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Exploring the integration of urban air mobility into Mobility-as-a-Service: A stated preference analysis of commuters

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ABSTRACT

This study introduces the concept of air mobility as a Service (AMaaS), integrating urban air mobility (UAM) into the framework of Mobility-as-a-Service (MaaS), with the goal of establishing highly synchronized mobility services. To facilitate the successful deployment of Urban Air Taxi (UAT) services, we aim to investigate people's preferences for multimodal air taxi services. A stated choice experiment was designed incorporating pay-as-you-go options for various multimodal UAT services and subscriptions to ride-based discounts. Using data collected in Beijing, China, a random parameter error component model was estimated to identify preference heterogeneity among different individuals and potential correlations between alternatives. Our findings indicate a general preference for subscription schemes over pay-as-you-go options across all UAT services. The choice within AMaaS is significantly influenced by the various attributes of UAT alternatives and incentive measures, e.g., stronger government support and/or price discounts increase the probability of using AMaaS. Workers aged 44 or above, high-income groups, car owners, regular car commuters, individuals in managerial positions, and those having helicopter experience are more inclined to commute via multimodal UATs. These findings provide valuable insights for policy decision-making in the planning of UAM, especially when integrated into MaaS.

1. Introduction

Urban Air Mobility (UAM) represents an innovative paradigm in aerial transportation, transporting passengers or cargo through aircraft within urban low-altitude airspace (Cohen and Shaheen, 2021). Urban Air Taxi (UAT) represents one of the most promising use cases within the UAM market (Hasan, 2019; Reiche et al., 2018). Benefiting from recent technology developments in electric vertical takeoff and landing (eVTOL), UAT holds the promise of providing passengers with superior aerial experiences. This includes reduced noise pollution, emissions, operational costs, and enhanced safety features (Garrow et al., 2021). It would be an important component of urban transportation systems.

Many cities in the world have actively promoted UAM. For example, Joby aviation is preparing to launch its air taxi services in New York city, and air taxi services for tourists on Jeju Island. In Japan, urban air taxi services are planned for the 2025 Osaka World Exposition, providing fast connections between the airport and the exhibition site. In China, the government outlined the National Comprehensive Three-dimensional Transportation Network Planning Outline (Central People's Government of China, 2021), aiming to establish a multidimensional transportation network. Rapid progress has been made, with Ehang launching its autonomous EH216-S aircraft, which has received airworthiness certification and approval for commercial passenger operations (EHang, 2023). Since early 2024, regions across China have begun implementing policies and measures to support intra-city and intercity passenger transport, freight services, sightseeing tours, and intercity air corridors.

An urban air taxi journey typically comprises one flying segment and two on-road segments (Rajendran and Zack, 2019), namely from the origin point to the departure vertiport (the first mile) and from the arrival vertiport to the final destination (the last mile), as presented in Fig. 1. Vertiports serve as UAM infrastructures for eVTOL air taxis to execute takeoffs and landings, as well as to accommodate passenger waiting, boarding, and disembarkation (Yedavalli and Cohen, 2022). Given that the first- and last-mile segments depend on ground transportation to facilitate connections, poor connections may diminish the time-saving benefits provided by UAT services (Wang et al., 2023). The need for transfers that may entail detours and encounters with congestion during on-road segments collectively presents a substantial challenge in the effective deployment of UAT services.

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Therefore, to maintain the time-saving and efficient advantages of UAT services, UAM needs to be integrated with existing ground transportation to ensure seamless connections and efficient and reliable transport services. Considering the unique feature of first/last mile trips, air taxi services need to be combined with at least one additional transportation mode, e.g., Taxi + UAT or Bike + UAT. The underlying principle of multimodality in UAT shares similarities with the concept of Mobility as a Service (MaaS). The key distinction lies in the fact that the value derived from the first/last mile ground transportation is comparatively significant in UAT, e.g., any inefficiency in this segment can diminish UAT's competitive advantage. Central to the MaaS operation is the connecting and transfer services, exemplified by mobility hub facilities. However, such an important issue has not been paid sufficient attention in the context of UAT (Long et al., 2023; Rajendran and Srinivas, 2020). In particular, it is essential to plan infrastructure that ensures the smooth operation of UAT services.

In this study, we attempt to introduce the concept of Air Mobility as a Service (AMaaS) which represents an extension of ground transportation-based MaaS, encompassing urban air taxis and various mobility services (such as public transit, active transport, taxis, shared mobility services, etc.). We contend that such an integration would be an important and necessary step to develop sustainable and efficient integrated transportation systems in the future. Given its capacity to create connections between transportation modes in various dimensions, AMaaS may serve as a powerful initiative to enhance network connectivity and operational efficiency of urban transportation systems, which serve a variety of travel purposes, such as commuting and business trips, tourism, and urgent travel needs (Zhao and Feng, 2025).

Recent studies on UAM have commonly investigated the potential of air mobility relative to the existing transportation systems with an emphasis on the issues related to safety, costs, and public acceptance (Al Haddad et al., 2020; Brunelli et al., 2023; Eker et al., 2020; Fu et al., 2019; Kim et al., 2022). On the other hand, studies on MaaS have not yet discussed the possibility of integrating air taxis into existing mobility services. Several issues related to the interplay between the two concepts may arise, e.g., optimal vertiport planning considering multimodal networks (Zhao and Feng, 2024), demand prediction of UAT, and multimodal UAT. Specifically, understanding the extent to which individuals will choose the multimodal air taxi service provided by the AMaaS platform is crucial, especially in the context of commuting trips.

To gain further knowledge on individuals' decisions regarding UAM mobility options, in this paper, we investigate commuters' willingness to use multimodal air taxi services in the context of AMaaS. We examine the preferences of commuters in monthly subscriptions and pay-as-you-go options among different UAM multimodality alternatives. A stated choice experiment was designed, incorporating various attributes of UAM alternatives and possible incentives that governments may consider in promoting the use of UAM. To investigate people's choice preferences among different air mobility options, a random parameter error component model was developed that incorporates users' unobserved heterogeneity in preferences and the possible correlation between alternatives.

This research contributes to the existing literature primarily in two folds. First, to the best of our knowledge, this is the first time the concept of AMaaS has been introduced in transportation. The core idea is to integrate UAT services into MaaS, facilitating the incorporation of this innovative service into existing ground transportation to provide seamless travel services. Second, the success of UAM largely depends on its integration with other transportation services. However, existing studies have not sufficiently addressed the impacts of access and egress segments in multimodal UAT trips on user travel behavior. Specifically, from the perspective of general concept of mobility as services, the impacts of access/egress segments on the choice of AMaaS needs to be further refined and explicitly investigated, such as preferences for a specific connection mode in UAM. By gaining insights into the preferences of different users regarding travel time components, such as total travel time and walking and waiting time involved in egress/access trip segments, this research will enhance our understanding of travel preferences and support effective policy decision-making.

The subsequent sections of this paper are organized as follows. Section 2 is a comprehensive review of the current literature regarding the adoption of UAM and MaaS, respectively. Section 3 elaborates on the design of the stated choice experiment and the process of data collection. Section 4 introduces the random parameter error component model. Section 5 presents the model results and policy implications. Lastly, the paper is summarized and concluded with the key findings and the avenues for future studies.

2. Literature review

In this section, we review the existing literature about UAM and MaaS with a specific focus on user adoption behavior. At the end of this section, research gaps are identified.

2.1. UAM demand studies

Among the existing UAM-related studies, public acceptance and the willingness to use urban air taxis or UAM airport shuttle services have been broadly investigated. Travel cost and time are generally identified as crucial determinants that negatively influence UAM choices, while the time effects could vary according to different scenarios of travel distances, such as short-distance intra-city trips, long-distance intra-city trips, and inter-city trips (Hwang and Hong, 2023). The time spent accessing UAM significantly impacts the inclination to utilize UAM

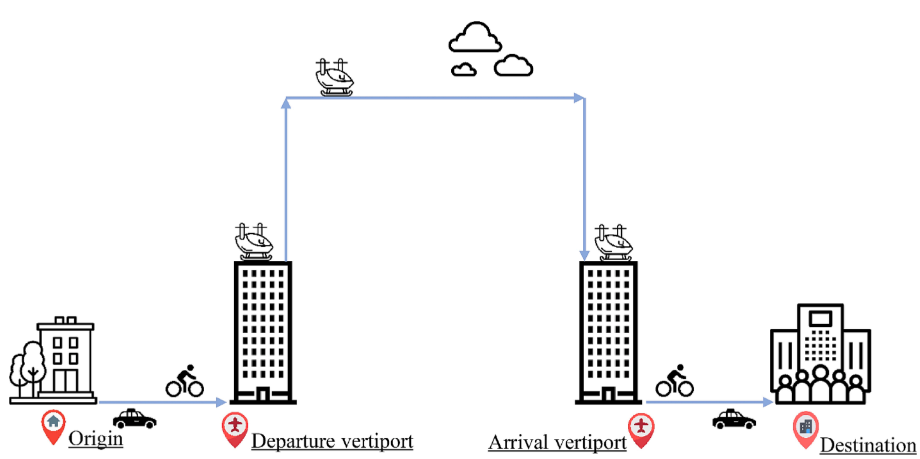

Fig. 1. Process representation of multimodal air taxi services.

across varying scenarios. Waiting time is found to exert a negative and significant impact on the use of UAM only for inter-city trips, while boarding time is found to negatively influence UAM choices for long-distance intra-city trips and inter-city trips. A survey carried out in Greater Jakarta, Indonesia, reported a significant adverse impact of access time on the use of UAM (Ilahi et al., 2021). Nevertheless, according to the empirical findings in the Munich metropolitan area (Fu et al., 2019), total travel time is the most influential factor, while walking and waiting time do not exhibit a significant impact on the use of autonomous air taxis.

