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Private Car Ownership in Presence of Shared Autonomous Vehicles, Case of Tehran

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ABSTRACT: With the advent of autonomous vehicles (AVs), researchers have conducted various studies on the impacts of these vehicles, but limited research is found on the influence of AVs on private car ownership. Since AVs are not well-aligned with sustainable development, shared autonomous vehicles (SAVs) would be an appealing alternative. Hence, this paper aims to investigate the impact of socio-economic and travel-related characteristics on private car ownership in the presence of SAVs among private car users in Tehran. After designing a web-based stated preference (SP) questionnaire and analyzing 2154 valid SP responses in 2022, more than a quarter (26%) of the observations are willing to reduce private car ownership level in presence of SAVs. Estimation results of binary logit model reveal that respondents aged 31-35 and 22-25 years old, as compared to other age categories, are more and less, respectively likely to sell their private cars. Further, due to the fact that users of SAVs, unlike private cars, do not need parking space, respondent are more likely to sell their private cars under this condition. Estimated coefficients of attributes considered in the SP scenarios indicate that increasing each of these attributes (travel time, waiting time, travel cost and number of passengers) in SAVs reduce the likelihood of selling a private car. Another important finding is the impact of respondents' experience with internet taxis (taxis ordered via an app on smartphones); those with frequent use or satisfy with this service, are more likely to reduce their car ownership.

KEYWORDS: Shared Autonomous Vehicle (SAV), Car Ownership, Stated Preference, Binary Logit.

1. INTRODUCTION

Increasing car ownership and population in the world, especially in developing countries, have led to numerous problems such as traffic congestion, increased accidents, reduction in utilization of sustainable and active travel modes, and dependence upon private cars (Abbasi & Hadji Hosseinlou, 2022; Abbasi et al., 2020). The car-oriented environment of Tehran leads to making a considerable proportion of trips (approximately 46%) by private cars (Aboutorabi Kashani et al., 2023; Seyedabrishami et al., 2012). Moreover, about 25 thousand Iranians died due to human error in accidents in 2013 (WHO, 2013). Furthermore, Tao et al. (2019) found that private car owners have a prejudice against other transportation modes (Tao et al., 2019). Accordingly, policymakers are thinking about the introduction of modern, efficient, and sustainable transportation systems in order to reduce reliance on private cars (Abbasi et al., 2023; Farzin et al., 2023). One of the solutions is autonomous vehicles (AVs), which have the potential to be beneficial in a variety of fields. Several studies have demonstrated that AVs can reduce car ownership, accidents, traffic congestion in urban areas, parking spaces, and air pollution (Duarte & Ratti, 2018; Jiang et al., 2019). Studies have found that AVs would offer greater convenience and comfort than sustainable modes of transportation, which will lead to an increased use of these vehicles (Litman, 2017). In this regard, shared autonomous vehicles (SAV) have emerged as a more sustainable transportation mode due to the integration of shared mobility services (e.g. car sharing and ride sharing) and autonomous technology (Golbabaei et al., 2021). There is a limited literature on SAVs, but the present studies have shown that they can reduce car ownership, vehicle kilometers traveled (VKT), congestion, and improve both road safety and air quality (Jones & Leibowicz, 2019; Menon et al., 2019). As AVs become increasingly popular and expanded, SAV services will become more affordable and convenient (Fagnant & Kockelman, 2015; Stocker & Shaheen, 2018). Although SAVs may offer many potential advantages, there are still many challenges associated with these vehicles such as public acceptance, legal liability, and system security.

As there is a lack of research pertaining to the effect of SAVs on car ownership, this study aims to identify the factors contributing to the decrease in household car ownership in Tehran. We investigated the effectiveness of these factors using a stated preference (SP) questionnaire and a discrete choice model. The main contributions of this study are:

1. The majority of previous studies have been conducted in developed countries, and not much attention has been paid to this issue in developing countries.
2. Designing and using the SP survey containing various attributes such as travel time, waiting time, travel cost and the number of passengers sharing their ride in the SAV.
3. The majority of previous studies, such as Menon et al. (2019) have focused on a specific group with a university degree, however, to better generalizing the findings, our study selected sample involving the respondents who use their household car as a driver or passenger.

