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Moving toward a More Sustainable Autonomous Mobility, Case of Heterogeneity in Preferences

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Abstract: Autonomous vehicles (AVs) have a number of potential advantages, although some research indicates that this technology may increase dependence on private cars. An alternative approach to bringing such technology to market is through autonomous taxis (ATs) and buses, which can assist in making transportation more sustainable. This paper aims at examining the role of attitudinal, travel-related, and individual factors in preferences for a modal shift from conventional cars toward ATs and exclusive-lane autonomous buses (ELABs), exploring the existence of heterogeneity and its possible sources. The proposed mixed logit model with a decomposition of random coefficients uses 1251 valid responses from a stated preference survey distributed in Tehran, in 2019. Results show that there is significant taste variation among individuals with respect to ATs' travel costs, ELABs' travel times, and walking distances to ELAB stations. Furthermore, exploring the sources of heterogeneity indicates that women are more sensitive to ATs' travel costs and walking distances to ELAB stations while they are less sensitive to ELABs' travel times. Moreover, travel time in discretionary activities reduces the utility of ELABs more than it does in mandatory activities. Transportation authorities can use these findings to establish more effective policies for the successful implementation of AVs.

Keywords: autonomous bus; autonomous taxi; mixed logit; preference heterogeneity; shifting behavior

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1. Introduction

Private vehicle ownership and use has led to many challenges facing metropolises, including threats to public health, air pollution, and congestion. This highlights the need to move towards sustainable cities [1]. In recent years, a growing focus has been placed on new technologies in pursuit of a sustainable urban development pathway [2]. Autonomous Vehicles (AVs), as a new paradigm in mobility, are closer to entering the mass market than ever before in the transportation sector [3,4]. AVs offer a variety of substantial benefits that are expected to revolutionize the transportation industry in the future [5] such as increasing traffic flow efficiency [6,7], allowing optimal use of transport infrastructures [8], reducing fatal accidents [9,10], increasing mobility [11], and development of sustainable and intelligent urban mobility by mitigating the externalities of conventional cars usage [12]. Several studies, however, are concerned about the possibility of negative consequences from these vehicles, including an increase in reliance on private cars [10], a reduction in the share of public transportation [13], and the affordability of purchasing such vehicles based on their expected high price [14]. Autonomous taxis (ATs) and autonomous buses (ABs) can be considered as a possible sustainable solution, as they decrease car ownership and increase vehicle occupancy as well as improve efficiency. ATs and ABs could diminish these detrimental effects and lead to an enhancement in transportation system performance. A combination of conventional car-sharing and automation could be offered by ATs. The use of autonomous taxis may reduce labor costs and waiting times compared to human-driven taxis [15,16]. ABs combine the advantages of public transportation with those of automation. In addition to providing more frequent bus services, ABs are able to cover a wider network of routes, and could thereby help to improve public transportation accessibility [15]. It is expected that if ATs and ABs solutions are used to meet the expectations of different groups, conventional private car ownership will decrease and, as a consequence, negative consequences associated with conventional car dominance will be reduced.

ATs in this study refers to an autonomous door-to-door mobility service, which is booked on-demand without intermediate stops and travels in regular traffic. While exclusive-lane autonomous buses (ELABs) serve passengers on a dedicated fixed route and have predefined stops and timetables, they do not offer door-to-door services and individuals have to walk to their destinations.

It is crucial to understand the factors that influence consumers' preferences for ATs and ABs in order to maximize their potential benefits. However, a limited number of studies have examined the willingness of consumers to choose ATs and ABs. A better understanding allows for better planning and decision-making in alignment with predefined objectives and visions. Potential users of these vehicles have heterogeneous attitudes, perceptions, motivations, preferences, socioeconomic characteristics, and mobility needs. An assessment of policies that takes heterogeneity into account will yield better results as well as a more reliable assessment [17]. This paper, therefore, attempts to (1) gain a more comprehensive understanding of the modal shift preference of conventional car users to ATs and ELABs by combining attitudinal, travel-related, and individual characteristics, and (2) explore the heterogeneity or random taste variation among individuals and the possible sources.

Previous studies have generally examined the effects of attitudinal factors on preferences for various types of AVs [18–21]; some have analyzed only travel-related variables [22–24]; whereas others have explored how individual characteristics may influence the willingness to choose AVs [25]. Considering that human behavior is complex, focusing on only one subgroup of variables (attitudes, travel-related, or individual characteristics) could lead to incomplete results [26]. Several studies have used simple logistic regression or multinomial logit models [27–29]; however, the assumption of homogeneity might fail due to differences in an individual's behavior. Relaxing such a limitative assumption would lead to a more realistic policy-making model since the impact of a particular variable will vary across individuals.