Research indicates that, despite concerns associated with safety and security, data privacy, noise, and vision pollution, 75.56 % of individuals are willing to use UAM within various adoption time horizons during the first six years following its implementation (Al Haddad et al., 2020). Early adopters are likely to be frequent ride-hailing users and frequent air travelers (Garrow et al., 2020), while users of public transportation or slow modes, such as walking or bicycling, are reluctant to use air taxis (Fu et al., 2019). Potential consumers of UAM may also encompass younger people (Ilahi et al., 2021), those possessing higher education (Eker et al., 2020), and high-income individuals (Brunelli et al., 2023). Moreover, people having different attitudes and perceptions regarding UAM tend to exhibit different behaviors in adopting UAM. For instance, sharing spaces with other passengers may be a concern to using shared mobility options, but it does not have a statistically significant impact on the use of UAM (Hwang and Hong, 2023). Furthermore, latent factors such as trust, perceived usefulness, attitudes, social influence, and performance expectations also influence the behavior of using UAM. Attitudes, performance expectations, and social influence facilitate the intention to use UAM, while anxiety tends to diminish such willingness (Ariza-Montes et al., 2023). Trust and perceived usefulness also exert positive influences on the intention to use UAM, with perceived safety yielding the greatest contribution to the trustworthiness of UAM (Kim et al., 2022). In many of these investigations, UAM is often treated as an independent alternative competing with existing mobility alternatives, rather than being systematically considered within the framework of mobility services.

As UAM emerges quickly in the market, how can this new type of air transport services be integrated into the existing transportation system becomes crucial. To this end, seamless integration of various transport services can guarantee the efficiency of UAM. In other words, UAM would not be successful without a synchronized connection with the existing multimodal transportation. This demands not only the development of physical infrastructure but also digital information platforms like mobile apps. This is in line with the concept of MaaS which also demands a high degree of system integration. Several researchers have mentioned the possible integration of UAM into the MaaS platform (Pons-Prats et al., 2022; Rajendran and Srinivas, 2020; Straubinger et al., 2020), yet no research on this subject has been identified.

2.2. MaaS demand studies

As an integrated platform of emerging mobility options, MaaS has garnered substantial research interest considering its potential to stimulate the use of sustainable transportation modes such as public transportation. Among these studies, the intention to use MaaS has been broadly examined in the context of bundle subscriptions and/or pay-as-you-go. Price is found to be a crucial factor influencing the choice of MaaS bundles, whereas a lower subscription price generally leads to a higher adoption rate. The subscription intention is high regarding long-term subscription plans (6–12 months) as opposed to short-term plans (1–3 months) (Caiati et al., 2020). Liu et al. (2023) investigated the effects of occasional activities on the use of MaaS options and found that, in scenarios without occasional activities, people are prone to opt for MaaS bundles featuring substantial discounts on public transportation and taxi fares. Ho et al. (2018) also found that providing discounts to subscribers can potentially attract more MaaS users. The subscription rate of MaaS can be increased by utilizing measures in traffic demand management. For instance, Farahmand et al. (2021) found lowering MaaS price in combination with increasing parking fees can position MaaS as a promising solution for traffic demand management.

Studies have also examined the behavior differences among MaaS users. Women are inclined to adopt MaaS or subscribe to MaaS services relative to men (Bahamonde-Birke et al., 2023), and younger people are more willing to adopt or subscribe to MaaS services (Krauss et al., 2023; Matyas and Kamargianni, 2021). However, the subscription behavior among different user groups is not always consistent. For example, Lopez-Carreiro et al. (2021a) found MaaS lovers often possess higher educational backgrounds, while Caiati et al. (2020) found higher educated people are unwilling to subscribe to MaaS. In addition, Liu et al. (2023) found that potential MaaS users tend to have relatively lower incomes, but Matyas and Kamargianni (2021) found that high-income people are more likely to use MaaS. Moreover, people who travel by public transportation or taxis may be the ideal target group for MaaS packages (Matyas and Kamargianni, 2021). In addition, research also identified household car ownership as a significant and positive predictor of MaaS subscription (Liu et al., 2023). However, users of cars and motorcycles are generally not interested in MaaS, while those relying on public transportation and shared mobility are more prone to avail MaaS (Lopez-Carreiro et al., 2021b).

In recent years, the development of MaaS shifted to integrating a wide range of emerging transportation modes and expanding the operational coverage of MaaS to facilitate travel convenience, e.g., encompassing shared mobility, carpooling, and autonomous vehicles (Chen and He, 2023; Wright et al., 2020; Yang et al., 2023). It is commonly confirmed that adding transportation modes to the existing mobility services could increase the probability of using MaaS. Furthermore, the concept of MaaS has also been extended to long-haul transportation by integrating air transportation and high-speed railways and/or buses (Yuan et al., 2021; Zhang et al., 2022). Different from city-scale applications, the mobility services for long-haul trips are more complicated considering the access and egress trips, which often involve a higher level of integration of existing mobility infrastructure and services (Raijmakers, 2019). Hence, such a concept of mobility integration underlying MaaS is important, especially considering the interplay with urban air mobility and its potential value to solve existing urban problems.

The discussion on the feasibility of multimodal air taxi services within the MaaS framework inevitably revolves around the decision between subscription plans and pay-as-you-go options. Research findings in this regard is still lack of consensus. Ho et al. (2018, 2020) found people are in general less likely to subscribe to MaaS in the context of Sydney, Australia, while potential subscribers are more likely than pay-as-you-go users in the context of Tyneside, United Kingdom. Scholars argue that while offering the pay-as-you-go alternative could increase the adoption rate of MaaS, this pattern could lead to less sustainable alternatives, as pay-as-you-go adopters tend to maintain their travel behaviors, whereas subscribers express more inclination to utilize sustainable modes such as PT and active mobility. A stated preference survey conducted in the Netherlands indicated that, on average, respondents were not yet ready to subscribe to this novel service (Caiati et al., 2020; Jang et al., 2021). Researchers attributed this to the additional decision-making burden brought about by the complexity of the choice experiments and the innovative nature of the survey topic. In addition to stated choice studies, the MaaS trial in Sydney (Hensher et al., 2021; Ho et al., 2021) provided new empirical evidence. This trial introduced subscription plans every month following an initial period of familiarity with pay-as-you-go. The findings suggested a substantial market for bundled mobility services, though some participants like the flexibility offered by the pay-as-you-go alternative. Researchers posited that relying solely on pay-as-you-go is unlikely to have the capacity to develop the market and achieve sustainable outcomes. Such a debate between subscription schemes and pay-as-you-go alternatives warrants further investigation into the choice of AMaaS.

The proposed concept of AMaaS in this study integrates multimodal air taxi services into traditional ground transportation-based mobility services. Given the scarcity of existing research related to this domain, it is essential to investigate individuals' preferences for multimodal air taxi services in the context of AMaaS and understand individual taste variations and potential correlations among various multimodal air taxi alternatives. In this paper, we represent the first attempt as such to examine commuters' choice behavior regarding the multimodal air taxi services provided by AMaaS platforms. We wish to contribute to the scarce literature and the comprehension of individual decision-making processes related to multimodal air taxis. Anticipated research outcomes are expected to support the formulation of effective and integrated policies that are crucial for demand management and facility planning of AMaaS.

3. Theoretical assumption and experimental design

3.1. Experimental design

Because the proposed concept of AMaaS is new, no historical data is available. Stated choice experiments represent a feasible and effective method to obtain data related to multimodal air taxi services. Although the general MaaS concept may also not be known to everyone, AMaaS could be more than the familiarity of one's life. However, prior knowledge would not be necessarily needed to participate in such a choice experiment, because the choice alternatives could be represented in the end as combinations of multimodal travel involving UAM. This would mean that to avoid errors in data caused by misunderstanding, prior knowledge regarding UAM should be sufficiently provided.

Therefore, in our choice experiment, respondents were provided background information in the format of texts, diagrams, and videos that were related to UAM services and the way they connect with other transportation modes. More specifically, the urban air taxi services were introduced as a novel aerial ride-hailing service, operated by a pilot navigating an eVTOL air taxi that is capable of accommodating 1 to 4 passengers. Users could book and pay for multimodal air taxi trips with one click through the AMaaS platform, subsequently proceeding to the vertiport to board an air taxi. To facilitate a comprehensive understanding of the concept of the AMaaS platform among respondents, we provided an illustrative example. For instance, the user could take a ground taxi to reach the departure vertiport, transfer to an air taxi, and subsequently take the subway to the destination place. Within the AMaaS platform, users could book and pay for all the transportation modes involved in this multimodal journey with one click, including the travel costs related to the ground taxi, air taxi, and subway. Additionally, respondents were exposed to a promotional video elucidating the entire process and realistic scenarios of using urban air taxi services.

To reduce the complexity of the choice experiment, it was assumed that respondents commute to work during peak hours and that the company is located within walking distance from the arrival vertiport. The alternatives include multimodal air taxis, each combined with one ground transportation mode for access and/or egress trips, e.g., from home to departure vertiport. Respondents were presented with a total of five alternatives, namely Bike + UAT, PT + UAT, Taxi + UAT, Car + UAT, and "No UAT" which represents the option using ground transportation alternatives other than UAT. Respondents were asked to select the most suitable commuting mode based on the varying contexts of travel conditions. Based on the scenarios of attribute levels, people choose either a monthly subscription or a pay-as-you-go (PAYG) option attached to each alternative. The ultimate goal here is to comprehensively evaluate the choice of UAT integrated with existing multimodal transportation.