The paper structure is summarized as: Section 2 reviews the impact of some factors on private car ownership in previous studies. The research methodology will be discussed in Section 3, and in section 4, the discussion and estimation result of the proposed model are presented. Finally, in Sec-

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tion 5, conclusions and suggestions for future research will be presented.

2. LITERATURE REVIEW

Firstly, this section examines the existing literature about the impact of various factors on private car ownership, and then it discusses what factors influence the level of private car ownership when AVs and SAVs are available in the market.

2.1. Impact of various factors on car ownership

In this section, a number of previous studies have been reviewed to determine the impact of different factors on private car ownership. A variety of results have been reached regarding the impact of socioeconomic characteristics. For instance, Millard-Ball and Schipper examined the data collected in consecutive years from United States, France, Australia, England, and Canada and found that ownership among the young generation has declined over time (Millard-Ball & Schipper, 2011). In addition, Dargay & Hanly (2007) investigated the effect of changes in living conditions and found that events such as employment and marriage lead to a statistically significant change in car ownership. Clark et al. (2016) investigated the impact of factors on change in the level of ownership over time and, as Dargay and Hanly (2007) noted, found that factors such as a family member reaching the legal driving age, marriage, and retirement significantly influence the changes in the level of car ownership. The household car ownership level, the role of each person in a household, as well as age and education, are other socioeconomic factors that affect car ownership level (Clark, 2012; Hossein Rashidi & Mohammadian, 2016). In addition to socioeconomic factors, transportation system network also influences household car ownership (Shaygan et al., 2017). Using a simulation tool, Mulalic & Rouwendal (2020) demonstrated that an increase in coverage of transit will reduce household car ownership. Furthermore, Holmgren (2020) concluded that an increase in public transportation level of service will affect private car ownership level.

2.2. The impact of shared mobility services on car ownership

A number of studies have confirmed the reduction of private car ownership as a consequence of shared mobility services. Using GPS data, Becker et al. (2018) examined the capability of free-floating car-sharing in reducing private car ownership. Zhou et al. (2020) explored the impact of car sharing on private car ownership using nested logit model. Their findings showed that this service was associated with a decrease in private car ownership (Zhou et al., 2020). Using latent class model, Liao et al. (2020) investigated the effect of car sharing on private car ownership in Germany. Their findings revealed that about 40% of drivers would prefer to use car sharing services rather than private car in some of their trips. In addition, 20% of the respondents would not purchase a car if sharing stations were easily accessible (Liao et al., 2020).

Many researchers believe that SAVs will revolutionize the transportation system due to the emergence of AVs and the rise of car sharing users (Bansal & Kockelman, 2017; Hawkins & Nurul Habib, 2019). The introduction of SAVs has motivated researchers to investigate their potential impacts on transportation systems. It has, however, been less investigated how these vehicles affect the private car ownership. In 2019, a study was conducted in the U.S. by Menon et al. (2019) and people were asked about the likelihood of selling a household car in presence of SAVs. The research sample consisted of employees of the American Automobile Association and students, and their willingness to sell private cars in presence of SAVs was asked through a 5-point Likert scale. According to their findings, a wide range of socio-economic factors affect the likelihood of selling private car in the presence of SAVs. The key variables were gender, age (people under 35 years tend to reduce the household car ownership), travel behavior and accident history (Menon et al., 2019). Their study was limited by only focusing on a specific group of participants (students and employees) and it used SPs without considering travel-related attributes and their levels for SAVs.

This study fills a number of gaps in the literature by considering the private car users in Tehran. Through the SP scenarios, respondents willingness to reduce private car ownership has been asked. Moreover, this study makes an insightful contribution to the existing body of literature on SAVs by considering the number of passengers in SAVs in the SP scenarios, which has not been considered in previous studies that dealt exclusively with AVs.

3. METHODOLOGY

The research flowchart (Fig. 1) shows that, firstly, the binary logit model is introduced as a research method (Sections 3-1), then the survey design and administration (Section 3-2) will be discussed; and finally, the collected sample (Section 3-3) will be analyzed.

