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Urban Air Mobility (UAM): Airport shuttles or city-taxis?

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A R T I C L E I N F O

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A B S T R A C T

In the last years, Urban Air Mobility (UAM) has been receiving increasing attention and even if the first services are expected to be launched shortly, there is still uncertainty about which type of commercial services (e.g., airport shuttles or city-taxis) will be implemented at an early stage, as well as which price point will be perceived as affordable by travelers. Based on data collected through a large-scale survey campaign in the Milan metropolitan area (Italy), in this paper passengers' value of travel time savings for different UAM services are estimated using advanced discrete choice modeling. Estimated mixed logit models allowed to comparatively analyze the differences between the two potential use cases, i.e., airport shuttle and city-taxi services. Results show a willingness to pay for UAM services from/to airports that is greater (in a range of 44%–57%) than for travelling within the metropolitan area, and greater (in a range of 31%–44%) for business travels than for other purposes, indicating that the most financially sustainable UAM services will potentially be available for airport-shuttle connections from/to central business districts.

1. Introduction

According to the United Nations, the world's urban population has grown from about 750 million in 1950 to 4.2 billion in 2018. This trend is expected to continue, with the world's urban population projected to reach 6.7 billion by 2050 (United Nations, 2019). A growing urbanization rate has been usually considered as beneficial for the economic growth (Youn et al., 2016; Glaeser et al., 1992), however this also poses enormous challenges to cities, to their services and particularly to the mobility system. Increases in traffic congestion, travel times and air pollution are among the expected negative externalities envisaged for a system which, as it stands today, would not be able to cope with such an expected increase in mobility demand. This claims for the need of exploring new mobility solutions and paradigms to face these forthcoming challenges.

After exploiting both ground and underground urban mobility, the idea of adding the "third dimension" to urban transport networks has been receiving increasing attention, making the Urban Air Mobility (UAM) concept always more popular. However, this is not new: first examples of UAM services using helicopters are dated to the 1940s and operated for more than two decades, ceasing their activities only due to several incidents of mechanical failures, highlighting safety concerns (Thipphavong et al., 2018). The list of direct and indirect enabling technologies related to the nowadays renewed idea of introducing UAM services is wide (Pons-Prats et al., 2022), but progresses in sensor and communication systems, together with recent advances in electric batteries (Li et al., 2021; Yang et al., 2021) have been identified as crucial for developing new aerial vehicles, the so called electric Vertical Take-Off and Landing (eVTOL) aircrafts (Rezende et al., 2018). Many vehicle manufacturers, such as Joby Aviation,[1] Airbus,[2] Volocopter[3] and Lilium[4], are competing to bring advanced eVTOL technologies to market for UAM commercially operating services, while national and regional administrative and political bodies are preparing roadmaps for a sustainable UAM adoption (for instance (Ente Nazionale Aviazione Civile, 2022; European Union Aviation Safety Agency, 2021; National Academies of Sciences, 2020)). Integration of these new services within the existing mobility system is one of the main challenges and a well-designed ground infrastructure system is fundamental to this aim (Wu and Zhang, 2021). UAM services need vertiports (Zelinski, 2020), i.e., eVTOL take-off and landing infrastructures, whose location must be

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[1] https://www.jobyaviation.com/.

[2] https://www.airbus.com/en/innovation/zero-emission-journey/urban-air-mobility.

[3] https://www.volocopter.com/.

[4] https://lilium.com/.

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optimally identified (see for instance (Brunelli et al., 2023a)) to favor integration within current mobility system and to maximize potential passenger demand. However, there is still uncertainty about what kind of use cases (for instance, airport shuttles, city-taxis, or inter-city services) should be prioritized at an early stage and what will be perceived as the most appealing ones from a user perspective.

For this reason, this study investigates passengers' value of (or users' willingness to pay for) travel time savings for UAM services, comparatively exploring the differences between two potential use cases, i.e., airport shuttles and city-taxis. The topic of how much travelers value UAM services is still underrepresented in the literature. To the best of the authors' knowledge, this study represents the first attempt to comparatively cover this aspect in relation to these two potential use cases. Data from a large-scale revealed and stated preference survey from the Milan metropolitan area (Italy) have been collected in the period 2021–2022 and have been subsequently analyzed by means of discrete choice models. The goal is to provide policy indications to both public and private transport planners interested in deploying and developing a sustainable UAM ecosystem.

It is important to point out that the results presented in this paper has been achieved through a survey carried out in the Milan metropolitan area and under some specific assumptions valid for the specific case study (e.g. number of airports, their distance from the city center, level of service on the competing modes, specifically car congestion and level of service of local public transport, …), that might not be directly transferable to other contexts. However, it is noted that the metropolitan area of Milan presents socio-economic characteristics and transport criticalities that are typical of the main European urbanized areas and Western cities, such as a highly densified city center and an extended periphery, a network of urban highways and regional rail services that, despite congestion in the peak periods, allow the presence of activities and services for a number of daily city-users, and so on. Therefore, even with some caveats, the results of the present study could be generalized at least for those metropolitan contexts that are characterized by similar multimodal transport systems and urban fabrics.

The remainder of this paper is organized as follows. A review of the UAM literature, focusing on potential use cases, announced pilots and demand studies clustered by service type, is presented in Section 2. A description of both data and methods used is given in Section 3, while results from the analysis are reported in Section 4. Discussion is contained in Section 5, while concluding remarks together with future research directions are finally reported in Section 6.

2. Literature review

The literature on UAM accelerated in the last years, together with industry announcements about the starting of eVTOL flying certification processes which have made UAM introduction seem ever closer. In fact, technology is the driving force behind this new mobility concept, and an advanced propulsion technology has been identified among the pillars to get reliable VTOL vehicles (Pons-Prats et al., 2022; Courtin et al., 2018). Electrification is generally seen as one of the most promising trends for motorized mobility in urban areas (see (Dia et al., 2019; Miskolczi et al., 2021; Coppola et al., 2023)) and the same happens for UAM. Industrial research and development has mostly focused on battery-powered eVTOLs rather than on their hybrid-powered or hydrogen fuel cell counterparts for short range urban services. Therefore, leveraging on the one side on electrification and its environmental benefits (see (Afonso et al., 2021; Cho and Kim, 2022; Mudumba et al., 2021; Rothfeld et al., 2021)), on the other on the potential urban ground congestion reduction, worldwide companies and operators entered or interested in entering the UAM market announced UAM service launches, with the perspective of starting first operations between 2024 and 2026 (see Table 1).