Although some helpful insights have been gained from research on factors that influence the choice of AVs, further research is needed. In addition to sociodemographic and travel characteristics, there is a need for more research on psychological factors affecting the choice of AVs. Thus, by investigating how sociodemographic, travel-related, and psychological factors impact conventional car users' shifting behavior to ABs and ATs, the authors attempted to fill in previous gaps. As part of this study, we are seeking to address several questions, such as which factors affect the shifting behavior of conventional cars to ABs and ATs? Furthermore, which of the significant factors is most impactful on modal shift? Motivated by addressing the aforementioned gaps, the main contributions of this paper are:

1. Most of the previous studies focused on AVs and less attention has been paid to the more sustainable form of this technology such as ABs and ATs.
2. We have considered the heterogeneity in individuals' preferences and explored the source of probable heterogeneity in respondents' behavior.
3. To the best of the authors' knowledge, a few studies considered the combination of attitudinal, travel-related, and individual-related factors in developed countries, and less attention has been paid to this matter in developing countries.

Throughout the rest of the paper, the following structure is followed. Next, we review the variables used in previous studies to evaluate respondents' preferences for AVs. The third section consists of a discussion of the method, questionnaire, and experimental design. The fourth section represents a descriptive analysis of the sample's characteristics. The fifth section presents estimation results for the modal shift model as well as a sensitivity analysis. Finally, conclusions and suggestions for future research are discussed in the sixth section.

2. An Overview of Factors Affecting Preference for AVs

It was a challenge to identify potential factors in this context since ATs and ABs have received relatively little attention, while most studies have focused on AVs. Three subgroups of critical factors were identified, namely (1) attitudinal factors (perceived ease of use, perceived usefulness, social influence, perceived risk, environmental concerns, and driving enjoyment); (2) travel-related variables (such as travel cost, travel time, walking distance, waiting time, and trip purpose); and (3) individual characteristics (such as gender, age, income, education, and the number of experienced accidents) that determine the preference for ATs and ELABs.

2.1. Attitudinal Variables

Attitude plays an important role in the decision-making process [30]. Attitudinal variables are often indirectly measured using psychometric constructs like Likert scales.

Perceived ease of use (PEOU) is one of the attitudinal variables considered in previous studies in the willingness to choose AVs. PEOU is defined as the degree to which an individual believes it would be possible to use a system or technology without physical or mental effort [30]. Studies found it has a positive effect on the preference for AVs [31,32].

Perceived usefulness (PU) is another attitudinal variable investigated in several studies on preferences for AVs [33,34]. It is defined as an individual's belief in increased performance due to the use of a particular system [30]. According to previous studies, PU is positively associated with the choice of AVs [33,34].

Social influence (SI), also referred to as social or mental norm [35], is defined as the impact of influential individuals on their preference for technology. Studies have acknowledged the positive effect of this variable on preference for AVs [36].

Perceived risk (PR) is recognized as the main barrier to the diffusion of technology [37]. In AVs, PR includes system reliability, information hacking, occupant safety, etc. This variable has been proven to have a negative impact on the preference for AVs [38]. Besides, some studies have concluded that PR undermines trust in such vehicles [39].

Environmental concerns (EC) address the awareness of environmental issues and efforts to resolve such problems [40]. A variety of views have been expressed regarding the impact of AVs on the environment. A number of researchers have found that AVs can reduce fuel consumption and will use alternative fuels [41]. On the other hand, some studies found that such vehicles increase environmental pollution due to higher mileage and fuel consumption [42]. According to research on the influence of environmental concern on AV preferences, individuals who are concerned about environmental issues are more likely to choose AVs, since people with a higher level of life quality have a greater concern for environmental problems and this would positively influence AVs preference [43].

Driving Enjoyment (DE) is defined as the enjoyment experienced through manual driving with an emphasis on the positive aspects of driving-related activities (rather than simply arriving at the destination). Under the fourth level of autonomy proposed by NHSTA [44], all driving tasks are carried out by the vehicle and all occupants are considered to be passengers. Thus, it is anticipated that people who drive for fun will be less likely to choose AVs [45].

2.2. Travel-Related Variables

Preferences toward AVs are also affected by instrumental variables, which can be described as factors that generally have a direct influence on travelers' preferences. In modal shift studies, these variables reflect the characteristics of a system and are considered to be the distinguishing characteristics of the alternatives [46]. A number of variables are crucial in this category, including travel time, travel cost, waiting time, and walking distance. A number of studies have examined the effect of these variables on travelers' preferences for AVs [22,23]. There have been studies that conclude that travel costs have the greatest influence on the willingness to choose AVs [22]. The benefits of AVs, despite the higher costs, have led some studies to assert that people are more willing to choose AVs [38]. In addition, the impact of travel time and waiting time has been explored on the preference for AV. In some studies, these two variables appear to have a key negative influence on the utility of AVs [22]. Several studies have also been conducted to investigate the productivity of travel time, as automation reduces the negative impact of long travel time by enabling travelers to make better use of their travel time [47]. Moreover, there is an influence of travel purposes on the willingness to choose AVs. For instance, on long-distance and leisure trips, people are more likely to choose AVs. On such trips, people are able to take advantage of the benefits of AVs, as well as do other activities such as spending time with their families and engaging in other leisure activities [26].