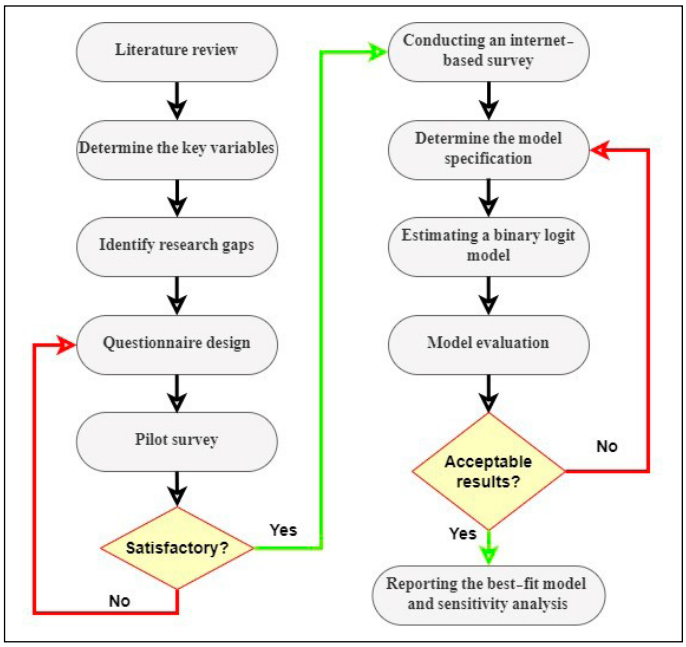


Figure 1. Research methodology flowchart.

3.1. Binary logit model

Considering the research objectives and the limitation in this case of linear models, a discrete choice model (binary logit) has been used. The basic assumption in this model is that each option for each person has a utility that consists of two parts including observed (V_{nj}) and random (ε_{nj}). Assuming an identical and independent distribution of the random part of the utility function, the probability of choosing option *j* by individual *n* is calculated for more than two options as equation (1) and two options as equation (2) as follows (Train, 2009).

$$(1) \quad P_{nj} = \frac{e^{V_{nj}}}{\sum_i e^{V_{ni}}}$$

$$(2) \quad P_{nj} = \frac{1}{1+e^{-V_{nj}}}$$

In order to estimate the binary logit model, the maximum likelihood estimation method has been used (Hensher & Johnson, 2018). Also, in order to check and evaluate the model,

various criteria such as the sign and value of the coefficients, the significance level and the likelihood ratio tests (equation (3) and (4)) have been used (Hensher et al., 2005).

$$(3) \quad \rho_0^2 = 1 - \frac{LL(\beta)}{LL\ (0)}$$

$$(4) \quad \rho_c^2 = 1 - \frac{LL(\beta)}{LL(c)}$$

In this research, the dependent variable is the likelihood of selling household car in presence of SAVs, and the independent variables include socio-economic and travel-related characteristics.

In the binary logit model, sensitivity analysis has been used to investigate the effect of changes in the independent variables. In order to perform a sensitivity analysis, two methods can be used including: elasticity and marginal effect. The elasticity is calculated as the changes (in percent) in the probability of choosing an option for a one percent change in an independent variable. The elasticity can be calculated using Equation (5) (Hensher et al., 2005).

$$(5) \quad E_{X_{ikq}}^{P_{iq}} = \frac{\partial P_{iq}}{\partial X_{ikq}} * \frac{X_{ikq}}{P_{iq}}$$

Equation (5) indicates the changes in the probability of option *i* for person *q* due to the change in the variable k (i.e. X_{ikq}).