Examining these announcements, two primary UAM service clusters promising to reshape the future of transport can be distinguished: air taxi and airport shuttle services. The first will be point-to-point (i.e., vertiport-to-vertiport) aerial services operating in metropolitan urban areas or connecting different cities, as for the Southern Spain case (Lilium, 2022) where they are expected to meet the high demand for premium tourism. Airport shuttle services instead will connect the city centers, or their near proximities, to the airports, providing travelers access and egress air connections allowing to avoid uncertainties of traffic congestion, delays, and other transport issues traditionally affecting ground-based routes. Examples of announcements for UAM airport shuttles pertain, for instance, to Rome (Volocopter, 2021b) and Milan (SEA, 2022) in Italy, as well as to Osaka (Aviation, 2022) in Japan: UAM operations are expected to commence concurrently with the Religious Jubilee in 2025, the "Milano-Cortina" Olympic Winter Games in 2026 and the World Expo 2025, respectively.

The same two clusters can be found analyzing the worldwide scientific literature on UAM demand (Long et al., 2023): on the one hand, studies that focus on air taxi services, on the other, those focusing on UAM airport shuttles (see Table 2).

Most of these studies explore the UAM demand by examining disaggregated data from surveys (as in (Cho and Kim, 2022; Ilahi et al., 2021; Ahmed et al., 2021; Boddupalli, 2019; Fu et al., 2019; Brunelli et al., 2023b; Al Haddad et al., 2020)). Some of them provide insights

Table 1
Examples of announced UAM services, by service type.

Service type	Continent	State	City	Announced year for starting UAM operations	Companies involved	Source
Air taxi	USA	Florida	Miami	2024	Archer Aviation	Archer (2021)
Air taxi	USA	California	Los Angeles	2024	Archer Aviation	Fox (2021)
Air taxi	Europe	France	Paris	2024	Groupe ADP, Volocopter GmbH, RATP Group	ADP (2021)
Air taxi	Europe	Spain	Algeciras, Ceuta, Málaga	–	Lilium GmbH, Helity Copter Airlines	Lilium (2022)
Air taxi	Asia	South Korea	–	2024	Volocopter GmbH, Kakao Mobility Co.	Volocopter (2021a)
Airport shuttle	USA	New York State	New York	2025	Archer Aviation, United Airlines Inc.	Archer (2022)
Airport shuttle	USA	Illinois	Chicago	2025	Archer Aviation, United Airlines Inc.	Archer (2023)
Airport shuttle	Europe	Italy	Rome	2025	AdR S.p.A., Atlantia S.p.A., Volocopter GmbH	Volocopter (2021b)
Airport shuttle	Europe	Italy	Milan	2026	S.E.A. S.p.A., F2i S.p.A., Skyports	SEA (2022)
Airport shuttle	Asia	Japan	Osaka	2025	ANA Holdings Inc., Joby Aviation	Aviation (2022)

Table 2
Main UAM demand studies, by service type analyzed.

Service type	Year	Continent	Country/ Nation	City	Data type (sample size)	Modelling specification	Source
Air taxi	2018	Asia	Indonesia	Greater Jakarta	RP/SP (5143 interviews)	Multinomial logit and mixed logit	Ilahi et al. (2021)
Air taxi	2017	Worldwide	–	–	SP (692 interviews)	Correlated grouped random parameters bivariate probit models	Ahmed et al. (2021)
Air taxi	2018	North America	U.S.A. (different States)	Atlanta, Boston, Dallas-Ft. Worth, San Francisco, and Los Angeles	SP (2500 interviews)	Multinomial logit, mixed logit and latent class models	Boddupalli (2019)
Air taxi	2018	Europe	Germany	Munich	SP (228 interviews)	Multinomial logit and mixed logit	Fu et al.(2019)
Air taxi	2019	North America	U.S.A., California	Northern California cities	Multiple datasets	Mixed logit	Rimjha et al. (2021a)
Airport shuttle	2022	Europe	Italy	Bologna	SP (225 interviews)	Multinomial logit and mixed logit	Brunelli et al. (2023b)
Airport shuttle	2019	Asia	South Korea	Seoul	Ground access to airport transport dataset	Multinomial logit and mixed logit	Hae Choi and Park (2022)
Airport shuttle	2019	North America	U.S.A., California	Los Angeles	Multiple datasets	Mixed logit	Rimjha et al. (2021b)
Air taxi/ Airport shuttle	2018	Europe	Germany	Munich	SP (221 interviews)	Exploratory factor analysis, multinomial logit and ordered logit model	Al Haddad et al. (2020)
Air taxi/ Airport shuttle	2020	Asia	South Korea	Seoul	SP (1011 + 699 interviews)	Multinomial logit and mixed logit	Cho and Kim (2022)

and structure their discussions around the various factors that can influence the demand for UAM services. Specifically, several studies have extensively analyzed the impact of various level of service attributes, such as travel times and monetary costs (Cho and Kim, 2022; Ilahi et al., 2021; Boddupalli, 2019; Fu et al., 2019; Brunelli et al., 2023b; Al Haddad et al., 2020), as well as socio-economic variables (Cho and Kim, 2022; Ilahi et al., 2021; Ahmed et al., 2021; Boddupalli, 2019; Fu et al., 2019; Brunelli et al., 2023b; Al Haddad et al., 2020), personal attitudes and expectations (Cho and Kim, 2022; Ahmed et al., 2021; Boddupalli, 2019; Brunelli et al., 2023b; Al Haddad et al., 2020), along with respondents' travel habits (Cho and Kim, 2022; Boddupalli, 2019; Fu et al., 2019; Brunelli et al., 2023b; Al Haddad et al., 2020), on the demand for UAM services. Moreover, some researchers (Cho and Kim, 2022; Rimjha et al., 2021a, 2021b; Hae Choi and Park, 2022) have focused their attention on travel demand forecasts for UAM services, examining and drawing conclusions from real-world case studies. In a related vein, other studies (Ilahi et al., 2021; Ahmed et al., 2021; Fu et al., 2019) have delved into the analysis of the willingness to pay for air taxi services, without considering that for UAM airport shuttles.

This study aims to contribute to the existing literature by investigating travelers' value of travel time savings for UAM services, comparatively exploring the differences between airport shuttles and city-taxis, and providing policy indications based on how much future potential users tend to value these new aerial mobility services.

3. Data and methods

As for detailed description in the following subparagraphs, the methodological approach consists of three main phases:

- Questionnaire design, i.e., creation of a revealed preference and stated preference (RP/SP) survey;
- Data collection, i.e., campaign design and survey administration;
- Travelers' behavior modeling, i.e., specification, estimation, and validation of discrete mode choice models aiming at assessing UAM value of travel time (VoTT) savings.