2.3. Individual Characteristics

Individual characteristics can be used to categorize participants into several groups and analyze their opinions regarding AVs. In terms of gender, previous studies found contradictory findings about preference toward AVs [48,49]; according to some studies, men are more likely to choose AVs due to a higher perceived risk level than women [48]. However, others suggest women are more likely to prefer AVs due to the fact that men prefer not to travel in fixed lanes and prefer to maneuver while driving [46]. Study results comparing the preference for AVs in North America and Israel reveal that gender has no significant effect in North America, whereas women are more likely to choose AVs in Israel [25]. In this regard, the literature does not demonstrate a clear relationship between preferences and gender. In terms of age, it is expected that AVs will increase the mobility of the elderly. Although cognitive limitations and a lack of willingness to take risks may prevent this age group from choosing AVs [50]. An intuitive relationship exists between income and preference for AVs. In general, individuals with higher incomes are more likely to choose AVs. Perceptions and preferences regarding AVs can be affected by education. As educated individuals spend a significant amount of time on the internet, they are likely to be more familiar with these technologies, which may enhance their confidence in AVs [51]. The most significant advantage of AVs, according to some studies, is a reduction in the number of accidents [52]. As a result of these vehicles, human error, the primary cause of most accidents, can be significantly reduced or eliminated. Therefore, individuals who have experienced accidents are more likely to choose AVs [53].

The literature review indicates that most studies have focused on preferences for AVs and less attention has been paid to other sustainable modes such as ATs and ABs. Furthermore, most studies have focused only on one of the influential factor categories that contribute to the willingness to choose AVs. In order to fill these gaps, we examine several barriers to the modal shift from conventional cars to the two types of AVs identified in the literature review. We also incorporate various variables into the choice model in order to gain a better understanding of how people prefer ATs and ELABs. The study also examines the heterogeneity among individuals and its possible sources with respect to attitudinal, travel-related, and individual characteristics.

3. Method and Materials

3.1. Mixed Logit with the Decomposition of Random Coefficients

Using a mixed logit model with the decomposition of random coefficients, it is possible to identify the existence of any heterogeneity and its possible sources. Unlike multinomial logit, this model does not exhibit the IIA restrictions and accounts for random taste variation and unrestricted substitution patterns, as well as the correlation among unobserved factors over time [54]. In this model, the utility function of alternative i for individual n is defined as Equation (1).

$$U_{ni} = {\beta'}_n X_{ni} + \varepsilon_{ni} \quad (1)$$

where ${\beta'}_n$ is the vector of the coefficients, X_{ni} is the vector of the attributes related to alternative i and individual n, and ε_{ni} is the stochastic part of the utility function [55].

Preference heterogeneity can be addressed in the model using Equation (2);

$$\beta_n = \beta + \Delta z_n + \eta_n \quad (2)$$

where β_n represents the random coefficients from the perspective of the nth individual. In this equation, systematic heterogeneity may be represented with the mean distribution of random coefficients as expressed by Δz_n, in which Δ is a vector of parameters related to the observed properties of z_n. Random heterogeneity is also expressed by the random vector (η_n). Finally, the probability of choosing alternative i by individual n is calculated as Equation (3).

$$P_{ni} = \int \frac{\exp\left({\beta'}_n X_{ni}\right)}{\sum_{j=1}^{J} \exp\left({\beta'}_n X_{nj}\right)} f(\beta|\theta, z_n) d\beta \quad (3)$$

where $f(\beta)$ is the density function, θ is the vector of underlying parameters of the distributions of the $\beta's$. Using simulation, the integral is approximated and a defined number of draws are performed for a given value of θ and β_n [55].

3.2. Conceptual Model Framework

Most research on the preferences for ATs and ABs has been conducted in developed countries [56,57]. However, it is not possible to generalize policy-setting results to developing countries due to expected differences in various context-based aspects. This research develops a choice model by incorporating attitudinal, travel-related, and individual variables to investigate preference for ATs and ELABs (Figure 1) in Tehran, the capital of Iran.

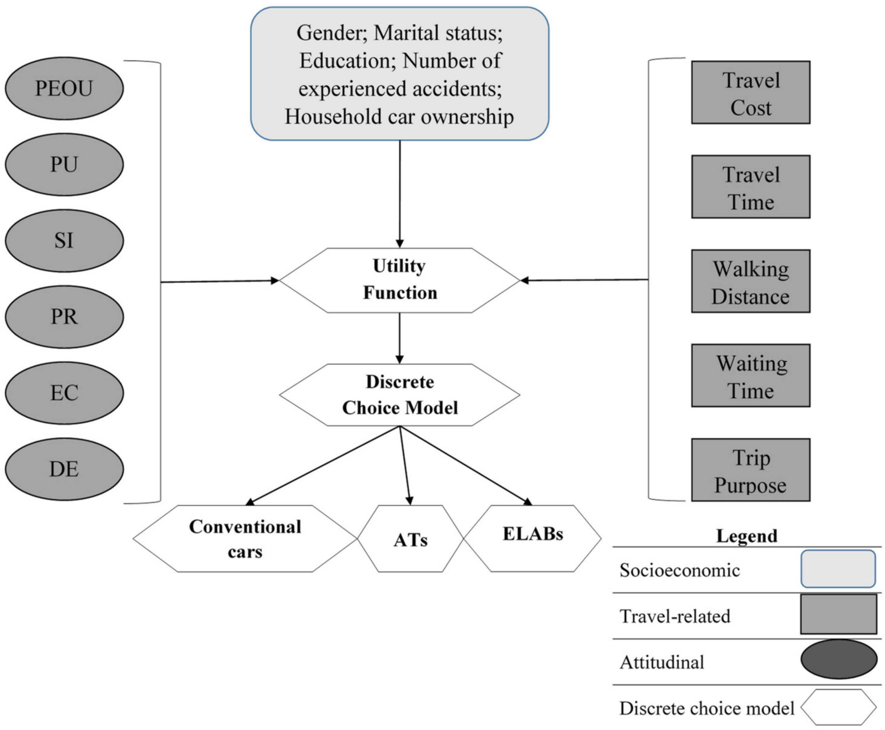

Figure 1. Conceptual model for investigating individuals' preference towards ATs and ELABs.