Moreover, the marginal effect is calculated as the change in the probability of choosing an option for a one-unit change of the independent variable. Marginal effect can be calculated using equation (6) (Hensher et al., 2005).

$$(6) \quad M_{X_{ikq}}^{P_{iq}} = \frac{\partial P_{iq}}{\partial X_{ikq}}$$

3.2. Survey design

A questionnaire has been designed to collect data. It is worth mentioning that due to the absence of SAVs in Tehran, the SP approach was used to identify the respondents' preferences. The dependent variable is a dichotomous (yes or no) variable which shows the respondents' willingness to sell a household private car in presence of SAVs. The independent variables are also introduced in the sections of questionnaire. The questionnaire is consisted of four sections, where the purpose of the survey and the confidentiality of the answers are stated at the outset. Then, in the first part, the details of respondents' trips include departure time, travel time, in-vehicle time, etc. were asked. In the second part, in order to familiarize people with SAVs, a short video clip containing how this technology works and their features like the way people booked, the way SAVs operate, an in-vehicle view, and sharing a ride with strangers were presented. Then people have to respond to the SP scenarios that include 4 attributes with 3-levels (Table 1). The considered attributes are travel time, waiting time, travel cost, and number of passengers who share their trips in a SAV. The reasons for considering the aforementioned attributes are the sensitivity of car users to various elements of time such as waiting time and travel time and number of accompanying individuals as an indicator of comfort (Aboutorabi Kashani et al., 2023).

Considering the time limitation and prevention of confusion of respondents, the fractional factorial design method has been used to design the scenarios. Using SPSS software, 18 orthogonal combinations were obtained. These 18 combinations were grouped into three blocks of six. Each block was randomly presented to each person. The respondents had to express their desire to sell the private car in presence of SAVs using dichotomous variable. Finally, socioeconomic characteristics such as age, gender, marital status, and education level were asked.

Attribute	Level		
	1	2	3
Travel time	- %20	Same	+ %20
Waiting time	5 min	8 min	10 min
Travel cost	3000 IRR* / min	4000 IRR / min	5000 IRR / min
Number of passengers in the SAV	1	2	3

*IRR accounts for Iranian Rials. 150,000 IRR were worth 1 US$ at the time the survey.

Table 1. The attributes and levels considered for the SP scenarios.

3.3. Data

Because of the outbreak of pandemic in Tehran, an internet-based survey was conducted in July 2021. Based on our research objectives (the impact of SAVs on private car ownership), it is considered that the research sample is composed of individuals who own a private car or who have a household member who owns a private car.

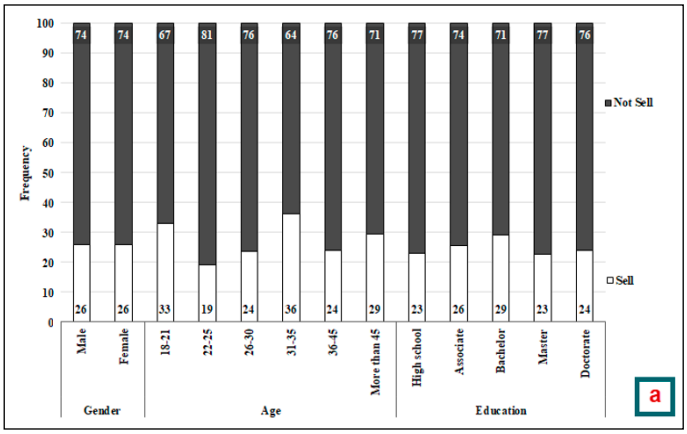
It is worth mentioning that before the main survey, a number of 30 questionnaires were conducted as a pilot. It demonstrated the ease of understanding and comprehension of the questions. Finally, after two months, 400 people were questioned, and after reviewing and removing outliers and incomplete answers, 395 valid questionnaires were used for analysis and modeling. Descriptive analysis of socioeconomic characteristics of the research sample (Table 2) shows that 54% of the sample are male and the remaining (46%) are female. In terms of age, 65% of the collected sample are at least 30 years old. Regarding education, about 60% of people have at least bachelor's degree, and four-member households accounts for 42.3% of the sample. In terms of private car ownership, 55.4% of people have only one car and 20.9% of people do not use insurance services for their car. According to Table 2, men, people who aged 22-25 years, bachelor's degree, four-member households and the households with one car have the highest frequency compared to other cohorts.