3.1. Questionnaire design

To understand users' approach towards future UAM services, a RP/SP survey was designed. Particularly, the RP section of the questionnaire consisted of sixteen questions and aimed at profiling the respondent with respect to socio-economic data (age, gender, educational level, job status, gross annual income, household composition, availability of driving license and car/private vehicle availability to take their travel), as well as her/his travel and mobility habits (origin, destination, transport mode chosen, trip duration, paid monetary cost, main trip purpose, weekly trip frequency, number of people she/he usually travel with). At the end of the RP section, a short (i.e., approximately 1 minute long) video describing the UAM service and travel experience was proposed. This have shown all the journey steps, starting from the UAM service booking to the vertiport access, from the check-in and security check procedures to the boarding, from the flight to the deboarding, concluding with the egress from vertiport till to destination. Finally, interviewees were asked to participate in a SP experiment. The SP experiment was constructed following the optimal, or statistically efficient, design approach (Hensher et al., 2015; Rose and Bliemer, 2009), which allow to identify the most efficient design minimizing the determinant of the inverse of the variance-covariance matrix. In each choice situation, interviewees were asked to implicitly compare and choose among four (three for those who declared not to have a car for their travel) transport solutions, i.e., car, taxi, public transport (PT) and UAM, to carry out their journey, considering level of service attributes, such as access/egress time, waiting/boarding time, in-vehicle time, and monetary cost (see an example in Fig. 1). These attributes have been identified as significant factors influencing mode choice based on literature, pre-survey consultations with transport service operators, and feedbacks from pilot interviews.

The interviewees were presented with up to six choice situations based on the information provided in the RP section of the questionnaire, considering their typical trip duration, the number of people they usually travel with, and the availability of a car for their journey. This approach aimed to align the choice situations with the respondents' actual experiences, reducing hypothetical bias in their responses (Hensher, 2010). A library of designs has been generated (as in (Merkert et al., 2022)) containing separate designs for specific segments within

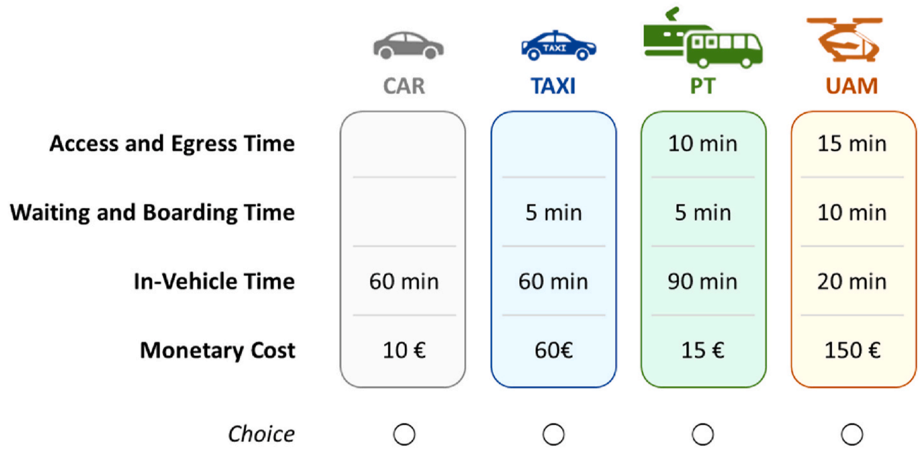

Fig. 1. Example of choice situation in the Stated Preferences experiment.

the population. Specifically, eight designs have been created by combining trip durations — over (O) or under (U) 60 min — travelling alone (I) or with others (C), and the availability (or lack thereof) of a car as an enabler for the car modal alternative in choice situations. The designs vary based on the number of alternatives (3 or 4 when a car is available) and attribute levels. The latter simulates that longer trips (O) are associated with increased travel times and higher monetary costs. Moreover, travelling with a group (C) ensures lower monetary expenses for taxis and UAM due to cost-sharing.

The time and cost levels for car, taxi, and public transport modal alternatives were varied around existing characteristics of Milan area transport system. Regarding UAM, the in-vehicle times and costs were tailored around estimated values obtained by assuming eVTOL technical specifications (such as a cruise speed of 150 km/h) and unit service fares (at 3.5 €/km, in line with values reported in (Rimjha et al., 2021a)). These assumptions considered feedback from industry experts and UAM service operators planning to enter the Italian market. Waiting/boarding times for UAM and access/egress times were instead assumed following input from companies specializing in vertiport and UAM network design. Table 3 shows the summary of the modal alternatives, together with level of service attributes and their levels of variation in each design. It is important to note that, to streamline interview duration, designs were separated by blocks, each comprising six choice situations. Only one block per respondent has been proposed. In this way the efficient designs have been split into smaller sets, guaranteeing balanced attribute levels within each block. This approach ensured that respondents did not encounter only low or high attribute levels for any given attribute, ensuring that the choice situations were evenly spread across the respondents.

Table 3
Attribute values for Stated Preferences experiment. I: travelling alone; C: travelling with a party; O: over 60 minutes; U: under 60 minutes.

Alternatives	Attributes	Values				Unit
		I - O	I - U	C - O	C - U	
Car (if available)	In-Vehicle time	60, 75, 90	30, 45, 60	60, 75, 90	30, 45, 60	min
	Monetary cost	20, 25, 30	10, 15, 20	10, 15, 20	5, 10, 15	EUR
Taxi	Waiting/ Boarding time	5, 10, 15	5, 10, 15	5, 10, 15	5, 10, 15	min
	In-Vehicle time	60, 75, 90	30, 45, 60	60, 75, 90	30, 45, 60	min
	Monetary cost	60, 75, 90	30, 45, 60	30, 40, 50	15, 25, 35	EUR
Public transport	Access/Egress time	10, 15, 20	5, 10, 15	10, 15, 20	5, 10, 15	min
	Waiting/ Boarding time	10, 15, 20	5, 10, 15	10, 15, 20	5, 10, 15	min
	In-Vehicle time	60, 75, 90	30, 45, 60	60, 75, 90	30, 45, 60	min
	Monetary cost	10, 15, 20	2, 5, 8	10, 15, 20	2, 5, 8	EUR
UAM	Access/Egress time	10, 15, 20	5, 10, 15	10, 15, 20	5, 10, 15	min
	Waiting/ Boarding time	5, 10, 15	5, 10, 15	5, 10, 15	5, 10, 15	min
	In-Vehicle time	20, 25, 30	10, 15, 20	20, 25, 30	10, 15, 20	min
	Monetary cost	150, 200, 250	90, 120, 150	75, 100, 125	40, 60, 80	EUR

3.2. Data collection

The survey, available both in Italian and English, was designed to be administered as Computer Assisted Personal Interviews (CAPI). Interviewees were on-site randomly approached at the major transport nodes or point of interest of the Milan metropolitan area, including airports (Milano Malpensa and Milano Linate), railway stations (Milano Cadorna, Milano Centrale, Milano Rogoredo, Monza), bus stations with interchange parking areas (Lampugnano, Famagosta) and other important attraction poles of the Municipality of Milan (such as City Life or Gae Aulenti square). The questionnaire ensured complete anonymity and was fully compliant with the European General Data Protection Regulation. It was submitted only to people of legal age, as defined by the Italian legislation, without any kind of discrimination. The data collection campaign lasted 3 months, from November 2021 till January 2022, collecting 2′145 interviews that have been subsequently used for modelling estimation.