3.3. Questionnaire and Experimental Design

The setting of this research is Tehran, the capital of Iran. We have chosen the city of Tehran as a case study because it is the most likely place in Iran where AVs will be used for the first time in the market. The questionnaire used in this study was designed using a stated preference approach and was randomly distributed among private car users in 2019. Two reasons suggest the use of a stated preference survey: first, the costs involved in collecting revealed preference data (both in terms of money and time), and, second, the absence of ABs and ATs in Tehran. In stated preferences data, respondents make decisions under hypothetical conditions in which personal constraints are not taken into consideration [55]. The questionnaire consists of five sections as follows.

- Section one: An explanation is provided to the participants about the anonymity and confidentiality of their responses, the objectives of the survey, and the research procedures. Afterward, they are asked to consider their last trip and to answer questions regarding the trip's purpose, departure time, and travel time.
- Section two: A short video clip is shown to participants to explain the characteristics and capabilities of AVs, as well as how these vehicles can meet their mobility needs.
- Section three: Addressing attitudinal variables affecting preference for AVs. Individuals are asked to rate their agreement with a series of statements on a five-point Likert scale (from 1 (strongly disagree) to 5 (strongly agree)).
- Section four: Using different stated preference scenarios of travel cost, travel time, waiting time, and walking distance, participants are asked to choose their preferred mode among conventional car (no modal shift), ATs or ELABs (modal shift from a conventional car to AVs). Waiting time and walking distance had a constant level while travel cost and travel time are expressed as deviations from the travel characteristics addressed in the first section of the questionnaire. The travel-related attributes and their levels considered in this section are presented in Table 1.

Table 1. Travel-related attributes and their levels were considered in the questionnaire.

Attributes	Levels for AT	Levels for ELAB
Travel cost (IRR * for every 5 min of travel)	20,000 32,000 46,000	6000 9000 20,000
Change in travel time (%)	−10 0 15	−15 0 10
Waiting time (min)	0 5 7	5 10 15
Walking distance (m)	N.A.	100 200 500

* 140,000 Iranian Rials (IRR) were worth 1 US$ at the time of the survey. N.A.: Not Applicable: since ATs offer door-to-door services.

Using SAS software, the choice experiment was designed based on the efficient design approach. The experimental design was based on the assumption that the efficient design method for linear models can also be applied to discrete choice models [58]. This design resulted in the use of only 18 choice tasks. Considering time limitations, the choice experiments were divided into six three-scenario blocks.

- Section five: socioeconomic characteristics such as gender, marital status, age, education, number of accidents experienced in the previous year, and the number of cars in the household (as a proxy of income) were asked.

For determining the sample size, we used Equation (4), proposed by [59] to find an adequate sample:

$$n_0 = \frac{pqz^2}{e^2} \tag{4}$$

where n_0 is the sample size, z is the standard error associated with the considered confidence level (Typically 1.96), p is the (estimated) proportion of the population that has the attribute in question, q equals $1 - p$, and e is the acceptable sample error. The statistical report of the "Transportation and Traffic Organization of Tehran Municipality" suggested a value of 0.43 for p (private car users in Tehran [60]), resulting in a required sample size of 377 at 95% confidence level $\pm$5% precision. However, the number of observations used in this study is 1251 (417 questionnaires and each questionnaire has 3 scenarios).

4. Sample Characteristics

After refining the collected data by omitting the incomplete questionnaire, a total of 417 valid responses were used for analysis purposes. Frequency analysis (Table 2) indicates that the distribution of respondents' gender is balanced (49% female vs. 51% male). The following had the highest share in their groups: individuals who are married, aged 25–44, graduated from a university, or have not experienced an accident in the last five years. Concerning the trip purpose, work trips (25%) had the highest frequency while personal affairs (such as visiting government offices) (12%) had the lowest. Since the age and gender distribution comparison of the sample data and Tehran's 2016 census showed an insignificant difference in the average age (μ = 35.9 in the sample vs. μ = 36.8 in the population [60]) and gender (51% male in selected sample vs. 52.3% in the population census), the sample is assumed to be a valid representation of Tehran population.

Table 2. Frequency analysis of individual characteristics and travel purpose in the research sample.