The experiment design begins with identifying the attributes and corresponding levels. Regarding travel contexts, Hwang and Hong (2023) found that the modal share of UAM is higher for long-distance intra-city travel than for short-distance intra-city travel or inter-city travel. Ilahi et al. (2021) also emphasized that UAM is suitable for long-distance travel. Therefore, in our experiment, we consider long-distance travel scenarios. Based on the actual spatial scale in Beijing, we define two commuting distances, namely 15 km and 30 km. In addition, Peeta et al. (2008) found that accessibility is crucial for on-demand air services. Since our study focuses on different ground access modes for UAM, the distance to access UAM services may also influence the choice. Hence, two access distances (1 km and 3 km) from the origin point (home) to the departure vertiport were also considered.

Previous studies have found that travel time and travel cost are key determinants of adopting UAM (Fu et al., 2019; Ilahi et al., 2021). Moreover, research has shown that people may also be sensitive to other time components when using UAM, such as access/egress time to vertipads (Song et al., 2024), and waiting time for boarding (Rimjha et al., 2021). Taking the existing literature as references, the attributes of UAM were selected, encompassing door-to-door travel time, walking and waiting time, and total travel cost. Notably, Brunelli et al. (2023) found that ride-sharing can increase the willingness to use UAM airport shuttles. Considering that sharing the UAT ride with others could also be a significant factor in explaining multimodal air taxi choices, we included it as an attribute in the experiment. The levels for these attributes were determined based on the average travel speed and pricing standards associated with each alternative mode during peak hours in Beijing. Moreover, the average travel speed for urban air taxis was set at 160 km per hour. The pricing for urban air taxis was referenced from Uber's expectation where the cost of urban air taxis is estimated to be $1.84 per mile (approximately 8.39 yuan per kilometer) through ride-hailing services (Garrow et al., 2021).

Notably, existing MaaS choice experiments typically encompass two unlabeled subscription alternatives (including multiple travel products) and/or labeled alternatives representing pay-as-you-go (Feneri et al., 2022; Ho et al., 2018; Krauss et al., 2023; Reck et al., 2020). This specification largely relies on people's understanding of the existing mobility alternatives. In the context of urban air mobility that has not yet been implemented, the conventional design of bundled mobility plans may be burdensome for the respondents. More importantly, the promotion of new mobility options like UAT might have strong effects when it comes along with incentivized policies. Therefore, we opt for a direct discount policy as an approximation of incentives and add it as an attribute of the alternatives related to monthly subscriptions.

As incentives or subsidies have often been treated as an effective policy intervention to promote subscriptions and certain mobility options (Ho et al., 2020, 2018; Liu et al., 2023), we examine its effects on the choice of UAT alternatives. The assumption is that policymakers may want to put forward incentive measures for UAT services at the initial stage of deploying UAM. Thus, we considered two types of main promotion strategies: government support and monetary incentives. Government support has been found to significantly influence people's choices in innovative mobility options like shared parking (Yan et al., 2020). Here, we set government support in two levels, namely no support and strong support. Another policy is formulated as the incentives for subscribing to multimodal UAT alternatives based on the percentage of discounts relative to the monthly price. Three levels are considered, e.g., 5 %, 10 %, or 15 % off the original price. Given that the pricing of UAT has already been benchmarked against Uber's anticipated reduced price, we did not devise additional cheaper discount levels, such as 40 % or 30 % off. These policy measures were integrated into a monthly subscription scheme with its price and were systematically varied between 88 yuan, 128 yuan, and 168 yuan, contingent on varying scenarios and respondents. It should be noted that this subscription fee is different from the total price in traditional MaaS bundles that allow subscribers to utilize pre-defined mobility packages. Instead, it is treated as a subscription in order to get a discount per ride. This implies that subscribers will be entitled to member-exclusive discounted prices on each UAT ride (Subscribe) and non-subscribers pay for each ride according to the list attribute levels (PAYG). Table 1 summarizes the attributes and corresponding levels involved in the experimental design.

The experiment comprises 14 three-level attributes and 6 two-level attributes. Due to the considerable number of attributes and levels, it is impractical to construct the full factorial design ($3^{14} \times 2^{6}$ configurations). Hence, we utilized SAS to generate the orthogonal fractional factorial design, consisting of 72 configurations. It is noteworthy that, considering the absence of available prior information, we omitted the use of efficient designs despite its value in model estimation. The 72 tasks were divided into 18 blocks, each containing 4 choice tasks. Respondents were randomly assigned to one block. This procedure was applied to the 15-kilometer scenarios and 30-kilometer scenarios, respectively. Ultimately, each respondent was asked to complete eight choice tasks involving the scenarios of two distances. Fig. 2. illustrates an example of choice tasks.

Table 1
Attributes and corresponding levels of the stated choice experiment.

Type	Attributes	Attribute levels
Context variables	Commuting distance (km)	15/30
	Access distance to the vertiport (km)	1/3
AMaaS incentives	Government support	No support, Strong support
	Monthly subscription price (yuan)	88/128/168
	Monthly subscription discount (per ride)	5 %, 10 %, 15 % off
Multimodal UAT options		
Bike sharing + UAT	Door-to-door travel time (min)	20/25/30 (for 15 km); 24/30/36 (for 30 km)
	Walking and waiting time (min) (Included in door-to-door travel time)	2/4/6
	Share UAT ride with others	Yes, No
	Travel cost (yuan)	65/80/95 (for 15 km); 160/200/240 (for 30 km)
PT (i.e., Bus or Subway) + UAT	Door-to-door travel time (min)	20/26/32 (for 15 km); 25/31/37 (for 30 km)
	Walking and waiting time (min) (Included in door-to-door travel time)	6/10/14
	Share UAT ride with others	Yes, No
	Travel cost (yuan)	66/83/100 (for 15 km); 162/203/244 (for 30 km)
Taxi or Ridesharing + UAT	Door-to-door travel time (min,)	17/21/25 (for 15 km); 21/26/31 (for 30 km)
	Walking and waiting time (min) (Included in door-to-door travel time)	4/7/10
	Share UAT ride with others	Yes, No
	Travel cost (yuan)	74/93/112 (for 15 km); 170/213/256 (for 30 km)
Car + UAT	Door-to-door travel time (min)	14/18/22 (for 15 km); 18/23/28 (for 30 km)
	Walking and waiting time (min) (Included in door-to-door travel time)	2/4/6
	Share UAT ride with others	Yes, No
	Travel cost (yuan)	74/92/110 (for 15 km); 170/212/254 (for 30 km)
Current options		
PT (i.e., Bus or Subway)	Travel time (min)	60 (for 15 km); 94 (for 30 km)
	Travel cost (yuan)	5 (for 15 km); 8 (for 30 km)
Taxi or Ridesharing	Travel time (min)	50 (for 15 km); 80 (for 30 km)
	Travel cost (yuan)	42 (for 15 km); 100 (for 30 km)
Car	Travel time (min)	50 (for 15 km); 80 (for 30 km)
	Fuel cost (yuan)	15 (for 15 km); 30 (for 30 km)

Note: Bike + UAT represents taking shared bikes to access the vertiport and then transferring to urban air taxis; PT + UAT, Taxi + UAT, and Car + UAT are explained in the same way.

3.2. Data collection and sample characteristics

The questionnaire survey was conducted in Beijing, China. As a densely populated city, Beijing grapples with severe traffic congestion issues. According to the "2023 Beijing Commuting Characteristics Annual Report", the single-way commuting time in Beijing was reported as 51 min on average, boasting an average commuting distance of 13.2 km (Beijing Transport Institute, 2023). Extended commuting contexts render the exploration of the third-dimension travel feasibility in Beijing a promising solution.

Data was collected online through a professional survey company from April to June 2023. The survey comprised four sections, covering sociodemographic characteristics, work and travel characteristics, the stated choice experiments, and attitudes toward UAM. The survey link was randomly distributed to respondents aged 18 and above, working in Beijing, and commuting to work at least once per week. Before respondents gave responses, introductory information about concepts such as UAT, vertiport, and the AMaaS platform was presented. The survey concluded with an open feedback section, allowing respondents to express their opinions or suggestions regarding urban air taxis and the AMaaS platform. Ultimately, 535 responses were collected, with an average completion time of 31 min. Preceding data analysis, data cleaning procedures were implemented to exclude invalid or exhibiting repetitive response patterns, such as instances where respondents consistently provided identical answers in the stated-choice experiments and/or attitudinal statements. The final model estimation was based on the sample comprising 3,736 observations from 467 respondents.

Table 2 presents the descriptive statistics of primary sociodemographic variables and commuting characteristics within the sample. It should be noted that our sample is composed of commuters only. In the absence of data specific to the commuting population in Beijing, we added the distribution of the total population (including commuters and non-commuters) as a reference. As a result, the two distributions may not be consistent.

The data reveal a nearly balanced gender distribution among respondents. Since our survey targeted commuters, the age distribution mainly consists of young and middle-aged individuals, with fewer elderly participants. Moreover, respondents generally demonstrate higher educational attainment than that of the overall population in Beijing. Among the sample, 34.7 % hold leadership positions, 51.2 % are in non-management roles, and 13.0 % are early-career employees. Regarding income distribution, approximately 61.2 % of respondents report annual incomes ranging from 100,000 to 300,000 yuan, with 7.5 % earning higher incomes. The remaining individuals report relatively lower incomes (below 100,000 yuan per year).