3.3. Modelling framework

The core of the modeling framework relies on discrete mode choice models under the assumptions of random utility theory (Ben-Akiva and Lerman, 2018; Train, 2009). Specifically, a mixed logit (ML) (McFadden and Train, 2000) specification has been used. Unlike traditional multinomial logit models (MNL), ML allows for a more appropriate representation of reality, where systematic and random components for each alternative included in users' choice sets differ among respondents. This allows to relax the assumption of constant marginal utilities across all individuals, identifying heterogeneity in travelers' tastes. Moreover, the ML formulation does not require the axiom of independence from irrelevant alternatives (IIA), that is behind the traditional MNL.

It is assumed that an individual n has preferences on each transport mode j, in the different choice situations s, which can be measured through the perceived utility function U_{nsj} (Equation (1)). The U_{nsj} function can be set equal to the sum of the systematic utility function V_{nsj} plus random residuals ε_{nsj}. The V_{nsj} function can be assumed as a weighted by β_{nk} linear combination of k explanatory variables x_{nsj} (Cascetta, 2009): these can be alternative specific (i.e., related only to an alternative j) or generic (i.e., equal for all the alternatives).

$$U_{nsj} = V_{nsj} + \varepsilon_{nsj} = \sum_{k} \left(\beta_{nk}\, x_{nsjk}\right) + \varepsilon_{nsj} \tag{1}$$

The probability of choosing a transport mode j among those available (see Equation (2)) can be expressed as:

$$Prob(choiche_{ns} = j) = \int \left(\frac{exp\left(V_{nsj}/\theta\right)}{\sum_{j=1}^{J_{ns}} exp\left(V_{nsj}/\theta\right)} \right) f(\beta) d\beta \tag{2}$$

The choice probability is a weighted average of the multinomial logit formula evaluated for different values of $\boldsymbol{\beta}$, with weights given by the mixture of distributions $f(\beta)$. Parameters estimation is performed by means of the maximum simulated likelihood estimation (MLSE) method.

4. Results

The following subparagraphs illustrate the sample composition and the estimated models, focusing on the simulated (in-vehicle) modal value of travel time savings.

4.1. Sample description

Socio-economic and trip characteristic breakdowns of the sample are reported in Table 4. The comparison with the Italian population shows some differences. For instance, middle age groups (i.e., from 35 to 54 years old) are overrepresented with respect to age population distribution percentages, at the expense of people lower than 25 or higher than 64 years old. The same goes for employed people that are over-represented at the expense of students or unemployed. However, these differences with respect to the Italian population must be intended as a direct result of the on-site random sampling approach for selecting interviewees: these reflect the actual characteristics of people frequenting places where the data collection campaign took place, i.e. mainly individuals of the working age population.

Table 4
Socio-economic and trip characteristics of the sample.

Variable	Collected interviews (Sample size = 2′145)		Italian population[a]
	n	%	%
Gender			
Male	1168	54.5	48.7
Female	977	45.5	51.3
Age group			
Less than 25	126	5.9	22.7
25 to 34	336	15.7	10.6
35 to 44	646	30.1	13.0
45 to 54	692	32.3	16.1
55 to 64	258	12.0	14.1
More than 64	87	4.1	23.2
Employment status			
Employed	1540	71.8	58.1
Student	132	6.2	11.8
Unemployed	100	4.7	13.7
Retired	184	8.6	16.4
Other	189	8.8	
Educational level			
Elementary school diploma	16	0.7	4.7
Middle school diploma	78	3.6	35.5
High school diploma	991	46.2	42.5
Bachelor's degree	327	15.2	17.4
Master's degree	647	30.2	
PhD	86	4.0	
Gross personal annual income			
Equal or lower than 120 K€	2054	95.8	n.a.
Higher than 120 K€	91	4.2	n.a.
Trip purpose			
Business	494	23.0	n.a.
Other	1651	77.0	n.a.
Spatial trip pattern			
From/to airport trip	1127	52.5%	n.a.
Metropolitan	1018	47.5%	n.a.

[a] Elaboration from ISTAT census of the Italian population data. Accessible at: https://www.istat.it/it/archivio/104317.

4.2. Modelling estimation

Using only respondents' socio-economic profile and SP data, two different mode choice models have been estimated. The first model is for trips to access or egress the airports, where the UAM modal alternative is intended as a proxy for an aerial airport shuttle service. The second model is for trips within the metropolitan area, where UAM is intended as a proxy for air taxi services. In both estimated models, the systematic utility function is based on the following mode-specific level of service variables:

- IVTT, in-vehicle travel time (min);
- AET, total access and egress time (min);
- WBT, total waiting and boarding time (min);
- MC, total monetary cost per person (EUR, €).

The beta coefficient related to MC has been assumed to be distributed as negative log-normal random variable with μ location parameter (i.e., mean of the logarithm of the distribution) and σ scale parameter (i.e., standard deviation of the logarithm of the distribution) in the mixed logit specifications. Moreover, the interaction with the μ value of the travelling for business purpose dummy (equal to 1 if the interviewee was travelling for business purpose, 0 otherwise) has been included in the specification. The portion of the systematic utility function related to the individual socio-economic characteristics has been included as a linear combination of four mode-specific main variables:

- Age (>45), dummy variable equal to 1 if the respondent is aged more than 45 years, 0 otherwise;
- Annual Income (>120 K€), dummy variable equal to 1 if the respondent has more than 120 K€ as personal gross annual income, 0 otherwise;
- Employment Status (employed), dummy variable equal to 1 if the respondent is employed, 0 otherwise;
- Gender (female), dummy variable equal to 1 if the respondent is female, 0 otherwise.

UAM has been taken as baseline alternative, therefore all the socio-economic dummies and all the Alternative Specific Constants (ASCs) must be interpreted in relative terms.

The estimated parameters for mixed logit models concerning both from/to airports and metropolitan trips are presented in Table 6, whereas those associated with multinomial logit specifications, included for benchmarking purposes, can be found in Table 5. All models account for the panel effect resulting from the same interviewee's repeated SP choices.

Each model has been estimated with a sample of more than 1′000 interviews and over 5′500 observation each. Consistent in sign (i.e., negative) time and monetary cost beta coefficients have been obtained in all the estimated models. To demonstrate that ML specifications

Table 5
Estimated multinomial logit models for both from/to airports and metropolitan trips. Significance level: ***p ≤ 0.01, **p ≤ 0.05, *p ≤ 0.10