Item	Frequency	Relative Frequency (%)
Gender		
Female	205	49
Male	212	51
Marital status		
Single	198	47
Married	219	53
Age		
14 or under	21	5
15–24	48	12
25–44	252	60
45–64	68	16
65+	28	7
Education		
High school or lower	30	7
Diploma degree	165	40
University degree	222	53
Accident in the previous year		
0	306	73
1	87	21
2+	24	6
Number of household cars		
0	57	14
1	198	47
2+	162	39
Travel Purpose		
Work	105	25
Educational	60	14
Shopping	80	19
Leisure	70	17
Returning home	56	13
Personal affairs	46	12

Figure 2 shows the shifting preferences of respondents, stratified by socioeconomic characteristics and trip purposes. It can be seen that women prefer ATs twice as much as men do. However, no significant difference has been observed in choosing ELAB. Furthermore, considering higher income and dependence on private cars among men, more than 50% of males preferred to continue using their conventional cars. Married individuals are equally likely to choose conventional cars or ELABs. Compared to single individuals, married were more likely to choose ATs or ELABs and less likely to choose conventional cars. As age and education level increase, individuals are more likely to choose ELABs. Moreover, it can be seen that elderlies are more willing to choose ATs or ELABS due to their limitations in using private cars. As the number of experienced accidents increases, conventional cars are less likely to be chosen and respondents prefer to choose ATs or ELABs. ATs were chosen more often when the trip purpose was to return home while ELABs were chosen more often when traveling for leisure or education.

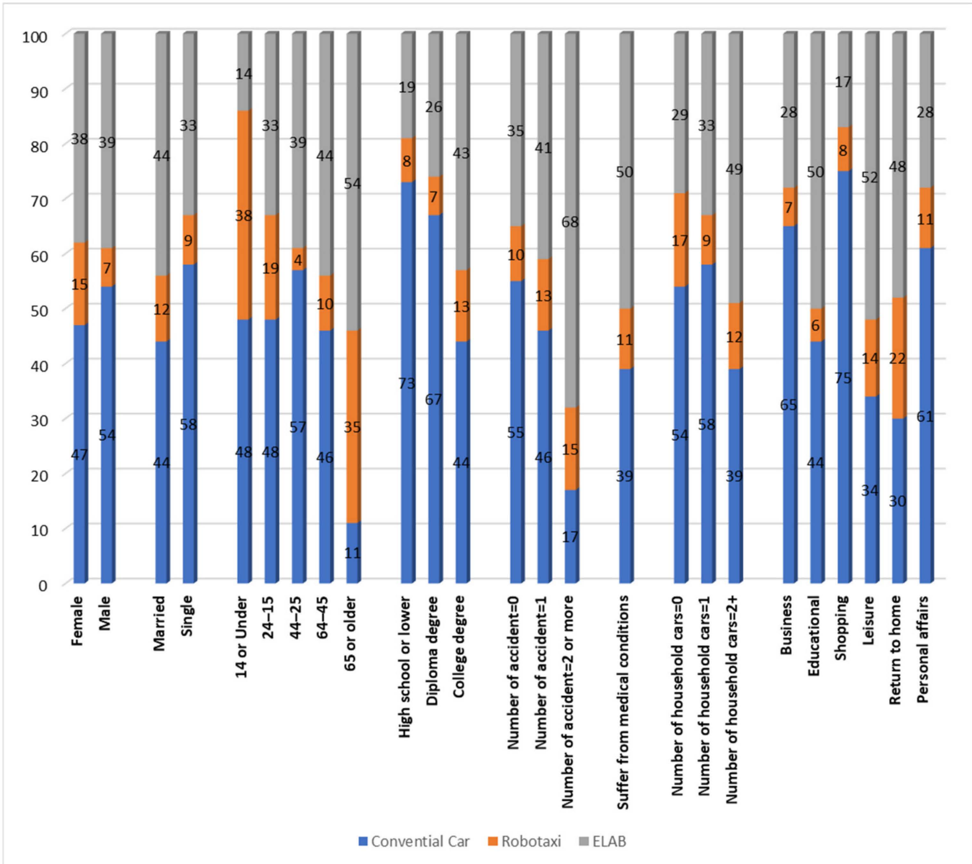

Figure 2. Modal shift preference across based on individual characteristics and travel purpose.

5. Estimation Results and Discussion

5.1. Confirmatory Factor Analysis

Confirmatory factor analysis was performed using Amos25 software (Table 3). To evaluate the reliability of factor analysis, all Construct Reliabilities (CRs) must be greater than 0.7. Convergent validity is accepted if four conditions are met: (a) significant regression coefficient, (b) standard regression coefficient greater than 0.5, (c) CR > Average Variance Extract (AVE), and (d) AVE > 0.5 [61]. An examination of these criteria (Table 3) as well as the goodness of fit evaluation criteria of confirmatory factor analysis (Table 4) indicate the data fit the model very well and the model met the reliability and validity criteria.

5.2. Mixed Logit Model with the Decomposition of Random Coefficients Estimation

Table 5 presents the significant explanatory variables in the best-fit model. The simulation-based mixed logit model was estimated using 200 Halton draws, which is suitable for calculating multi-dimensional integrals or in quasi-Monte Carlo simulations [55].

We investigated five distributions of random heterogeneity for all coefficients, namely normal, lognormal, uniform, triangular, and Weibull. A number of attitudinal, travel-related, and individual variables were used in order to investigate whether there was any source of heterogeneity in the data. (Table 6).