In terms of commuting, 83.3 % of respondents possess at least one car in their households, indicating a relatively high ownership rate. However, public transport remains the primary commuting mode in our survey, with 40.1 % of respondents using public transport (bus or subway) for their daily commutes, 27.4 % utilizing private cars, and 20.3 % opting for active transport (walking or bicycling). This implies that over half of the respondents depend on sustainable transportation modes for their commutes. Additionally, 28.5 % of respondents have the experience of helicopters.

Fig. 3 illustrates the distribution of respondents' choices in multimodal air taxi services across various socio-demographic groups, including gender, age, and income levels. In addition, among the 3,736 choice observations, the Bike + UAT option was selected in 8.97 % of

Task 1 of 8

Suppose that you commute to work during peak hours, with a single-way commuting distance of **15 km**. The access distance from your home to the departure vertiport is **3 km**, and the company is within walking distance from arrival vertiport. Which multimodal UAT option would you prefer for this journey?

	Bike sharing + UAT		PT (i.e., Bus or Subway) + UAT		Taxi or Ride-sharing + UAT		Car + UAT		No UAT
Door-to-door travel time	20 min		26 min		17 min		18 min		**Current options**: PT (i.e., Bus or Subway): 60 min, 5 yuan Taxi or Ride-sharing: 50 min, 42 yuan Car: 50 min, fuel 15 yuan
Walking and waiting time (included in door-to-door travel time)	2 min		6 min		4 min		6 min		
Share UAT ride with others	No		Yes		Yes		Yes		
Total travel cost	80 yuan		100 yuan		93 yuan		110 yuan		
AMaaS incentives	✓ Government **strongly supports** UAM development ✓ Subscribe to **168 yuan** monthly scheme and enjoy **15% off** per ride								
Your choice	**PAYG**	**Subscribe**	**PAYG**	**Subscribe**	**PAYG**	**Subscribe**	**PAYG**	**Subscribe**	○
	○	○	○	○	○	○	○	○	

Fig. 2. An example of the stated choice experiment (translated from Chinese).

cases under the PAYG alternative and 15.71 % under the subscription; PT + UAT was chosen in 7.71 % (PAYG) and 13.25 % (subscription); Taxi + UAT was selected in 7.71 % (PAYG) and 12.71 % (subscription); Car + UAT was chosen in 8.57 % (PAYG) and 14.53 % (subscription). The “No UAT” option accounted for 10.84 % of the total choices.

Fig. 4 presents the distribution of multimodal air taxi service choices under different commuting scenarios (commuting distance and access distance). It was found that Bike + UAT was selected the most for 15 km commuting distance, while Car + UAT was selected the most for 30 km commuting distance. In addition, Bike + UAT was mostly selected in the case of one km access distance. When the access distance is 3 km, the choices among PT + UAT, Taxi + UAT and Car + UAT are at a similar level.

4. Model specification

The model established in this study is based on Random Utility Theory, where individual $n (n \in N)$ evaluates various alternatives provided within context $t (t \in T)$ and selects the alternative with the highest utility (McFadden, 1978). The choices are nested and pertain to multimodal air taxis and subscription schemes. The utility of alternative i evaluated by individual n in choice situation t can be expressed by the following equation.

$$U_{nti} = \beta_{i0n} + \boldsymbol{\beta}^B_{in}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{in}\boldsymbol{X}^A_{nti} + \boldsymbol{\beta}^C_{n}\boldsymbol{X}^C_{nti} + \theta_{ni}\boldsymbol{Z}_n + \varepsilon_{nti} \tag{1}$$

In this equation, $\boldsymbol{X}^B_{nt}$ represents the context vector for commuting, $\boldsymbol{X}^A_{nti}$ is the attribute vector related to multimodal air taxis, $\boldsymbol{X}^C_{nti}$ denotes the attribute vector associated with subscription schemes, and $\boldsymbol{Z}_n$ signifies the vector of socio-demographic variables for individual n. β_{i0n} represents the constant parameter for alternative i, while $\boldsymbol{\beta}^B_{in}$, $\boldsymbol{\beta}^A_{in}$, $\boldsymbol{\beta}^C_{n}$ and θ_{ni} are the parameter vectors to be estimated. ε_{nti} is the random error term adhering to Gumble distribution.

To account for preference variations among different individuals arising from repeated choice experiments, we employ the random parameter model. This involves the specification of random parameters, which follow certain distributions, to capture the taste differences among decision-makers (Hensher and Greene, 2003). The random parameter for attribute k of alternative i for individual n can be defined as follows:

$$\beta_{ikn} = \overline{\beta}_{ik} + \sigma_k \nu_{ikn} \tag{2}$$

The constant for alternative i is:

$$\beta_{i0n} = \overline{\beta}_{i0} + \sigma_{i0} \nu_{i0n} \tag{3}$$

Among them, $\overline{\beta}_{ik}$ and $\overline{\beta}_{i0}$ denote population means, whereas ν_{ikn} and ν_{i0n} are random terms following the standard normal distribution with zero mean and standard deviation of one. σ_k and σ_{i0} represent the standard deviations regarding the distributions of β_{ik} and β_{i0}, respectively.

In addition, it is worth mentioning that some alternatives within the choice experiments may share common features. The alternatives related to subscribing to various multimodal air taxis all include the “Subscribe” feature, while choices involving pay-as-you-go and subscription for “Bike + UAT” both include the bike element. This may violate the correlation of IIA assumption among the alternatives. To capture potential similarities among alternatives and allow for additional sources of preference heterogeneity unexplained by random parameters, we employ a random parameter error component (RPEC) model by introducing additional error components into the utility functions associated with the alternatives (Train, 2009). In other words, alternatives encompassing “Subscribe” features all have an added error component $\xi_{n,Sub}$. Similarly, alternatives involving pay-as-you-go, bikes, PT, taxis, and cars respectively encompass corresponding error components $\xi_{n,PAYG}$, $\xi_{n,Bike}$, $\xi_{n,PT}$, $\xi_{n,Taxi}$, and $\xi_{n,Car}$. Ultimately, the utility functions for all alternatives in the random parameter error component model can be specified as follows.

Bike + UAT:

$$\text{PAYG}: \ U_{nt1} = \beta_{10n} + \boldsymbol{\beta}^B_{1n}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{1n}\boldsymbol{X}^A_{nt1} + \theta_{n1}\boldsymbol{Z}_n + \xi_{n,PAYG} + \xi_{n,Bike} + \varepsilon_{nt1} \tag{4}$$

$$U_{nt2} = \beta_{20n} + \boldsymbol{\beta}^B_{2n}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{1n}\boldsymbol{X}^A_{nt1} + \boldsymbol{\beta}^C_{n}\boldsymbol{X}^C_{nt1} + \theta_{n2}\boldsymbol{Z}_n + \xi_{n,Sub} + \xi_{n,Bike} + \varepsilon_{nt2} \tag{5}$$

PT + UAT:

$$\text{PAYG}: \ U_{nt3} = \beta_{30n} + \boldsymbol{\beta}^B_{3n}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{2n}\boldsymbol{X}^A_{nt2} + \theta_{n3}\boldsymbol{Z}_n + \xi_{n,PAYG} + \xi_{n,PT} + \varepsilon_{nt3} \tag{6}$$

$$\text{Subscribe}: \ U_{nt4} = \beta_{40n} + \boldsymbol{\beta}^B_{4n}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{2n}\boldsymbol{X}^A_{nt2} + \boldsymbol{\beta}^C_{n}\boldsymbol{X}^C_{nt2} + \theta_{n4}\boldsymbol{Z}_n + \xi_{n,Sub} + \xi_{n,PT} + \varepsilon_{nt4} \tag{7}$$

Taxi + UAT:

Table 2
Socio-demographics and commuting characteristics of the respondents (commuters only).

Variables	Categories	Number of cases	Percentage (%)[1]	Percentage of the Total population in Beijing[2]
Gender	Male	227	48.6	51.0 %
	Female	240	51.4	49.0 %
Age	18–24	67	14.4	15–24: 7.7 %
	25–34	85	18.2	25–34: 18.6 %
	35–44	141	30.2	35–44: 18.3 %
	45–54	122	26.1	45–54: 14.5 %
	55–59	50	10.7	55–59: 7.5 %
	>=60	2	0.4	>=60: 21.3 %
Education level	High school and below	14	3.0	43.8 %
	Vocational education	19	4.1	22.2 %
	Bachelor	300	64.2	26.6 %
	Master	121	25.9	6.4 %
	Doctorate	12	2.6	1.0 %
	Other	1	0.2	
Job position	Chair/C-Suite	9	1.9	48.2 % of people have a job
	Director/Manager	153	32.8	
	Non-managerial staff	239	51.2	
	Intern/Trainee/Apprentice	61	13.0	
	Other	5	1.1	
Annual income (yuan)	<50,000	90	19.3	178,476 on average for working people
	50,000–100,000	56	12.0	
	101,000–150,000	78	16.7	
	151,000–200,000	80	17.1	
	201,000–250,000	71	15.2	
	251,000–300,000	57	12.2	
	>300,000	35	7.5	
Household car ownership	Have cars	389	83.3	60 cars per 100 households
	No cars	78	16.7	
Main commute mode	Bus or Subway	187	40.1	–
	Private car	128	27.4	
	Private e(bike) or Bike-sharing	85	18.2	
	Taxi or Ride-sharing	53	11.3	
	Walk	10	2.1	
	Other	4	0.9	
Commuting distance (km)	<5	124	26.6	13.2 km on average
	5–10	141	30.2	
	10.1–15	102	21.8	
	15.1–20	49	10.5	
	>20	51	10.9	
Commuting time (min)	<15	71	15.2	51 min on average
	15–30	192	41.1	
	30.1–45	78	16.7	
	45.1–60	90	19.3	
	>60	36	7.7	
Helicopter experience	Have experience	133	28.5	–
	No experience	334	71.5	