MNL Parameters	From/to airports trips			Metropolitan trips		
	Estimate	t-statistic		Estimate	t-statistic	
Alternative specific constants						
Car	−0.653	−3.54	***	−0.263	−1.18	
PT	−0.334	−1.78	*	0.054	0.27	
Taxi	0.331	1.34		−2.070	−6.90	***
Level of Service variables						
IVTT Car	−0.023	−11.93	***	−0.013	−5.46	***
IVTT PT	−0.021	−8.30	***	−0.011	−4.56	***
IVTT Taxi	−0.059	−18.57	***	−0.027	−7.63	***
IVTT UAM	−0.061	−9.01	***	−0.056	−7.05	***
AET PT	−0.037	−5.86	***	−0.008	−1.29	
AET UAM	−0.013	−1.90	*	0.034	4.09	***
WBT PT	−0.006	−0.92		−0.014	−2.28	**
WBT Taxi	−0.021	−0.57		−0.063	−3.42	***
WBT UAM	−0.015	−2.19	**	0.031	3.84	***
MC Car	−0.051	−8.69	***	−0.080	−11.43	***
MC Car: Business	0.036	4.54	***	−0.016	−1.75	*
MC PT	−0.052	−6.36	***	−0.037	−4.55	***
MC PT: Business	−0.002	−0.12		−0.060	−4.82	***
MC Taxi	−0.034	−9.25	***	−0.017	−1.56	
MC Taxi: Business	0.012	3.39	***	0.003	0.86	
MC UAM	−0.018	−16.94	***	−0.024	−17.78	***
MC UAM: Business	0.006	5.05	***	0.002	1.38	
Socio-Economic variables						
Car: Age (>45)	0.230	3.19	***	−0.148	−1.60	
PT: Age (>45)	−0.094	−1.25		0.181	2.32	**
Taxi: Age (>45)	0.129	1.17		−0.103	−0.71	
Car: Annual income (>120 K€)	−1.398	−8.37	***	−0.364	−1.44	
PT: Annual income (>120 K€)	−0.685	−4.63	***	−1.033	−4.45	***
Taxi: Annual income (>120 K€)	−0.882	−3.89	***	−0.348	−0.84	
Car: Employment status (employed)	−0.115	−1.42		−0.388	−3.71	***
PT: Employment status (employed)	−0.316	−3.83	***	−0.396	−4.38	***
Taxi: Employment status (employed)	−0.066	−0.53		−0.328	−2.02	**
Car: Gender (female)	−0.024	−0.33		0.130	1.43	
PT: Gender (female)	−0.008	−0.11		0.167	2.15	**
Taxi: Gender (female)	0.051	0.46		0.288	2.04	**
Sample size	1′127			1′018		
# Observations	5′617			5′732		
Log-likelihood at observed shares (ASA)	−7′246			−6′270		
Log-likelihood final (β)	−6′529			−5′719		
McFadden Rho-squared	0.10			0.09		

outperform their MNL counterparts, likelihood ratio tests were conducted (Hensher et al., 2015). For the models concerning trips from/to airports, the likelihood ratio test value was 3′015, while for metropolitan trips models, it was 2′853. These values are far higher than 18.47, i.e. the Chi-square statistic at α equals to 0.001 with 4 degrees of freedom (i.e., the difference in the number of parameters between ML and MNL specifications). Therefore, the null hypothesis that the ML specifications are not better than their MNL counterparts can be rejected. Goodness-of-fit statistics of mixed logit specifications, namely McFadden rho-squared statistics, are in a range commonly considered as valid in literature (i.e., higher than 0.3 for both models).

Table 6
Estimated mixed logit models for both from/to airports and metropolitan trips. Significance level: ***p ≤ 0.01, **p ≤ 0.05, *p ≤ 0.10

ML Parameters	From/to airports trips			Metropolitan trips		
	Estimate	t-statistic		Estimate	t-statistic	
Alternative specific constants						
Car	−1.105	−2.67	***	−3.266	−5.31	***
PT	−0.006	−0.11		−1.509	−2.52	**
Taxi	0.334	0.63		−4.761	−7.47	***
Level of Service variables						
IVTT Car	−0.048	−13.80	***	−0.019	−4.71	***
IVTT PT	−0.039	−9.26	***	−0.018	−7.67	***
IVTT Taxi	−0.093	−17.33	***	−0.040	−10.06	***
IVTT UAM	−0.045	−3.04	***	−0.060	−3.73	***
AET PT	−0.075	−6.33	***	−0.059	−5.47	***
AET UAM	−0.039	−3.47	***	−0.022	−1.44	
WBT PT	−0.011	−0.94		−0.044	−4.08	***
WBT Taxi	−0.029	−0.85		−0.073	−5.76	***
WBT UAM	−0.016	−1.48		−0.015	−1.22	
MC Car μ (neg. log-normal)	−1.970	−17.78	***	−1.196	−13.74	***
MC Car μ (neg. log-normal): Business	−0.409	−2.54	**	−0.427	−3.24	***
MC Car σ (neg. log-normal)	1.189	9.16	***	1.274	12.84	***
MC PT μ (neg. log-normal)	−0.922	−4.35	***	−2.080	−8.81	***
MC PT μ (neg. log-normal): Business	−0.327	−3.49	***	−0.138	−1.81	*
MC PT σ (neg. log-normal)	0.806	6.94	***	1.048	9.72	***
MC Taxi μ (neg. log-normal)	−2.091	−14.51	***	−2.369	−8.67	***
MC Taxi μ (neg. log-normal): Business	−0.355	−2.46	**	−0.397	−5.27	***
MC Taxi σ (neg. log-normal)	0.954	7.63	***	1.207	5.45	***
MC UAM μ (neg. log-normal)	−2.882	−46.02	***	−2.220	−35.07	***
MC UAM μ (neg. log-normal): Business	−0.370	−3.83	***	−0.294	−2.18	**
MC UAM σ (neg. log-normal)	0.896	14.85	***	0.552	18.94	***
Socio-Economic variables						
Car: Age (>45)	0.269	1.44		−0.274	−0.94	
PT: Age (>45)	−0.391	−1.71	*	0.201	0.73	
Taxi: Age (>45)	0.134	0.54		−0.071	−0.21	
Car: Annual income (>120 K€)	−2.009	−4.96	***	−0.628	−0.59	
PT: Annual income (>120 K€)	−0.493	−1.26		−1.577	−1.54	
Taxi: Annual income (>120 K€)	−1.677	−3.28	***	−0.260	−0.23	
Car: Employment status (employed)	−0.397	−1.94	*	−0.842	−2.59	***
PT: Employment status (employed)	−0.502	−2.02	**	−1.113	−3.63	***
Taxi: Employment status (employed)	−0.432	−1.58		−0.590	−1.59	
Car: Gender (female)	−0.009	−0.05		0.446	1.54	
PT: Gender (female)	−0.365	−1.62		0.465	1.70	*
Taxi: Gender (female)	0.026	0.11		0.719	2.17	**
Sample size	1′127			1′018		
# Observations	5′617			5′732		
Log-likelihood at observed shares (ASA)	−7′246			−6′270		
Log-likelihood final (β)	−5′022			−4′292		
McFadden Rho-squared	0.31			0.32		

4.3. Value of (in-vehicle) travel time savings

Investigating travelers' behavior through ML and random parameters offers a more accurate reflection of its inner stochasticity, however, this approach introduces complexities in estimating the value of time savings (i.e., the ratio between time and monetary cost coefficients). In fact, when it is statistically proved that the beta cost coefficient differs across the population, as in this study, using the ratio of the time and cost average beta coefficients as estimator for the value of time leads to a loss of information, as it overlooks differences in individuals' tastes. Therefore, the approach suggested by (Hess et al., 2005) has been used. Using the ML estimated parameters, the population of time and cost coefficient ratios has been simulated, using inferential statistics to deduce underlying distribution properties. A Monte Carlo simulation with a size of 10′000 has been conducted for each identified demand segment. Therefore, 16 Monte Carlo simulations have been carried out, combining ML estimated in-vehicle time and monetary cost parameters for 4 modal alternatives (i.e., car, public transport, taxi, and UAM), 2 spatial trip patterns (i.e., from/to airports and metropolitan trips) and 2 trip purposes (i.e., business, and non-business trips). For each generated distribution, the median has been considered as central tendency measure, providing a more robust estimate in the presence of outliers or extreme values distant from the mean. Cumulative distributions summarizing simulation outputs for the in-vehicle value of travel time (VoTT) savings are depicted in Figs. 2 and 3 for non-business and business trips, respectively. Moreover, statistics related to the simulated distributions have been reported in Table 7.