Table 3. Results of confirmatory factor analysis for attitudinal variables.

Construct	Item	Standardized Regression Weight *	CR	AVE	Reference
PU	AVs give me faster and easier access to transportation.	0.714	0.876	0.707	Adapted from [21] [52]
	Overall, they are a good transportation alternative.	0.898			
	They relieve my driving stress.	0.759			
	They reduce traffic.	0.713			
PEU	It will be easy for me to learn how they work.	0.959	0.856	0.600	[62]
	It will be easy for me to learn the skills required to use them.	0.871			[53]
	I do not need much mental effort to interact with them.	0.665			[50]
SI	If individuals who are important to me use it, I will be more likely to choose them myself.	0.728	0.863	0.615	[17]
	Individuals who are important to me will think I should use them too.	0.843			
	In the future, individuals will use them because others use them.	0.665			[19]
	Individuals who influence my behavior will encourage me to use it.	0.881			[18]
PR	I am generally worried about using it.	0.844	0.875	0.703	[38]
	I am concerned about its safety.	0.958			
	I am concerned about the shared use of transportation infrastructure by AVs and conventional cars.	0.692			
EC	I am worried about global warming.	0.577	0.758	0.517	[28]
	We must decide and act on controlling greenhouse gas emissions.	0.701			
	I would like to pay more to buy products that are more environmentally friendly.	0.853			
DE	I find driving to be very entertaining.	0.871	0.778	0.546	[52]
	I enjoy driving.	0.744			
	My driving skills are superior to those of others.	0.570			

* All standardized regression weights have become significant at the level of less than 0.05.

Table 4. Evaluation of confirmatory factor analysis.

Criteria	Symbol	Acceptable Threshold [61]	Obtained Value
Chi-square/df (CMIN/DF)	$??^2/df$	<3.0	2.775
Comparative Fit Index	CFI	>0.90	0.947
The Normed Fit Index	NFI	>0.90	0.920
Goodness of fit	GFI	>0.90	0.920
Adjusted Goodness of fit	AGFI	>0.80	0.897
Root Mean-Square Error of Approximation	RMSEA	<0.08	0.053

Table 5. Estimation results of mixed logit model with the decomposition of random coefficients.

Alternative	Variable	Description	Coefficient	t-Value
Car (without modal shift)	PU	Perceived Usefulness	−1.40 **	−2.51
	PR	Perceived Risk	0.46 **	2.31
	DE	Driving Enjoyment	0.77 ***	2.96
	Education	Level of education (ordered)	−0.72 ***	−3.16

Table 5. *Cont.*

Alternative	Variable	Description	Coefficient	t-Value
AT	ASC	Constant	−3.05	−1.44
	CostAT(R)	Cost of ATs (in terms of 100,000 IRR)	−7.91 ***	−2.69
	Female	Gender (Female = 1)	4.31 ***	3.77
	Fveh2+	Number of cars in household (2 or more = 1)	3.09 ***	2.80
ELAB	ASC	Constant	−1.72	−0.86
	SI	Social Influence	−0.66 **	−1.97
	EC	Environmental Concerns	0.82 **	2.47
	TtELAB(R)	Travel time by ELABs (minute)	−0.13 **	−2.02
	WalkELAB(R)	Walking distance to reach ELAB stops (meter)	−0.01 ***	−3.29
	Educational	Educational trip (1 = yes)	2.07 **	2.01
	Leisure	Leisure trip (1 = yes)	2.41 ***	3.54
	ACC	Number of accidents in the previous year (ordered)	0.93 **	2.70
Model Statistics: Number of observation = 1251 LL(β): −810.99 LL(0): −1374.36 $\rho^2 = 0.41$				

Note: ***, ** = Significance at 1%, 5%, levels; LL(β): Log-likelihood at convergence; LL(0): Log-likelihood at zero; R: Random.

Table 6. Distributions of the random parameters and source of heterogeneity.

Alternative	Random Parameter	Distribution	S.D.	Source	
				Attribute	Coefficient
AT	CostAT	Normal	1.98 **	Female	−3.77 ***
ELAB	TtELAB	Weibull	0.06 ***	Discretionary	−0.05 *
				Female	0.07 *
	WalkELAB	Normal	0.004 **	Female	−0.006 **

Note: ***, **, * = Significance at 1%, 5%, 10% levels.

Based on the estimated coefficient for perceived usefulness (β= −1.40) it can be concluded that if individuals believe AVs enhance their performances, they are less likely to choose conventional cars which is in line with previous findings [33,34]. AVs can be beneficial in many ways, including the ability to use online information to travel more quickly and safely, and the possibility of spending time on other activities, such as watching TV, working, doing personal tasks, or other productive activities.

This research examines the physical risk (injury to passengers resulting from improper operation of AVs). In line with previous studies [38,39], PR has been significant with a positive sign (β = 0.46), indicating a lower likelihood of modal shift to AVs among car users. Thus, if AVs are perceived to be more dangerous, individuals will be more inclined to choose conventional cars. Consequently, it is recommended that AVs be mainstreamed by raising awareness of their proper operation (reducing accident risk) and enhancing passenger safety.