Note: [1]Commuting distance and time data are from the Beijing Transport Institute (2023), and other statistics of the total population in Beijing is from the Beijing Municipal Bureau of Statistics (2023).
[2] Percentage of the total population (both commuters and non-commuters) is treated as a reference, which might not be directly comparable with the percentage distribution of commuters only in the sample data.

$$PAYG: \quad U_{nt5} = \beta_{50n} + \boldsymbol{\beta}^B_{5n}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{3n}\boldsymbol{X}^A_{nt3} + \theta_{n5}\boldsymbol{Z}_n + \xi_{n,PAYG} + \xi_{n,Taxi} + \varepsilon_{nt5} \tag{8}$$

$$Subscribe: U_{nt6} = \beta_{60n} + \boldsymbol{\beta}^B_{6n}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{3n}\boldsymbol{X}^A_{nt3} + \boldsymbol{\beta}^C_{n}\boldsymbol{X}^C_{nt3} + \theta_{n6}\boldsymbol{Z}_n + \xi_{n,Sub} + \xi_{n,Taxi} + \varepsilon_{nt6} \tag{9}$$

Car + UAT:

$$PAYG: U_{nt7} = \beta_{70n} + \boldsymbol{\beta}^B_{7n}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{4n}\boldsymbol{X}^A_{nt4} + \theta_{n7}\boldsymbol{Z}_n + \xi_{n,PAYG} + \xi_{n,Car} + \varepsilon_{nt7} \tag{10}$$

$$Subscribe: U_{nt8} = \beta_{80n} + \boldsymbol{\beta}^B_{8n}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{4n}\boldsymbol{X}^A_{nt4} + \boldsymbol{\beta}^C_{n}\boldsymbol{X}^C_{nt4} + \theta_{n8}\boldsymbol{Z}_n + \xi_{n,Sub} + \xi_{n,Car} + \varepsilon_{nt8} \tag{11}$$

$$NoUAT: U_{nt9} = \beta_{90n} + \varepsilon_{nt9} \tag{12}$$

Among them, the six error components ξ_{nm} are assumed to be independent and follow the standard normal distribution ξ_{nm} $N[0,1]$. The individual n's conditional choice probability for alternative i is:

$$p_{nt}(i|\xi_n) = \frac{\exp\left(\beta_{i0n} + \boldsymbol{\beta}^B_{in}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{in}\boldsymbol{X}^A_{nti} + \boldsymbol{\beta}^C_{n}\boldsymbol{X}^C_{nti} + \theta_{ni}\boldsymbol{Z}_n + \sum_m \lambda_{im}\xi_{nm}\right)}{\sum_{j=1}^{J}\exp\left(\beta_{j0n} + \boldsymbol{\beta}^B_{jn}\boldsymbol{X}^B_{nt} + \boldsymbol{\beta}^A_{jn}\boldsymbol{X}^A_{ntj} + \boldsymbol{\beta}^C_{n}\boldsymbol{X}^C_{ntj} + \theta_{nj}\boldsymbol{Z}_n + \sum_m \lambda_{jm}\xi_{nm}\right)} \tag{13}$$

where λ_{im} is a binary variable. If the utility function of alternative i includes the error component ξ_{nm}, then $\lambda_{im} = 1$; otherwise, $\lambda_{im} = 0$.

Conditioned on the error components, in choice scenario t, the individual n's unconditional choice probability for alternative i is:

$$p_{nti} = \int (P_{nt}(i|\xi_n) f(\xi_{nm}))\, d\xi_{nm} \tag{14}$$

Integrating the random parameters for taste variations, the unconditional choice probability is:

$$p_{nti} = \iint ((P_{nti}|\xi_{nm}, \beta_{in}) f(\xi_{nm}, \beta_{in}|\boldsymbol{X}^B_{nt}, \boldsymbol{X}^A_{nti}, \boldsymbol{X}^C_{nti}, \boldsymbol{Z}_n))\, d\xi_{nm} d\beta_{in} \tag{15}$$

The complete log-likelihood function of the model is specified as follows:

$$LL = \sum_{n=1}^{N} \log \prod_{t=1}^{T} \prod_{i=1}^{I} (P_{nti})^{\delta_{nti}} \tag{16}$$

where δ_{nti} equals 1 if individual n chooses alternative i in choice scenario t, and 0 otherwise.

5. Results and discussion

Before model estimation, effect coding was applied to all attributes, designating the middle level of each attribute as the reference. We utilized R to estimate several different model specifications, including the basic multinomial logit model, the random parameter model, and the random parameter error component model. Finally, parameters related to door-to-door travel times, total travel costs of four multimodal UAT alternatives, and the constants were set as random. It was assumed that both the random parameters and error components followed a normal distribution. Halton draws were tested from 100 to 2000 times in the simulation maximum likelihood estimation. The results reported in this study are based on stable estimation derived from 2000 Halton draws. The estimation results of the random parameter model and the RPEC model are presented in Table 3.

In comparison to the random parameter model, the RPEC model demonstrates superior goodness of fit in terms of Rho-squared values. The log-likelihood (LL) increases from −6737.00 (random parameter model) to −6475.30 (RPEC model) and the adjusted Rho-squared value improves from 0.164 (random parameter model) to 0.195 (RPEC model). This suggests that incorporating taste heterogeneity among individuals and potential correlation among alternatives in the model enhances the overall goodness of fit. Moreover, the estimated coefficients align with theoretical expectations, with most key parameters being statistically significant. Given the superior performance of the RPEC model, we discuss the results based on the RPEC model.

As observed from Table 3, under the condition of long commuting distances (30 km), people are inclined to opt for Taxi + UAT or Car +

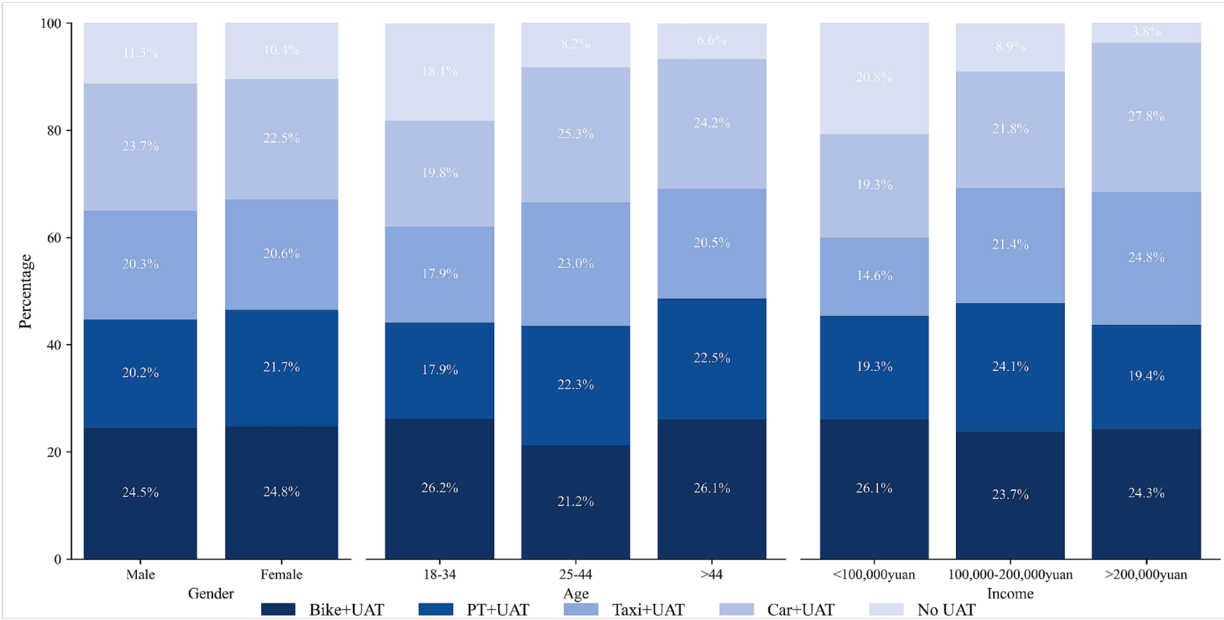

Fig. 3. Multimodal air taxi choices by socio-demographic characteristics (an example).

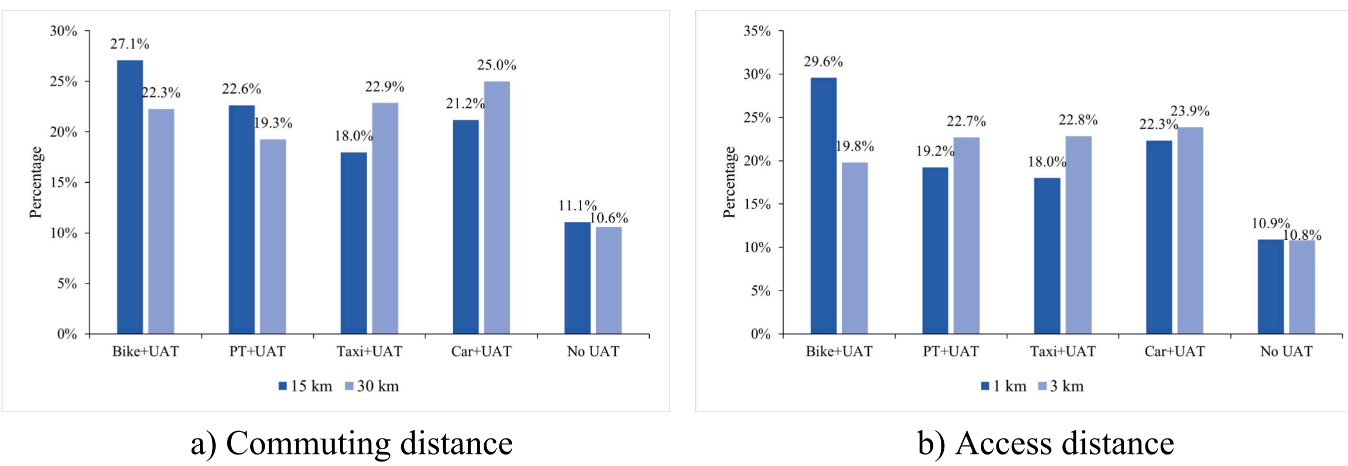

Fig. 4. Distribution of multimodal air taxi choices by commuting distance and access distance.