5. Discussion

Results from the modeling estimation reported in Table 6 have shown some behavioral differences among travelers based on the spatial pattern of their trips, i.e., from/to airports and metropolitan journeys. Focusing on ASCs, it is worth noting that passengers prefer choosing UAM services over cars and public transport, holding other variables constant. However, for trips accessing or egressing airports, passengers exhibit an inclination towards traditional taxis service. This might be attributed to the travelers' familiarity with this mode of transport to arrive or depart from airports, also due to its wide accessibility/capillarity in airport settings. Taxis are in fact available almost everywhere in the Milan metropolitan area and pick-up or drop-off can be customized and arranged also at each single origin or destination (e.g., home, office, …).

Information regarding the relative importance attributed by

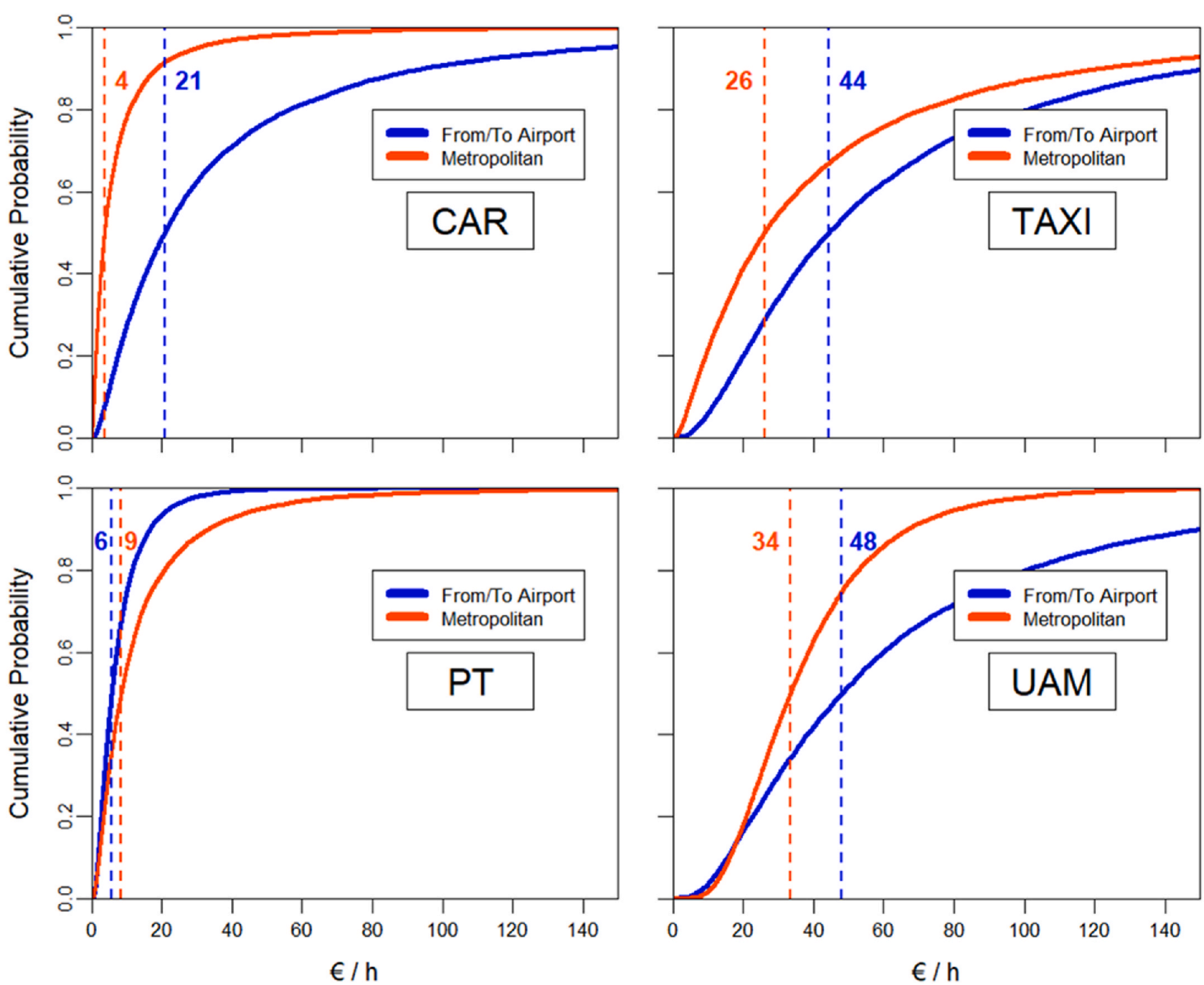

Fig. 2. Cumulative distributions and median values (vertical dotted lines) for in-vehicle value of travel time savings, non-business trips.