As the level of automation increases, driving enjoyment decreases while the psychological gap between the driver and the vehicle widens. A fully operational AV operates as an independent entity, which means the driver is no longer confronted with challenging situations and is not able to utilize their skills. It was observed that respondents who enjoy driving are more inclined to choose conventional cars (β = 0.77), which is consistent with previous research [45,62].

In line with previous research [25,51], it is observed that as education level increases, the probability of choosing the conventional car decrease (β = −0.72), which is due to a higher awareness of AV technologies as well as a higher willingness to try new technologies. Moreover, this group has a higher value of time and, therefore, a higher interest in being able to accomplish other tasks while traveling.

An examination of variables in the utility of ATs shows that as the travel cost increases, the probability of choosing such vehicles will decrease (β = −7.91). Moreover, women are more likely to choose the ATs than men (β = 4.31). This can be due to higher privacy/security or preventing possible crime/harassment on public transport [63].

Considering the number of cars in a household as a proxy of income, the positive sign of coefficient (β = 3.09) for individuals owning at least two private cars indicates that high-income individuals are more likely to choose ATs because they tend to embrace new technologies. Moreover, they have a higher value of time and prefer ATs because of their superior flexibility, less waiting time, and shorter walking distances.

According to the social influence coefficient (β = −0.66), it can be concluded that if individuals think that the people influencing them will encourage them to choose AVs, they will be less inclined to choose ELABs which is explained by the fact that status (prestige) is important to such individuals.

Due to their efficient driving method, ELABs combine public transportation with an environmentally friendly driving system [64]. Researchers have concluded that ABs are an appealing alternative for individuals who have high environmental concerns [56]. Individuals with an environmentally conscious attitude are more likely to choose ELABs, based on the positive sign of the coefficient (β = 0.82).

As individuals experience more accidents, their preference for ELABs will be increased (β = 0.93), which is in line with the findings of previous research [53]. This is due to potential concerns arising from past experiences. These individuals prefer to choose ELABs because they operate in an exclusive lane.

People are more likely to choose ELABs on educational trips (β = 2.07). People traveling for such purposes are usually young people who have a greater understanding of AVs due to their increased access to the internet. Alternatively, this group prefers ELABs, which are cheaper, due to a lack of financial independence. By taking advantage of AVs, people can have leisure activities during their trips. Previous studies have also shown that people are less willing to pay for discretionary trips compared to mandatory ones [24]. Based on the proposed model, people on leisure trips are more likely to choose ELABs (β = 2.41). There is an expected negative sign to the coefficient of variables for travel time (β = −0.13) and walking distance (β = −0.01) to the bus station. The results show that the disutility of ELABs increases with the increase of these two variables, therefore reducing the likelihood of choosing such technology.

5.3. Preference Heterogeneity

Findings indicate significant taste variations in response to travel cost by ATs (CostAT), travel time by ELABs (TtELAB), and walking distance to ELAB stations (WalkELAB) variables. It appears that the Weibull distribution is more suitable for explaining the random taste variation among individuals in response to TtELAB, whereas the normal distribution may best explain the heterogeneity of preferences regarding CostAT and WalkELAB (Table 6).

The Observable part of the utility function of three alternatives can be mathematically expressed as Equations (5)–(7). The source of heterogeneity for these variables was discovered using decomposition effects. A negative sign of the female variable for the random coefficients (−3.77 for CostAT in ATs and −0.006 for WalkELAB in ELABs utility) indicates that this dummy variable (female) will reduce marginal utilities of cost in AT, and walking distance in ELABs. More specifically, women are more sensitive to the cost of traveling by ATs, and walking distance to reach the ELAB stations. Moreover, considering the positive sign of this variable in Equation (7) (0.07), indicate women are less sensitive to travel time by ELABs than men are.

Besides, the marginal utility of travel time by ELABs is partially influenced by trip purpose. The negative sign of this variable (−0.05) indicates that in discretionary trips, travel time has a more negative effect on the utility of ELABs.

$$V_{Conventional\ car} = -1.40 \times PU + 0.46 \times PR + 0.77 \times DE - 0.72 \times Education \quad (5)$$

$$V_{AT} = -3.05 + [-7.91 - 3.77 \times Female + 1.98 \times n] \times \text{Cost}AT + 4.44 \times Female + 3.25 \times Fveh2 \quad (6)$$

$$V_{ELAB} = -1.72 - 0.66 \times SI + 0.82 \times EC + [-0.13 - 0.05 \times Discretionary + 0.07 \times Female + 0.06 \times w] \times TtELAB + [-0.01 - 0.006 \times Female + 0.004 \times n] \times WalkELAB + 2.07 \times Educational + 2.41 \times Leisure + 0.93 \times ACC \quad (7)$$

Note: In Equations (5)–(7) w and n mean Weibull and Normal distribution for random variables, respectively [63].

5.4. Policy Implications

This study determined the elasticity of a number of attitudinal and travel-related variables that are affected by policy-making in order to better understand the sensitivity of individuals to changes in variables and to make optimal decisions (Table 7). According to the results, the elasticity of travel cost by ATs is −1.43, indicating a one percent increase in travel cost of ATs will decrease the likelihood of choosing ATs by 1.43% while increasing the probability of choosing conventional cars and ELABs by 0.17% if other variables are held constant.