UAT compared to Bike + UAT or PT + UAT. This is perhaps because people generally prefer fast transportation modes in combination with UAT for long-distance trips. Moreover, individuals are more prone to choose discounted subscriptions as opposed to pay-as-you-go in the context of long-distance trips. Because long-distance UAT trips normally entail higher expenses than short-distance UAT trips (15 km), enjoying discounted prices would be more economical.

The choice of the multimodal UAT alternatives however is not fully equivalent to access mode to UAT as the access distance may also have an impact. We found when the access distance is as short as one kilometer, commuters are inclined to use shared bikes to the vertiport, especially subscribing to this alternative. Conversely, when the access distance is three kilometers, taxis become appealing. See (Table 4).

5.1. Effects of alternative-specific attributes

The estimation results of alternative-specific constants indicate that, in contrast to pay-as-you-go alternatives, respondents generally prefer to subscribe to the AMaaS schemes associated with multimodal UAT, particularly for sustainable subscription schemes such as PT + UAT and Bike + UAT. This may be an important indication of the UAT's contribution to sustainability considering the green connecting transportation modes.

Results of the alternative-specific attributes demonstrate door-to-door travel time and total travel cost are negatively correlated with the likelihood of purchasing multimodal UAT scheme alternatives. In other words, individuals tend to choose the alternatives characterized by shorter travel times and lower travel costs. Similar conclusions were found also by Fu et al. (2019), which highlights the important role of travel time and cost in UAM choices.

Moreover, Fu et al. (2019) reported that walking and waiting times do not significantly impact the choice of UAT. However, other researchers obtained different conclusions. Song et al. (2024) found that people are more sensitive to the time spent accessing/egressing vertipads than to flight time or time spent using ground modes. Rimjha et al. (2021) discovered that demand is highly sensitive to waiting time, whereas Hwang and Hong (2023) found that waiting time has a negative impact only on intercity trips. In our study, we found that walking and waiting times significantly influence the decision to use PT, taxis, or cars as transfer modes. People are more inclined to commute via multimodal

Table 3
Results of random parameter model and the RPEC model.

Attributes		Alternatives	RP model		RPEC model	
			Coef.	*p*-value	Coef.	*p*-value
Random parameters						
Door-to-door travel time (min) Bike + UAT	Low	Bike + UAT	0.359***	0.000	0.340***	0.000
	High		−0.253***	0.001	−0.257***	0.000
Door-to-door travel time (min) PT + UAT	Low	PT + UAT	0.231***	0.001	0.238***	0.001
	High		−0.307***	0.000	−0.312***	0.000
Door-to-door travel time (min) Taxi + UAT	Low	Taxi + UAT	0.354***	0.000	0.317***	0.000
	High		−0.176**	0.023	−0.172**	0.018
Door-to-door travel time (min) Car + UAT	Low	Car + UAT	0.215***	0.003	0.207***	0.003
	High		−0.219***	0.003	−0.203***	0.004
Travel cost (yuan) Bike + UAT	Low	Bike + UAT	1.065***	0.000	1.045***	0.000
	High		−0.930***	0.000	−0.909***	0.000
Travel cost (yuan) PT + UAT	Low	PT + UAT	0.838***	0.000	0.852***	0.000
	High		−0.544***	0.000	−0.533***	0.000
Travel cost (yuan) Taxi + UAT	Low	Taxi + UAT	0.888***	0.000	0.842***	0.000
	High		−0.817***	0.000	−0.776***	0.000
Travel cost (yuan) Car + UAT	Low	Car + UAT	1.026***	0.000	0.967***	0.000
	High		−0.843***	0.000	−0.806***	0.000
Constant1		PAYG: Bike + UAT	−0.568**	0.018	−0.216	0.451
Constant2		Subscribe: Bike + UAT	0.547***	0.007	1.243***	0.000
Constant3		PAYG: PT + UAT	−0.654**	0.010	−0.227	0.423
Constant4		Subscribe: PT + UAT	0.517**	0.012	1.111***	0.000
Constant5		PAYG: Taxi + UAT	−0.360	0.137	0.036	0.900
Constant6		Subscribe: Taxi + UAT	0.277	0.193	1.076***	0.000
Constant7		PAYG: Car + UAT	−0.479*	0.053	−0.068	0.819
Constant8		Subscribe: Car + UAT	0.146	0.511	0.973***	0.000
Non-random parameters						
Commuting distance (km)	30 km	PAYG: Bike + UAT	−0.274***	0.001	−0.304***	0.001
		Subscribe: Bike + UAT	−0.011	0.882	0.026	0.752
		PAYG: PT + UAT	−0.221**	0.012	−0.254***	0.008
		Subscribe: PT + UAT	0.027	0.729	0.057	0.501
		PAYG: Taxi + UAT	0.088	0.326	0.043	0.653
		Subscribe: Taxi + UAT	0.267***	0.001	0.290***	0.001
		PAYG: Car + UAT	0.026	0.761	−0.014	0.881
		Subscribe: Car + UAT	0.251***	0.001	0.273***	0.001
Access distance (km)	3 km	PAYG: Bike + UAT	−0.258***	0.003	−0.254***	0.007
		Subscribe: Bike + UAT	−0.312***	0.000	−0.300***	0.000
		PAYG: PT + UAT	0.121	0.176	0.122	0.209
		Subscribe: PT + UAT	0.067	0.397	0.070	0.420
		PAYG: Taxi + UAT	0.074	0.421	0.074	0.457
		Subscribe: Taxi + UAT	0.169**	0.038	0.169*	0.053
		PAYG: Car + UAT	−0.068	0.445	−0.077	0.422
		Subscribe: Car + UAT	0.063	0.436	0.053	0.542
Walking and waiting time (min) Bike + UAT	2 min	Bike + UAT	−0.024	0.731	−0.016	0.816
	6 min		−0.039	0.577	−0.037	0.586
Walking and waiting time (min) PT + UAT	6 min	PT + UAT	0.214***	0.002	0.206***	0.003
	14 min		−0.191***	0.007	−0.189***	0.008
Walking and waiting time (min) Taxi + UAT	4 min	Taxi + UAT	0.142*	0.050	0.126*	0.071
	10 min		−0.093	0.206	−0.080	0.255
Walking and waiting time (min) Car + UAT	2 min	Car + UAT	0.146**	0.038	0.145**	0.032
	6 min		0.135*	0.055	0.126*	0.067
Share UAT ride with others	Yes	All	−0.010	0.708	−0.013	0.595
Government support	Strong support	Subscribe	0.095**	0.017	0.108**	0.016
Monthly subscription price (yuan)	88 yuan	Subscribe	0.209***	0.000	0.266***	0.000
	168 yuan		−0.176***	0.002	−0.217***	0.001
Monthly subscription discount	15 % off per ride	Subscribe	0.277***	0.000	0.379***	0.000
	5 % off per ride		−0.308***	0.000	−0.401***	0.000
Socio-demographics						
Gender	Male	PAYG: Bike + UAT	−0.197*	0.080	−0.463***	0.002
		Subscribe: Bike + UAT	−0.085	0.413	−0.094	0.493
		PAYG: PT + UAT	0.029	0.799	−0.298**	0.047
		Subscribe: PT + UAT	−0.287***	0.008	−0.225	0.123
		PAYG: Taxi + UAT	−0.286**	0.016	−0.593***	0.000
		Subscribe: Taxi + UAT	−0.076	0.477	−0.069	0.618
		PAYG: Car + UAT	0.022	0.850	−0.326**	0.035
		Subscribe: Car + UAT	−0.081**	0.470	−0.086	0.547
Age	18–44	PAYG: Bike + UAT	−0.432***	0.000	−0.623***	0.000
		Subscribe: Bike + UAT	−0.476***	0.000	−0.420***	0.004
		PAYG: PT + UAT	−0.521***	0.000	−0.707***	0.000
		Subscribe: PT + UAT	−0.408***	0.000	−0.325**	0.033
		PAYG: Taxi + UAT	−0.496***	0.000	−0.656***	0.000
		Subscribe: Taxi + UAT	−0.343***	0.003	−0.290**	0.048
		PAYG: Car + UAT	−0.455***	0.000	−0.637***	0.000
		Subscribe: Car + UAT	−0.394***	0.001	−0.377**	0.012

(*continued on next page*)

Table 3 (*continued*)