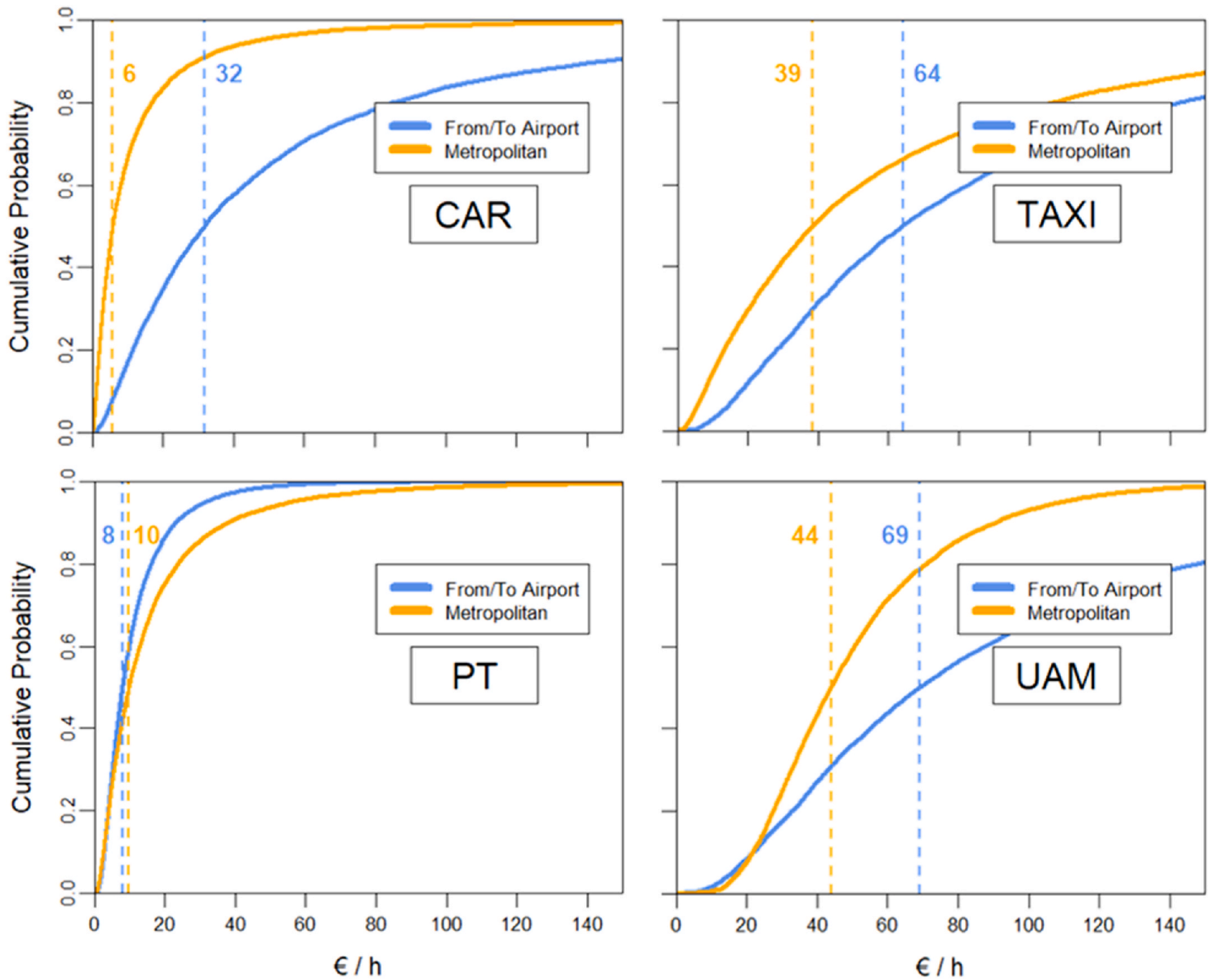

Fig. 3. Cumulative distributions and median values (vertical dotted lines) for in-vehicle value of travel time savings, business trips.

Table 7
Statistics of the simulated value of travel time (VoTT) savings distributions.

Trip Purpose	Spatial Trip Pattern	Mode	1st Quartile	Median	Mean	3rd Quartile
Non-business	From/to airports	Car	9	21	42	46
		Public transport	3	6	8	10
		Taxi	24	44	71	85
		UAM	26	48	72	87
	Metropolitan	Car	2	4	8	9
		Public transport	4	9	15	17
		Taxi	11	26	53	58
		UAM	23	34	39	48
Business	From/to airports	Car	14	32	63	70
		Public transport	5	8	11	14
		Taxi	34	64	101	123
		UAM	38	69	105	126
	Metropolitan	Car	3	6	13	14
		Public transport	5	10	17	20
		Taxi	17	39	81	88
		UAM	30	44	51	64

travelers to variables included in the systematic utility can be inferred through a comparative analysis of the estimated beta values. For instance, by examining those related to the level of service attributes, it has been found that travelers are generally more sensitive to the IVTT when travelling from/to airports compared to metropolitan trips (as found by (Cho and Kim, 2022)). This suggests that minimizing travel time remains a priority for journeys to/from airports. However, this phenomenon has not been observed for UAM. In fact, the IVTT beta for

UAM services is greater for flights in the metropolitan area rather than for those from/to airports. This can be explained by a combination of factors, including the impact of flying at low altitudes over a densely urbanized environment, such as the metropolitan one, which may negatively affect the safety perception (as reported in (Yedavalli and Mooberry, n.d.)) and consequently the pleasure of the time spent flying with eVTOL aircrafts. Similarly, it has been found that travelers are more sensitive to MC for metropolitan journeys across all transport options, except for public transport and taxis. This can be attributed, on the one hand, to the in-force PT subscription policies in the Milan metropolitan area, which might reduce the perceived cost of using public transport for regular commuters. On the other hand, low fares for taxis over short distances characterizing the metropolitan environment may reduce the perception of travel costs associated with taxi use. As expected, business travelers turned out to be less sensitive to costs compared to non-business ones (as in (Pels et al., 2003; Gupta et al., 2008)) across all modal alternatives.

As highlighted by (Ilahi et al., 2021; Rimjha et al., 2021a; Al Haddad et al., 2020), income plays a significant role in shaping traveler preferences for UAM. Estimated models identify that travelers with a gross annual income exceeding 120 K€ are more inclined to choose UAM over other transport modes. Moreover, the influence of other socio-economic variables on mode choices has been proved. In fact, modelling results revealed that travelers aged more than 45 years exhibit a higher inclination towards choosing UAM over public transport for trips accessing and egressing airports. This aged-related preference could be attributed to several factors. For instance, older travelers, who may value convenience and time-saving options more than cost considerations, find UAM attractive due to its potential to reduce travel times, bypassing ground congestion and avoiding delays and idle times. However, a contrasting trend emerges for metropolitan trips, where older travelers show a lower inclination towards UAM (in line with findings by (Ilahi et al., 2021)). This is probably due to the availability of other efficient and competing modal alternatives, such as public transport as for the Milan case. Finally, gender differences emerge as another influential factor in UAM preferences. Particularly, females show less inclination towards choosing UAM for metropolitan trips compared to males (as found by (Al Haddad et al., 2020)). The reasons for this gender discrepancy might be multi-faceted (see (Nasrin and Bunker, 2021) for a review) and it is worth investigating them, for example, in societal norms or safety perceptions related to aerial vehicles.

The analysis of in-vehicle VoTT savings for non-business trips has shown the following results at the sample median for the different transport modes:

- car travels, 4 €/h for metropolitan trips and 21 €/h for trips from/to airports;
- public transport, 9 €/h for metropolitan trips and 6 €/h for trips from/to airports;
- ground taxi services, 26 €/h for metropolitan trips and 44 €/h for trips from/to airports;
- UAM services, 34 €/h for metropolitan trips and 48 €/h for trips from/to airports.