Figure 2 presents only the frequency analysis of selling willingness of respondents. However, the statistically significant effect of each variable should be evaluated in the estimated model, which will be explained in Section 4. For instance, in terms of age, respondents who are 18-21 years have the second most willingness to sell their household car. However, the only significant age groups in the estimated model are 22-25 and 31-35 years old. The key reason for the least willingness of the age group of 22-25 years is that these respondents are younger and more likely to be interested in ownership because of the importance of social influence as an attitudinal factor. This psychological reason is also true for younger age group (i.e., 18-21), however, due to the lower car ownership level compared with the average car ownership level in our sample as well as lower income, they are more interested in collaborative consumption rather than ownership. Moreover, this figure shows that there is no difference between male and female in terms of their willingness to sell a household car. There is not much difference between the respondents' willingness to sell their household car based on their education level. However, respondents who hold Bachelor's degree are the most inclined individuals. In terms of household size, respondents who are belonging to at most 2-member households are the most inclined individuals in selling their household car. As household car ownership increases, the willingness to sell household car also increases. This relationship is also true for the number of insured private cars in a household. In other words, as the number of cars with insurance increases, the households' willingness to sell their cars also increases.

Variables used in the modeling process are also presented in Table 3.

Variable	Category	Absolute frequency	Relative frequency (percentage)
Gender	Male: 1	194	54
	Female: 0	165	46
Age	18-21	52	14.5
	22-25	98	27.3
	26-30	81	22.6
	31-35	43	12
	36-45	44	12.3
	46+	41	11.4
Education	High school: 0	8	2.2
	High school diploma:1 and associate	59	16.4
	Bachelor: 2	148	41.2
	Master: 3	121	33.7
	Doctorate: 4	23	6.4
Household size	2 ≥	36	10.1
	3	91	25.3
	4	152	42.3
	5+	80	22.2
Household car ownership	1	199	55.4
	2	129	35.9
	3+	31	8.6
Number of car have an insurance	0	75	20.9
	1	175	48.7
	2	94	26.2
	3+	15	4.1

Table 2. Descriptive analysis of the socioeconomic characteristics.



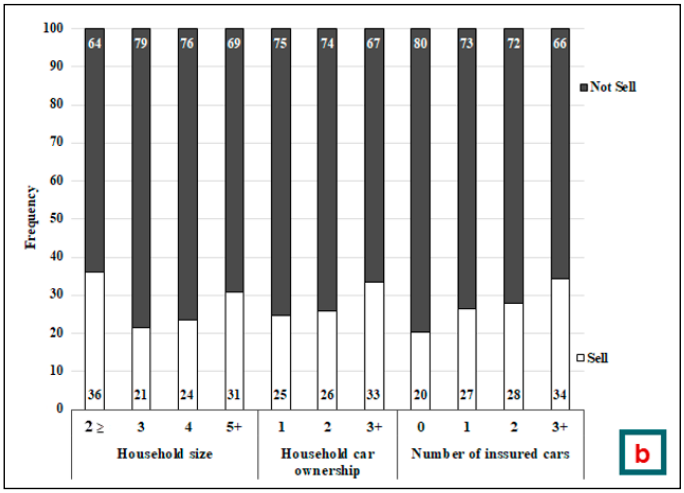


Figure 2. Frequency analysis of selling willingness based on (a) socioeconomic and (b) household characteristics.

Variable type	Symbol	Variable definition	Mean	Standard deviation	Min	Max
SP attributes	Tt	Relative travel time of SAV	1	0.816	0	2
	Tc	Relative travel cost of SAV	500	81.668	400	600
	Nop	The number of people in the SAV	2	0.816	1	3
	wt	Waiting time for a SAV (min)	7.666	2.055	5	10
Dummy	nosatot	Dissatisfied with internet taxis for some reason, 1; otherwise, 0	0.036	0.186	0	1
	ppcost	Do not use private car due to parking fee, 1; otherwise, 0	0.030	0.172	0	1
	pmcost	Do not use private car due to maintenance cost, 1; otherwise, 0	0.108	0.311	0	1
	wtaxiua	Did not use a taxi last week, 1; otherwise, 0	0.757	0.428	0	1
	uberaue	People who use internet taxi 2-3 times a week, 1; otherwise, 0	0.022	0.147	0	1
	Owner	A person who owns a car, 1; otherwise, 0	0.401	0.490	0	1
	Noocarin	People who did not insure any of their cars, 1; otherwise, 0	0.208	0.406	0	1
	Ageb	Age between 22-25, 1; otherwise, 0	0.273	0.445	0	1
	Aged	Age between 31-35, 1; otherwise, 0	0.119	0.324	0	1
	Chilper	People who accompany their children to school by private car, 1; otherwise, 0	0.114	0.318	0	1
Continuous	vpno	The ratio of the number cars in the household to the size of the household	0.431	0.217	0.13	1.5