Attributes		**Alternatives**	RP model		RPEC model	
			Coef.	*p*-value	Coef.	*p*-value
Job position	Manager	PAYG: Bike + UAT	0.647***	0.000	0.878***	0.000
		Subscribe: Bike + UAT	0.259*	0.055	0.124	0.474
		PAYG: PT + UAT	0.299**	0.037	0.565***	0.002
		Subscribe: PT + UAT	0.312**	0.028	0.158	0.384
		PAYG: Taxi + UAT	0.184	0.207	0.453**	0.014
		Subscribe: Taxi + UAT	0.388***	0.005	0.209	0.226
		PAYG: Car + UAT	0.281**	0.046	0.518***	0.004
		Subscribe: Car + UAT	0.025	0.867	−0.113	0.521
Annual income (yuan)	<150,000	PAYG: Bike + UAT	0.000	1.000	−0.034	0.843
		Subscribe: Bike + UAT	−0.247**	0.046	−0.480***	0.003
		PAYG: PT + UAT	−0.374***	0.006	−0.379**	0.025
		Subscribe: PT + UAT	−0.215	0.104	−0.526***	0.002
		PAYG: Taxi + UAT	−0.834***	0.000	−0.800***	0.000
		Subscribe: Taxi + UAT	−0.312**	0.016	−0.583***	0.000
		PAYG: Car + UAT	−0.598***	0.000	−0.619***	0.000
		Subscribe: Car + UAT	−0.527***	0.000	−0.800***	0.000
Household car ownership	Have cars	PAYG: Bike + UAT	0.744***	0.000	1.016***	0.000
		Subscribe: Bike + UAT	0.397***	0.003	0.461***	0.009
		PAYG: PT + UAT	0.983***	0.000	1.085***	0.000
		Subscribe: PT + UAT	0.213	0.133	0.295	0.114
		PAYG: Taxi + UAT	0.441**	0.014	0.643***	0.004
		Subscribe: Taxi + UAT	0.417***	0.004	0.464**	0.010
		PAYG: Car + UAT	0.822***	0.000	0.979***	0.000
		Subscribe: Car + UAT	0.517***	0.001	0.573***	0.002
Mainly commute by private car	Yes	PAYG: Bike + UAT	−0.081	0.611	0.051	0.796
		Subscribe: Bike + UAT	0.280**	0.049	0.362*	0.055
		PAYG: PT + UAT	0.430***	0.004	0.527***	0.005
		Subscribe: PT + UAT	0.382**	0.010	0.371*	0.058
		PAYG: Taxi + UAT	0.856***	0.000	0.867***	0.000
		Subscribe: Taxi + UAT	0.376**	0.010	0.421**	0.026
		PAYG: Car + UAT	0.522***	0.000	0.583***	0.002
		Subscribe: Car + UAT	0.383**	0.012	0.427**	0.028
Helicopter experience	Have experience	All	0.472***	0.000	0.582***	0.000
The standard deviation of random parameters						
Door-to-door travel time (min) Bike + UAT	Low	Bike + UAT	0.434***	0.000	0.367**	0.025
	High		0.312*	0.062	0.224	0.248
Door-to-door travel time (min) PT + UAT	Low	PT + UAT	0.128	0.495	0.005	0.982
	High		0.004	0.987	0.154	0.429
Door-to-door travel time (min) Taxi + UAT	Low	Taxi + UAT	0.486***	0.001	0.376**	0.010
	High		0.374**	0.024	0.198	0.507
Door-to-door travel time (min) Car + UAT	Low	Car + UAT	0.377**	0.024	0.204	0.338
	High		0.216	0.234	0.002	0.993
Travel cost (yuan) Bike + UAT	Low	Bike + UAT	0.375**	0.010	0.413***	0.001
	High		0.083	0.598	0.162	0.261
Travel cost (yuan) PT + UAT	Low	PT + UAT	0.354**	0.043	0.523***	0.000
	High		0.051	0.853	0.177	0.407
Travel cost (yuan) Taxi + UAT	Low	Taxi + UAT	0.452***	0.001	0.348**	0.029
	High		0.097	0.605	0.015	0.930
Travel cost (yuan) Car + UAT	Low	Car + UAT	0.538***	0.000	0.558***	0.000
	High		0.220	0.311	0.103	0.628
Constant1		PAYG: Bike + UAT	1.324***	0.000	0.733***	0.000
Constant2		Subscribe: Bike + UAT	1.346***	0.000	0.732***	0.000
Constant3		PAYG: PT + UAT	1.235***	0.000	0.555***	0.007
Constant4		Subscribe: PT + UAT	1.448***	0.000	1.034***	0.000
Constant5		PAYG: Taxi + UAT	1.297***	0.000	0.713***	0.001
Constant6		Subscribe: Taxi + UAT	1.396***	0.000	0.714***	0.000
Constant7		PAYG: Car + UAT	1.285***	0.000	0.613***	0.002
Constant8		Subscribe: Car + UAT	1.580***	0.000	0.917***	0.000
The standard deviation of error components						
Standard deviation		Bike			0.721***	0.000
Standard deviation		PT			0.637***	0.000
Standard deviation		Taxi			0.393***	0.004
Standard deviation		Car			0.623***	0.000
Standard deviation		PAYG			2.023***	0.000
Standard deviation		Subscribe			1.813***	0.000
Number of observations			3736		3736	
Number of draws			2000		2000	
LL(0)			−8208.83		−8208.83	
LL(β)			−6737.00		−6475.30	
Rho^2			0.179		0.211	
Rho^2 adjusted			0.164		0.195	

Note: ***, **, * mean the level of significance at 1%, 5%, and 10% respectively.

Table 4
Value of time of multimodal air taxi alternatives.

Multimodal air taxi alternatives	Value of time (yuan/hour)
Bike + UAT	101.98
PT + UAT	102.80
Taxi + UAT	145.88
Car + UAT	90.03

UAT when walking and waiting times are shorter, while longer walking and waiting times induce a negative utility to the alternatives, and as a result, lead to a decreased probability of using UAT. In addition, the parameter estimates of walking and waiting times associated with the Bike + UAT alternative are insignificant. This is reasonable, given that the time spent waiting and walking for this transportation mode is almost negligible.

As UAT involves sharing spaces between multiple passengers, we examine the effects of whether space is shared with others on the choice of UATs. However, no significant impact was observed. Hwang and Hong (2023) also found that the presence of other passengers does not exert a statistically significant impact on UAM choices.

Regarding subscription schemes, monthly subscription prices and discounts were found to influence the decision to choose multimodal UAT subscriptions. A low subscription price (88 yuan per month) results in a high probability of subscribing to the UAT schemes. A high discount level of the subscription price of 15 % is positively associated with the probability of subscriptions, which may indicate people expect a larger discount promotion from the subscription of AMaaS. Moreover, government support was observed to have a positive and significant impact on multimodal UAT schemes in the sense that having strong government support would positively increase the subscription probability. This indicates the crucial role of government support to encourage people to subscribe to this emerging transportation mode.

5.2. Effects of socio-demographic characteristics

In addition to the main attributes, it is also important to understand the extent to which the choice preferences vary according to different socio-demographic characteristics of people. To mitigate possible impacts of limited sample size on model performance, we re-categorized certain socio-demographic variables (age, job position, and annual income) before model estimation, reducing the number of categories such that each category has a better representativeness. Age was categorized into two groups (18 to 44, and over 44 years). Job position was classified into two categories: managers, and non-managerial staff, with managers encompassing roles such as chairperson and manager. Income levels were segmented into two categories: annual income less than 150,000 yuan, and over 150,000 yuan.

As presented in Table 3, there is a tendency for female commuters to use multimodal UAT although the effects are only statistically significant for pay-as-you-go options. Females are more inclined to utilize pay-as-you-go rather than subscriptions when opting for multimodal UAT rides for commutes. Among the four multimodal UAT alternatives, they are more likely to choose Taxi + UAT compared to the other three modes.

Previous research on the age effect often indicated younger individuals are inclined to adopt UAM (Fu et al., 2019; Ilahi et al., 2021). Nevertheless, in this study, there was a positive correlation between age and the willingness to commute by UAT. Commuters over 44 years old exhibit a higher interest in multimodal UAT. This may be because older commuters (aged over 44 years old) are relatively wealthy, enabling them to afford the high commuting costs that happened to the use of UAT, which might pose a burden for younger commuters. Hence, those aged between 18 and 44 are less inclined to utilize UAT for commutes. Additionally, commuters over 44 years old show more tendency to choose PT or taxi access to UAT through pay-as-you-go.

It should be noted that job positions also play a pivotal role in the choice of multimodal UAT. We observed that manager positions exert a positive impact on the choice of multimodal UAT in the sense that managers are more likely to use UAT, whereas non-managerial staff are less likely to commute by multimodal UAT. This is understandable as managers are more capable of affording the relatively high commuting cost of UAT. Moreover, managers are more willing to adopt Bike + UAT based on pay-as-you-go compared to other options.

Income is found to be a significant influential indicator of respondents' commuting decisions. As delineated in Table 3, the low level of annual income (less than 150,000 yuan) negatively and significantly influences people's choice of UAT. This indicates that UAT is not a favorable option for low-income people who may not be able to afford the high costs. Clearly, the willingness to adopt multimodal UAT for commutes increases with the increase in income. Among the four multimodal UAT alternatives, high-income commuters (annual income exceeding 150,000 yuan) show a higher inclination to use UAT while transferring with taxis or cars. Furthermore, these people are most likely to subscribe to the monthly discounted scheme related to Car + UAT.

In addition to the connection between UAT with public transport and shared bikes, cars are probably another major transportation mode connecting UAT, e.g., intercity trips. Our results show that household car ownership contributes positively and significantly to the choice of multimodal UAT in the sense that car owners are willing to commute by urban air taxis, especially via Car + UAT. Compared to subscription schemes, car owners are more prone to choose pay-as-you-go options, which is understandable.

