncertain environments, previous studies have extensively focused on calibrating the parameters involved in the CPT model using empirical data [32,62]. Although there is currently no universally applicable form of the CPT model that fits all application scenarios, the underlying assumptions guiding individual decision making are consistent across various studies. Specifically, individuals are more sensitive to losses than gains and tend to overestimate extreme but unlikely events. In this study, five parameters, namely α, β, λ, γ, and δ, in the hybrid CPT-MNL model are used to characterize the risk attitudes of travelers in uncertain environments. Based on the maximum likelihood estimation and the Gauss–Newton iteration method, the calibrated values of these parameters are obtained as $\alpha = 0.611$, $\beta = 0.359$, $\lambda = 1.508$, $\gamma = 0.692$, and $\delta = 0.632$.

The parameters α and β are used to assess the decreasing marginal sensitivity of utilities. In this study, the values of these parameters are observed to be less than 1, indicating that travelers always hold risk-averse attitudes towards gains and risk-seeking attitudes towards losses. In addition, the relatively small values of α and β imply that travelers who commute to the airport are not inclined to make risk decisions. Specifically, when faced with potential gains of early arrival, travelers are unwilling to take risks for higher gains. Similarly, when confronted with losses, they are unwilling to stand losses to avoid risks. One potential explanation for this finding could be attributed to the current fast-paced lifestyle, where timeliness is highly valued by most travelers, rendering early arrival relatively insignificant. Therefore, they tend to select a mode that aligns closely with their expected delay time so as to meet their punctuality expectations.

The coefficient of loss aversion λ is estimated to be larger than 1, indicating that travelers are more sensitive to losses than gains. Compared to the values of loss aversion coefficients reported in the literature, the value of λ in this study is relatively large, providing further evidence of the aversion towards uncertain travel time. This finding is also consistent with the fact that travelers prioritize timely arrival at the airport to mitigate the risk of missing their flights. Based on the above parameters, the value function employed in the hybrid CPT-MNL model is shown in Figure 3. Similar to the assumptions made in previous studies, the value function obtained in this study also demonstrates a concave shape in the gain domain and a convex shape in the loss domain.

In terms of parameters in the probability weighting function, a comparison with the weighting function curves in the relevant literature reveals that the curve plotted with the calibrated parameters γ and δ in this study has a similar shape. This means that travelers tend to underestimate high probability events and overestimate low probability events [35,63]. Figure 4 illustrates that this characteristic is particularly significant in the context of travel time delays.

Based on the aforementioned analysis, it can be inferred that the estimation result of the uncertain attribute in the hybrid CPT-MNL model, as developed in this study, is deemed satisfactory. It is also worth noting that the sign of the cumulative prospect value (CPV) for travel time advances/delays consistently remains positive, implying that travelers tend to select transport modes that offer advantages in terms of timely arrival at their destinations. This result is also consistent with theoretical expectations.

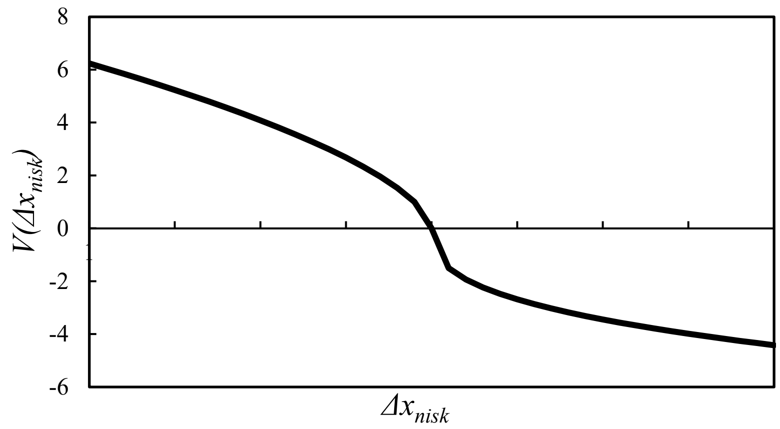


Figure 3. Hypothetical value function.