Table 3. Definition, symbol, and descriptive analysis of the variables.

4. ESTIMATION RESULTS AND DISCUSSION

Based on the estimation results of more than 400 models in Nlogit 5.0 software, the coefficients along with their significance and marginal effects are presented in Table 4. In order to evaluate the model goodness of fit, various statistics such as likelihood ratio index and chi-square have been used. Moreover, to determine the significance of the estimated coefficients, a t-test has been also used. All the estimated coefficients were statistically significant at the 0.01 significance level, except for waiting time (0.05). Analysis of respondents' willingness to sell a household private car showed that out of 2154 observations, only 559 observations, equivalent to 26%, were willing to sell a household car in presence of SAVs.

The estimated coefficient of *Nosatot* variable indicates that dissatisfaction with internet taxis (taxis ordered via an app on smartphones) is negatively associated with the likelihood of selling private cars. In other words, if an individual is dissatisfied with internet taxis for some reasons, they are less likely to sell their household car when SAVs are available in the market. Among the reasons for this, as suggested by previous studies, dissatisfaction with internet taxis may lead to reduced use of this travel mode, which will decrease the willingness of these individuals to reduce their car ownership level (Shaheen & Cohen, 2019). On the other hand, the positive and statistically significant sign of *Uberaue* variable indicates that people with a higher level of use (2 to 3 times a week) of internet taxis are more inclined to sell their household's car, which is in line with the findings of previous studies (Blumenberg et al., 2021). The positive and statistically significant sign of *Ppcost* and *Pmcost* variables indicates that people who do not use a private car due to parking and maintenance costs, has a higher likelihood of selling the household private car which is line with Zhou et al.'s findings (2020). Relative travel time (*Tt*) and travel cost (*Tc*), waiting time (*Wt*), and the number of passengers in an SAV (Nop) have a negative and statistically significant effect on the willingness to sell a private car. This indicates that an increase in any of these variables is associated with a reduction in the individuals' willingness to sale the household private car, which is in line with previous findings (Holmgren, 2020).

In terms the effect of age, the only significant age groups are 22-25 and 31-35 years old. One of the interesting results in this research is the effect of age on the willingness to sell a household private car, in such a way that people in the age group of 22-25 years have a lower willingness to sell, but people in the age group of 31-35 years have a higher willingness to sell a private car. One of the reasons for this issue is that in the age group of 22-25 years, most of the people are young and due to the influence of attitudinal factors such as social influence, they are more interested in ownership. This finding is in accordance with previous studies (Menon et al., 2019; Polzin et al., 2014). The negative and statistically significant coefficient of *Chilper* variable indicates that people who take their children to school with a private car have a lower willingness to sell their private car. The lack of insurance for any household cars (*Noocarin*) also has a negative and statistically significant effect on the willingness to sell a private car. Also, it can be seen that the household car ownership (*Vpno*) is positively associated with the likelihood of selling a private car. In other word, an increase in household car ownership level increases the probability of selling a private car. Finally, people who own a private car are more inclined to sell their car and use SAVs than other household members. Also, no statistically significant relationship was found between the likelihood of selling a private car and socioeconomic characteristics such as income and gender.