It is widely expected that transferring part of ground traffic to the air may alleviate on-road congestion. The choice behavior of regular car commuters is important in this regard. Our study estimates the choice preferences of private car commuters for various multimodal UAT alternatives. Among the four multimodal UAT alternatives, car commuters express higher willingness for Taxi + UAT and Car + UAT, particularly for pay-as-you-go utilization involving taxis.

Given that most people are unfamiliar with this new air mobility service, one may be curious about how individual experiences with flying vehicles could influence their choices regarding UAT. To be specific, we included the variable of prior experience in using helicopters in the model instead of that of conventional airplanes experienced by many people. The positive and significant estimation suggests that people who have prior helicopter experience are likely to use multimodal UAT for commuting. In spite that helicopters are not the same as the UAT we are referring to in this study, the way they operate, e.g., inter-city trips and vertical taking-off/landing, is similar.

5.3. Results of random parameters and error components

To investigate the heterogeneous choice behavior, random parameters were estimated. Results of the standard deviations of constants seem to indicate that heterogeneity is relatively high in the cases of subscription to PT + UAT and Car + UAT. Moreover, the results of the standard deviations are significant at the lowest travel time levels for shared bikes and taxis as connecting modes. This implies that there is significant preference heterogeneity among individuals for these two multimodal UAT alternatives when the travel time is exceptionally short. Similar results are found for the travel cost parameters, with the standard deviations being significant at the lowest price levels for all multimodal UAT alternatives. This indicates that substantial variation exists in respondents' choice behavior when the total travel cost is at the lowest level. Conversely, we did not find significant heterogeneity for the highest cost levels. This perhaps implies homogenous preferences regarding high cost.

The estimation results from the six error components associated with pay-as-you-go, "Subscribe", bikes, PT, taxis, and cars, are all statistically significant. This suggests the presence of significant preference heterogeneity among alternatives characterized by features related to pay-as-you-go, “Subscribe”, bikes, PT, taxis, and cars. This indicates the potential existence of a “cross-nested structure” in the decision-making process when individuals decide to adopt a specific multimodal UAT commuting option.

5.4. Practical implications: A value of time analysis

An issue related to practical considerations is the extent to which commuters are willing to pay for multimodal UAT services. The existing assessment of the value of time (VOT) in UAM has shown significant variation. In Munich, 55 USD per hour were found (Fu et al., 2019), while in some American cities (New York, Los Angeles, and Washington D.C.), the values of in-vehicle and out-of-vehicle travel time are 25.7 USD and 15.4 USD per hour, respectively (Haan et al., 2021). In Tehran, Karimi et al. (2024) estimated the value of in-vehicle UAM travel time to be 26.4 USD per hour. Conversely, Song et al. (2019) in Dallas and Los Angeles and Ilahi et al. (2021) in the Greater Jakarta area found much lower values. The former estimated value of in-vehicle time at 13.9 USD per hour, and in the Greater Jakarta area, the value of travel time savings for UAM is approximately 4.98 to 8.23 USD per hour.

To gain further insights into the practical implications, we calculated the value of time based on a basic version of the multinomial logit model without distinguishing between user profiles, accounting for the door-to-door travel times and total travel costs for each of the four multimodal UAT alternatives. We found a VOT of 101.98 yuan per hour (14.30 USD per hour) for Bike + UAT, 102.80 yuan per hour (14.42 USD per hour) for PT + UAT, 145.88 yuan per hour (20.46 USD per hour) for Taxi + UAT, and 90.03 yuan per hour (12.63 USD per hour) for Car + UAT respectively. While these values are generally lower than most empirical findings in other cities, it is essential to note that the average salary in Beijing is also relatively low when compared to those in the listed cities. More importantly, the VOTs obtained in previous studies are all specific to UAM and no empirical values for the multimodal UAT are available. In the current study, we utilized the parameters for the total travel cost and total door-to-door travel time. Thus, the VOTs obtained for multimodal UAT services are considered to be at the combined scales, e.g., one could expect a higher VOT for UAT and a much lower VOT for connecting modes such as public transport. Nevertheless, the VOTs for all the multimodal UAT are much higher than that of existing ground transportation in Beijing (e.g., 17.81 yuan per hour for taxis, and 11.34 yuan per hour for subway from Kou et al. (2017)).

Among the four VOTs, Taxi + UAT has a higher value than the other three alternatives, indicating that the users for this alternative are more time sensitive. This aligns with other UAM studies where taxi users are often assumed to be early adopters. Thus, policies for a smooth connection between UAM and taxi services are crucial, such as fast-track access and priority to taxi users to minimize travel time as much as possible. In addition, the VOTs for PT + UAT and Bike + UAT are relatively low, suggesting relatively less cost-sensitive behavior. It is also found the VOT for Car + UAT is the lowest, which is out of our expectations. However, connecting a private travel mode (car) with UAT would involve additional considerations, e.g., parking availability, and parking cost, which are not a component in the settings of the other three multimodal UAT alternatives. In this regard, detailed specifications may be needed on the connections between the car and UAT such that the VOT can be further speculated.

6. Summary and conclusions

With the advancement of eVTOL technology and the implementation of associated policies, UAM is anticipated to influence the market share of different transportation modes. However, the first/last mile travel issue for multimodal air taxis has emerged as a major challenge for the successful deployment of UAT services. This study proposes the concept of AMaaS based on the integration of UAT services and the MaaS platform, aiming to develop an efficient and sustainable integrated transportation system. Given that the choice behavior regarding the multimodal UAT services offered by the AMaaS platform is unknown, we explore commuters’ willingness to adopt multimodal UAT within the AMaaS framework. Results offer valuable insights for policy decision-making in the development of UAM.

To account for the unobserved heterogeneity stemming from structural variations in alternatives, this study employed a random parameter error component model. Alternatives sharing the same travel mode or utilization method in multimodal trips encompass identical corresponding error components. Estimations were executed by deploying a random parameter model and an RPEC model to analyze the impact of UAT attributes, incentive measures, and socio-demographic characteristics. Results show that both the standard deviations related to random parameters and error components are statistically significant, indicating significant heterogeneity in individual preferences for travel time and costs. Compared to pay-as-you-go alternatives, people, on average, have a greater preference for subscriptions, particularly for sustainable discounted schemes, such as those involving PT or shared bike access to UAT. In addition to that commuters generally prefer travel options characterized by shorter travel times and lower travel costs, government support and incentives represented as discount prices are crucial determinants influencing the subscription of multimodal UAT schemes.

While the choice preferences of AMaaS are identified, observed variations in the tastes also exist. For instance, females show a strong preference for multimodal UAT, and older commuters exhibit a greater interest in multimodal UAT. In comparison to non-managerial staff, managers are more willing to commute through multimodal UAT. Managers are more inclined to adopt Bike + UAT through pay-as-you-go. High-income commuters show more tendency to leverage taxis and cars as transfer modes and express more interest in subscribing to the Car + UAT scheme. Additionally, car owners are likely to commute by multimodal UAT, especially via Car + UAT. Compared to those commuting by other travel modes, respondents mainly commuting by private cars prefer selecting multimodal UAT for commutes, particularly Taxi + UAT and Car + UAT. Also, individuals having prior helicopter experience are interested in commuting by UAT services.

The research findings of this study hold practical implications for policy decision-making. Firstly, the proposed concept of the AMaaS can assist government departments and UAM operators in synchronizing the planning and deploying of UAM and MaaS. The AMaaS platform facilitates the rational planning of multimodal UAT journeys, addressing the connecting issues of multimodal UAT. Given that government support can promote AMaaS subscriptions, government agencies should launch public awareness campaigns to inform supportive policies and the advantages of UAM, particularly its role in alleviating congestion and supporting sustainable development. Secondly, this study provides valuable insights for UAM operators regarding viable incentive measures and subscription schemes, which could be useful for governments to promote UAM services. Our study results highlight the role of financial incentives in encouraging UAT subscriptions. Therefore, government agencies could provide subsidies or tax incentives to UAM service providers to help launch attractive UAT subscription schemes, especially during the early stages of UAT service implementation.

Thirdly, the derived insights into choice preferences for multimodal UAT services contribute valuable guidance for urban and transportation planning departments in the development of integrated transportation systems and infrastructure planning. Given people are sensitive to walking and waiting times, vertiports should be located near existing transportation hubs (such as train stations and metro transfer stations) to facilitate seamless transfers. UAM service providers should also plan for sufficient parking facilities to encourage car users to park and transfer to UAT. Finally, study findings could also help UAM operators develop targeted marketing strategies to satisfy the needs of various socio-demographic groups. For instance, the study reveals that individuals in managerial positions are more likely to avail of air taxi services. UAM operators in Beijing could collaborate with employers in business districts (such as Zhongguancun Science Park or China World Trade Center) to offer corporate commuting packages tailored for managerial employees. Moreover, UAM service providers could consider offering targeted subsidies or discount packages for long-distance commuters from suburban areas in Beijing (like Tongzhou, Shunyi, or Yanjiao).

To facilitate the smooth deployment of AMaaS, much research is needed to delve further into the demand market for multimodal UAT services. Firstly, the current study focuses on commuting scenarios. Future investigations incorporating other travel purposes are needed, such as business trips and tourism. Secondly, the potential social influence should be also investigated, as the "crowd effect" may hold significance in individuals' decision-making processes. In addition, future research could expand the analysis by using data from different cities or larger sample sizes. Lastly, some initiatives of urban air mobility have been running in different cities, necessitating further research to understand people's actual choices that may progressively influence the dynamics in the demand of UAM.

CRediT authorship contribution statement

Ying Zhao: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yan Hu:** Writing – review & editing. **Tao Feng:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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