Table 7. Aggregate elasticities (direct and cross) of attitudinal and travel-related variables.

Variable	Alternative		
	ELAB	**AT**	**Conventional Car**
PU	0.84	1.14	−0.88
PR	−0.24	−0.29	0.24
EC	0.71	−0.61	−0.42
CostAT	0.17	−1.43	0.17
TtELAB	−0.35	0.22	0.22
WalkELAB	−0.38	0.33	0.21

According to PU, the aggregate direct elasticity of choosing conventional cars is −0.88%. Perceived risk elasticity analysis indicates a one percent increase in such a variable increases the likelihood of choosing conventional cars by 0.24%, and the probability of choosing ATs and ELABs by 0.29% and 0.24%, respectively. The conclusion can be drawn that if individuals are informed that AVs have successfully passed multiple safety tests, they are likely to shift to AVs that are less likely to cause accidents, reduce physical injuries, and reduce financial losses. EC variable elasticity is 0.71 for ELABs, −0.42 for conventional cars, and −0.61 for ATs, indicating individuals with environmental concerns are more inclined to choose ELABs. Thus, it is, therefore, possible to encourage more individuals to shift to ABs by electrifying them or increasing their fuel efficiency.

By offering fare subsidies to women and by setting up bus stations within acceptable walking distance, authorities can also increase the use of ATs and ELABs. Furthermore, optimal navigation can lead to a reduction in travel time, which increases the willingness to use these vehicles.

6. Summary and Conclusions

The development of fully Autonomous Vehicles (AVs) is one of the key achievements that significantly impact various aspects of the transportation system. There are many potential benefits and costs associated with AVs. The use of autonomous taxis (ATs) and buses (ABs) can be one of the effective alternatives to reducing the negative impact of privately owned AVs. ATs and ABs can be used to achieve sustainable urban transport goals more effectively. By increasing vehicle occupancy and decreasing car ownership, these vehicles may reduce the negative environmental and public health effects of private AVs. Several studies have been conducted to examine the factors influencing preference for

ATs and ABs. There is still a need to research factors influencing the choice of ATs and ABs over conventional cars, especially in light of the effects of heterogeneity among individuals.

It is imperative to note that most research concerning AV preferences is conducted in developed countries, which is not applicable to developing countries. In general, developing countries lack customized national policies to encourage their people to use AVs, so they mainly follow policies established by developed countries. We, therefore, aim to understand and investigate the preferences of such modes of travel in Iran, as a developing country. In this study, we examined how potential users prefer ATs or exclusive-lane autonomous buses (ELABs) to conventional cars. To determine the explanatory variables affecting the modal shift preference of individuals, this research categorizes the factors into attitudinal (perceived ease of use, perceived usefulness, social influence, perceived risk, environmental concerns, and driving enjoyment), travel-related (travel time, travel cost, waiting time, walking distance, and travel purpose) and demographic characteristics (gender, education, number of accidents experienced in the previous year, and the number of vehicles in the household). Using 1251 observations gathered through a stated preference survey conducted in Tehran in 2019, the mixed logit with the decomposition of random coefficients (with the ability to explore sources of heterogeneity across respondents) is then estimated.

Descriptive analysis of data shows that more than 50% of respondents' trips with leisure and educational purposes, individuals over 65 years of age, or who had experienced two or more accidents in the previous year are more likely to choose ELABs. However, respondents who were married, women, those possessing an advanced educational degree, those living in a household without a car, those returning home, those having experienced more than one accident in the past year, or those less than 14 years of age were more likely to utilize ATs.

Estimation results of the random parameter model indicate the existence of heterogeneity in preferences in the random coefficients of travel cost by ATs as well as travel time and walking distance for ELABs. Based on the results, gender and discretionary trip purpose explain taste variations in marginal utility between individuals, indicating that women are more sensitive to the travel costs of ATs and the walking distance to ELAB stations than men. Women, however, are less sensitive to ELABs' travel time than men. Moreover, on discretionary trips, travel time by ELABs will have a more negative impact on utility.

7. Limitations and Recommendations for Further Research

In this study, a variety of variables were considered in the evaluation of willingness to choose ATs and ABs. Concerning the limitations of this study, it should be noted that it was conducted in Tehran, Iran. In light of the diversity of many factors, it may be difficult to generalize findings. Nevertheless, this model may be applicable to other contexts as a way to predict how people will shift to ABs and ATs. Even with some insightful findings that could help decision-makers, there are still some unanswered questions that need to be addressed in future research.

First: due to the absence of AVs in Iran, we used a stated preference questionnaire. After the introduction of AVs, further research can be conducted by comparing the results of the stated preference questionnaire to those of the revealed preference questionnaire.

Second: the participants in the current study were informed that ELABs were scheduled. There is the potential for future studies to examine the perception of waiting time on preference for ABs.

Third: in this study, we explore general consumer preferences for two types of AVs. It may be possible to compare and evaluate the preferences of different groups in the future, such as the elderly and those without driving licenses.

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