Regarding trips in the metropolitan area, results indicate that travelers exhibit a greater willingness to pay for public transport IVTT savings rather than car ones (the same has been found in (Ilahi et al., 2021; Belgiawan et al., 2019) with reference to other case studies). This finding reflects the perception of the Milan public transport network as highly efficient and timesaving for moving in the city's congested streets. On the contrary, for trips from/to airports, car VoTT savings are about four times higher than PT ones and this could be due to the ability to have more control over travel times when using cars with respect to public transport, therefore reducing the risk of delays and, in turn, of missing a flight. The significantly higher value of car VoTT savings than for PT ones can also be more evident for travelers whose origin or destination is not efficiently connected to the airport by public transport, therefore making potential delays, or even service disruptions, even more predictable.

Moving to the comparison between willingness to pay for UAM and ground taxi IVTT savings, a different behavior for trips from/to airports and for those within the metropolitan area has been found. Particularly, for trips to access or egress airports, the VoTT savings resulted to be slightly different (44 €/h for ground taxis and 48 €/h for UAM services), suggesting how they are perceived as similar competing options. However, the situation changes for metropolitan trips, where the willingness to pay for UAM time savings is about 30% higher than that of ground taxis (34 €/h vs 26 €/h, respectively). This indicates how users perceive aerial services differently from ground ones, and how they are willing to pay a premium for UAM services that avoid the risk of being potentially delayed by congested metropolitan ground networks. Furthermore, when examining VoTT savings for UAM airport shuttles versus metropolitan air taxis, the value for airport shuttles time savings (48 €/h) is found to be approximately 40% higher than that of metropolitan air taxis (34 €/h), underlining the relevance of the spatial pattern of the journey, together with the activities for which it is performed, in relation to its value.

Focusing on the in-vehicle VoTT savings for business trips, the analysis has shown the following results at sample median for the different transport modes:

- car travels, 6 €/h for metropolitan trips and 32 €/h for trips from/to airports, representing a 56% and a 52% increase respectively compared to the non-business counterparts;
- public transport, 10 €/h for metropolitan trips and 8 €/h for trips from/to airports, with a 15% and 37% increase respectively compared to non-business travels;
- ground taxi services, 39 €/h for metropolitan trips and 64 €/h for trips from/to airports, indicating 48% and 44% increase respectively compared to non-business travels;
- UAM services, 44 €/h for metropolitan trips and 69 €/h for trips from/to airports, with a 31% and 44% increase respectively compared to non-business travels (these percentage differences between business and non-business travels are higher than that estimated by (Birolini et al., 2019), dealing with access and egress airport modal alternatives and focusing on the Lombardy Region, but lower to those estimated by (Gupta et al., 2008) or (Tam et al., 2011), in relation to US or Chinese case studies respectively).

Looking at the overall in-vehicle VoTT savings results, it is worth outlining that users tend to value UAM airport shuttle services more than metropolitan air taxi ones. The percentage difference in VoTT savings between these two UAM potential use cases is in a range between 57% and 44%, depending on the demand segment considered, i.e., business, or non-business travelers.

Considering the relationship between the value of travel time savings (i.e., willingness to pay) and ticket fares, along with the anticipated high costs of first UAM services, introducing aerial airport shuttles could potentially yield better financial performances compared to air city-taxis. As a result, aerial airport shuttle services might be the preferred choice for the initial UAM launch and potential UAM operators could be focused on studying current transport services to/from airports to identify those market segments for whom UAM services can be more attractive. Given the highlighted differences in VoTT savings, UAM fare policies could contemplate segmenting tickets based on business and non-business users, while providing differentiated mobility services (or ancillary ones, still enhancing the overall travel experience) tailored to each traveler category. By tailoring UAM services starting from these insights, a more efficient and financially sustainable urban aerial system can be developed, offering a valuable alternative to conventional transport options.

Furthermore, focusing on aerial airport shuttles and considering the competition with other modes of transport, results showed that UAM VoTT savings are 8% higher than ground taxi ones. This relatively small difference indicates that UAM could represent a competitive alternative to taxis for airport-related travels. This analysis can lead to two policy indications for two different stakeholders of the UAM ecosystem. On the one hand, companies interested in building and managing the UAM infrastructures should analyze the origin-destination relations currently served by taxis connecting the city centers to the airports (and vice versa). This would allow to determine the initial optimal locations for vertiports within the metropolitan area. On the other hand, potential UAM operators should carefully plan their pricing policies, addressing as much as possible fare discrepancies between aerial and ground taxi services: ensuring increasingly competitive and affordable fares could lead to a significant modal shift from taxis to UAM services, encouraging the adoption of a new aerial dimension for passenger mobility.

6. Conclusions

This study aimed to contribute to the existing literature by investigating the value of travel time savings (or willingness to pay) for Urban Air Mobility (UAM) services. The research specifically explored the differences between two potential UAM use cases: airport shuttle and city-taxi services. Data from a large-scale revealed (RP) and stated preference (SP) survey from the Milan metropolitan area (Italy) have been collected in the period 2021–2022 and have been subsequently analyzed by means of mixed logit discrete choice models.

Results highlight that the in-vehicle value of travel time (VoTT) savings for UAM airport shuttle services falls in the range of 48–69 €/h, with higher values related to those travelling for business purposes. Likewise, the estimated VoTT savings for UAM city-taxi services fall within the range of 34–44 €/h. Depending on the trip purpose, the VoTT savings for UAM airport shuttle services were found to be approximately 44–57% higher than those for city-taxi ones. These findings suggest that the implementation of UAM airport shuttle services could be the most financially sustainable UAM services, especially in the initial phase when new aerial mobility services are expected to have high fares, gradually decreasing over time. Furthermore, when focusing on airport shuttle services and examining the competition between transport modes, users' willingness to pay for UAM services (48–69 €/h) was found to be 8% higher than that for traditional ground taxis (44–64 €/h). This indicates that differences between the pricing policies of the two modes of transport should be minimized to generate a significant modal shift from ground taxis to new aerial services connecting city centers, or central business districts to intercept those travelling for business purpose, with airports.

Among the limitations of this research, it is important to note that the outcomes of this study rely on specific assumptions and survey data, that might not be directly transferable to other contexts. As stated in the introductory section of this paper, our results could be transferred only to contexts that are characterized by similar multimodal transport systems and urban fabrics. Nevertheless, the methodology proposed can be adapted for the VoTT savings investigation in relation to other case studies.

Future studies could deepen the analysis by researching the impact of individuals' latent traits, such as personal attitudes (e.g., aversion to fly, vocation for technology) and perceptions (e.g., expectations and safety concerns), on VoTT savings for UAM services. Additionally, a joint RP-SP modeling estimation could be conducted, combining information from current RP users' behavior and hypothetical future ones (SP data), thereby reducing potential biases related to the choice situations in the SP experiment. This would provide further insights into the factors influencing users' preferences and decision-making when considering UAM services.

Declarations of interest

None.

CRediT authorship contribution statement

Pierluigi Coppola: Conceptualization, Validation, Writing – review & editing. **Francesco De Fabiis:** Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Fulvio Silvestri:** Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft.

Data availability

The data that has been used is confidential.

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