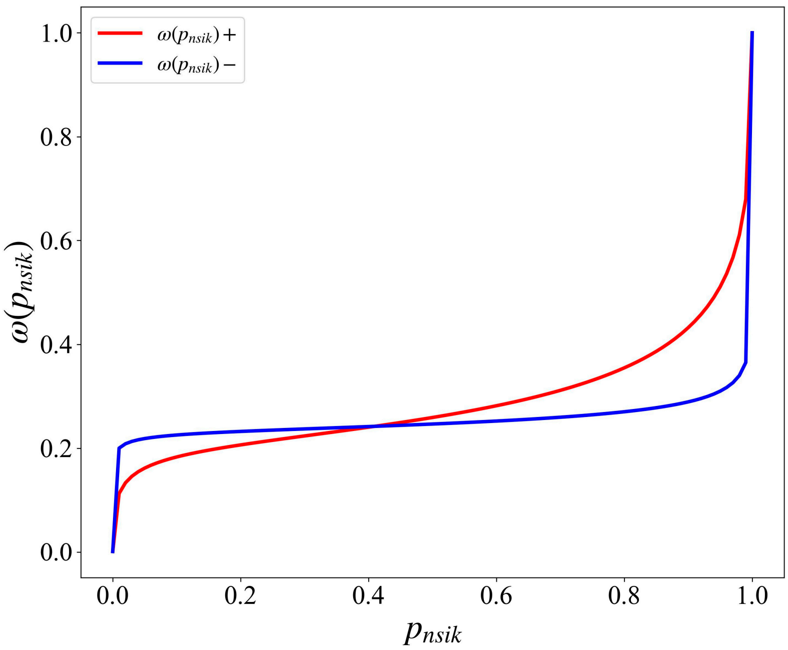


Figure 4. Hypothetical probability weighting functions for gains and losses.

6. Conclusions

Taking Xi'an Xianyang International Airport as an example, this study particularly focuses on the adoption of sustainable options in airport ground access mode choice behavior. By employing a stated preference choice experiment, this study examines the influences of low-carbon incentives and carbon-reduction awareness. In addition, the impact of travel time uncertainty on mode choice decisions is also explored in this study to understand travelers' risk aversion attitudes.

The estimated results based on the sample demonstrate that low-carbon incentives could, to a certain extent, encourage the adoption of sustainable modes in airport ground access mode choices. Specifically, the positive and statistically significant coefficient indicates that the introduction of low-carbon incentives has a positive impact on the preference of public transport among travelers, as they are motivated to take the advantage of additional discounts or incentives. Moreover, the findings suggest that heightened carbon-reduction awareness has the potential to further enhance the market share of sustainable transport modes. Nonetheless, it is important to highlight that the inherent inconvenience associated with public transport prompts travelers to opt for taxis over private cars, rather than choosing public transport. The findings of this study offer valuable insights and empirical evidence that can inform the implementation of effective carbon-reduction policies, the promotion of sustainable travel practices, and the improvement of public transport services. By investigating low-carbon incentive strategies, this study has gained a deeper understanding of travelers' preferences regarding airport ground access mode choice. Based on these findings, potential measures to encourage travelers to transition towards sustainable transport modes can be inferred. Specifically, the estimation results regarding travel time uncertainty suggest that reducing the non-linearity coefficient of transit routes, which could lead to a shorter detour time, could be an effective approach to incentivize traveler to use public transport. In addition, based on the results of the attribute (e.g., the number of transfers), it can be concluded that enhancing the scientific planning of transit network, reducing the number of transfer, and improving transfer convenience are also beneficial strategies attracting travelers to select public transport. Furthermore, the implementation of favorable policies could also contribute to increased acceptance and frequency of public transport involvement. On the other hand, measures such as charging zone-based or time-based parking fees for private cars could effectively raise the cost of car usage, thereby encouraging travelers to opt for public transport. Finally, urban transportation authorities should consider the development of additional low-carbon incentive strategies. Relevant businesses can propose targeted discounts and services to enhance the competitiveness of sustainable transport modes and facilitate the adoption of sustainable travel habits. These measures could not only facilitate carbon reduction but also enhance the efficiency of urban transportation systems, thereby making a significant contribution to urban sustainable development.

It is important to acknowledge that this study has several limitations. First, it is essential to recognize that the airport ground access mode choice behavior is influenced by various factors. While the findings of this study suggest that low-carbon incentives have a positive effect on encouraging the choice of sustainable transport modes, their effects may differ across different regions, travel contexts, and populations. Hence, this study could be further improved in the future by incorporating preference heterogeneity. Second, the choice set in this study was limited to three alternatives. Specifically, the metro and conventional buses were grouped together as public transport. Given the distinctive characteristics of the metro and bus, it is suggested that future studies present more detailed alternatives to respondents with the objective of capturing the nuances and variations between these alternatives. Third, the data collection was conducted during the peak growth period of the COVID-19 pandemic. Despite the explicit instructions provided to respondents in this study before the formal survey, urging them to disregard the influence of the pandemic on their travel decisions, it is acknowledged that a complete concordance between respondents' choices and real-world non-pandemic contexts may not be definitively assured. Consequently, future research could contemplate the prospect of additional data collection to bolster the validation of our findings.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data after pretreatment presented in this study are available on request from the corresponding author. The raw data are not publicly available due to ethical restrictions.

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