Variable	Coefficient	t-stat	Marginal effect
Constant	1.746***	4.03	-
Nosatot	-1.310***	-3.51	-0.224
Ppcost	1.009***	3.39	0.172
Pmcost	0.686***	4.22	0.117
Wtaxiua	-0.454***	-3.78	-0.0776
Uberaue	1.036***	3.33	0.177
Tt	-0.204***	-3.15	-0.035
Tc	-0.278***	-4.3	-0.047
Nop	-0.352***	-5.42	-0.060
Wt	-0.060**	-2.37	-0.010
Ageb	-0.515***	-3.59	-0.088
Aged	0.416***	2.68	0.070
Chilper	-0.739***	-3.93	-0.126
Owner	0.230***	2.06	0.039
Noocarin	-0.498***	-3.63	-0.085
Vpno	0.694***	2.82	0.118
Number of observations		2154	
LL(β)		-1118.16	
LL(C)		-1232.22	
LL(0)		-1493.03	
ρ_C^2		0.092	
ρ_0^2		0.251	

***, **, *: significance at 1%, 5%, and 10% levels, respectively

Table 4. Estimation result of the binary logit model of the likelihood of selling a household private car in presence of SAVs.

5. CONCLUSIONS AND SUGGESTIONS

Today, factors such as the increase in population, car ownership and dependence on private cars, especially in developing countries, have caused environmental problems, congestion, and increased accidents. In the metropolis of Tehran, the private car is the most common mode of travel for citizens. Thus, policy makers have focused on development of new and sustainable transportation systems to reduce the use of private cars. One of the emerging and sustainable modes is SAV, which has many potential benefits. Since the achievement of all the potential benefits of SAVs requires determining the behavior and needs of its future users, the present study examines how socioeconomic and travel-related characteristics can affect car ownership level among private car users in Tehran in presence of SAVs. Due to the absence of SAVs in Tehran, the willingness to sell one of the household private car(s) was asked using SP scenarios consisting of 4 three-level attributes including the number of passengers in the SAV, travel time, waiting time and travel cost. The questionnaire includes 3 sections:

- Last trip characteristics (such as travel time, predominant transportation mode and accident history),
- SP scenarios (including travel time, number of passengers in the SAV, waiting time and travel cost), and
- Socio-economic characteristics (including age, gender, number of cars, income, etc.).

After collecting and refining the answers of the respondents, 2154 valid observations were used to estimate the binary logit model.

The estimated marginal effect values indicate that the most significant variables which negatively affect the willingness to sell household private cars are: dissatisfaction with internet taxis, individuals who take their children to school using private car, belonging to age group of 22-25, not insuring their cars, and number of passengers sharing their ride in SAVs, respectively. While the factors which mostly affect the willingness to sell household private cars positively are: internet taxi users, parking cost, and per capita household car ownership, respectively. To motivate the users to be more inclined to use SAVs, some implications for policies and practices are suggested. Since dissatisfaction with internet taxis and their usage frequency are the most influential factors, it is recommended to pay particular attention to current internet taxis service qualities. The effect of parking cost and per capita household car ownership further highlight the importance of establishing

travel demand management policies such as parking pricing and increasing the tax and related costs of households' additional car(s). As a motivation for individuals who take their children to school by private car, it is recommended to provide special services in SAVs which will be used as a travel mode of children to school such as real-time location and inside view of SAVs to ensure the parents of safety and security of their children. In terms of number of passengers sharing a ride, it is recommended to provide a passenger-adjusted level of comfort based on travel cost which enables passengers to select the preferred number of people to share the trip at various levels of travel cost (Aboutorabi Kashani et al., 2023).

This study has limitations that are mainly due to the lack of SAVs and people's lack of access to this travel mode, people's opinion change after the presence of SAVs along with other travel modes. Also, since the survey was online at the time of the pandemic, some possibly significant questions (e.g., the age of other household members) could not be asked. Moreover, most of the respondents were young individuals which is due to nature of online survey. It is suggested to investigate the taste variation and heterogeneity among respondents as well as examining the effect of attitudinal factors on the likelihood of selling private car in future studies. Future studies can also examine the impact of different variables (such as trip purposes and life events such as marriage, adding a new member to the family, job change) on the willingness to sell private cars in presence of SAVs. Moreover, it is recommended to use discriminant analysis to predict the criteria groups and their weights for better understanding the differences between and within groups.

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