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Explaining expected non-shared and shared use of driverless cars in Edinburgh

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Abstract

The rollout of driverless cars (DC) may reshape human mobility drastically. Urban roads may face a surge of car traffic if DC technologies continue to enhance the use of private cars. Shared DC use can remedy this by reducing the number of urban trips that non-shared-use DC could otherwise make. While recent research has proven the importance of socioeconomic factors on shared DC use, the influence of present sharing behaviour, personality traits, and social norms on shared DC use has not been extensively explored to date. To address this gap in this study, we employed a panel of 500 Edinburgh-based respondents through an online survey to examine the likelihood of accepting the non-shared-use and shared-use DC options for regular urban trips. We have collected data on respondents' present carsharing and ridesharing behaviour, personality traits, social norms, and sociodemographic characteristics. To elicit the impact of these factors on the likelihood of accepting non-shared-use and shared-used DC options, ordered probit models were estimated. The model findings imply that frequent household car users and those influenced by social expectations to preserve the environment are willing to use non-shared-use DC. In contrast, city centre dwellers, cooperative and younger adults with sharing attitudes show a higher tendency towards shared DC. High-earning, working-aged and young respondents are more inclined to use a driverless taxi, whereas city-centre dwellers and those influenced by social expectations to share personal resources are more favourable towards ridesharing with a stranger in DC. These results can assist the policymakers and transport planners shape policies for promoting shared DC use and transport service providers to deliver and operate shared DC fleets efficiently.

Keywords: Driverless car; shared use; ordered probit models.

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1. Introduction

With the rapid advancement in automation and robotics, Driverless Cars (DC) are likely to replace human driving significantly. If current car ownership and usage patterns are likely to sustain DCs, the most predicted scenario might be the higher usage propensity of privately-owned and individually used DCs because of their enhanced ease of use. Non-shared DC use is likely to be favoured to all (e.g., elderly, disable, young generations, non-license holders), thus exacerbating traffic congestion (Harper et al., 2016). On the contrary, the possibilities of shared use of DC can reduce traffic (Fagnant et al., 2015), while offering more efficient usage of travel-time (OECD - International Transport Forum, 2015), can reduce parking demand (Zhang and Guhathakurta, 2017), and can contribute protecting the environment (Fagnant and Kockelman, 2014). With all these possible benefits, whether and to what extent people are willing to use shared DC to non-shared DC and the possible determinants' role in these diversifications are discussed in this paper. By providing comparable insights into these determinants for shared and non-shared DC use, this paper aims to identify the shared versus non-shared use propensity of DCs. To discuss non-shared DC use, we studied (a) private ownership of DC, for which the owner entirely pays the costs of purchasing, maintenance and running the vehicles in return for full availability of the vehicle at any time; (b) riding alone in a household DC, without a family member's presence or close contacts. In terms of shared-use DC, the options are (a) driverless taxi, for which users might have to pay a one-time rent for the time being used instead of bearing the total costs of ownership (we note that lower costs are likely to pay because of the absence of a driver onboard); (b) riding with another passenger (stranger) outside of the family with shared rental cost, which otherwise has to be paid by one passenger. In line with the research aim and context above, we collected data for the non-shared and shared DC use responses through an online survey disseminated in Edinburgh, UK.

Research gaps in the existing literature

Several agent-based simulations analysed hypothetical shared DC market scenarios with area-wide implementation (Firnkorn and Müller, 2015; Martinez and Viegas, 2017). Although applicable to define the benefits of shared use of DC, these studies underpinned the assessment of shared-use DCs with observed variables.

Assessing the likelihood of DC use has been an active area of research recently. A few studies test the shared use of DC through an experimental approach involving selected population groups (e.g. young people, elderly, students, employees of an association) and limited spatial settings (e.g. campus settings, office location, part of the city) (Nordhoff et al., 2018; Menon et al., 2019). A few of these studies discussed regular and occasional sharing variations and compared the sharing propensity with strangers and family members. Barbour et al.(2019) considered commuting distance, one-way distance to the grocery, to record existing travel behaviour. Nazari et al. (2018) applied commute related factors to understand present travel behaviour. In contrast, our study uses current commuting habits as determinants of the likelihood of adopting shared and non-shared models of use of DC. To this aim, we identified three groups of respondents: frequent users of the household car, who use car rental; frequent users of the household car, who do not use car rental; non-frequent car users.

Very few current research efforts are concerned with personality traits' effects on the likelihood of shared DC use. (Kyriakidis et al., 2015) considered the influence of personality on the use of DC, but the study was not concerned with sharing. In this study, we seek to unveil the relationship of personality characteristics (represented by the big five personality traits) (Gosling et al., 2003) with the likelihood of accepting non-shared-use and shared-use DC. Besides, this study is the first of its kind to the authors' knowledge to account for the impact of subjective social norms about sharing, preserving the environment and seeking a better quality of life (Bamberga et al., 2007).

A few studies focused on the shared and individual use of DC in the public interest (Nazari et al., 2018; Wang et al., 2020), but the relevant discussions lacked the data to understand the household users preferences. Decisions of transport service providers to include DC in their fleets (e.g., Uber, Lyft) has propelled the idea of flexible car ownership to reduce household car usage by 2025 (Kosoff, 2016). A few studies discussed various flexible ownership models (Masoud and Jayakrishnan, 2016) with shared costs and responsibilities (Jaynes, 2016). To this end, this study analysed household data to unearth the DC sharing propensities with other members of the household.

2. Data collection

We have reviewed several relevant studies concerning the shared use of DC (Nordhoff et al., 2018; Menon et al., 2019) to design our online data collection method. Eventually, we collected data by inviting participants with leaflets at their physical addresses. The addresses were carefully selected to draw a representative sample of the Edinburgh population regarding the Scottish Index of Multiple Deprivation (Shaw et al., 2017). We distributed 7,500 leaflets during August – November 2019 and received 500 responses. Our questionnaire, based on a thorough literature review and interviews with DC experts, and had four core sections (respondents' current carsharing and ridesharing attitudes; determinants of attitudes towards carsharing and ridesharing; responses for different DC ownership and ridership models; personality traits, social norms, and sociodemographic characteristics), featuring a total of 26 questions. The online questionnaire was initiated with a video demonstrating the shared use of DC. Likelihoods of adopting DC options were measured on a 5-point Likert scale from very unlikely to very likely. The ordered probit model (Mckelvey and Zavoina, 1975) is a handy tool to treat ordered responses concerning shared and non-shared DC choices (e.g., very-unlikely - very likely) (Washington et al., 2011). Statistically, these models generate a robust explanation for variation in responses with fewer explanatory variables. A few researchers successfully applied the ordered probit model to access DC ownership and usage (Menon et al., 2019; Lavieri et al., 2017; Sheela and Mannering, 2019).

Analytical framework

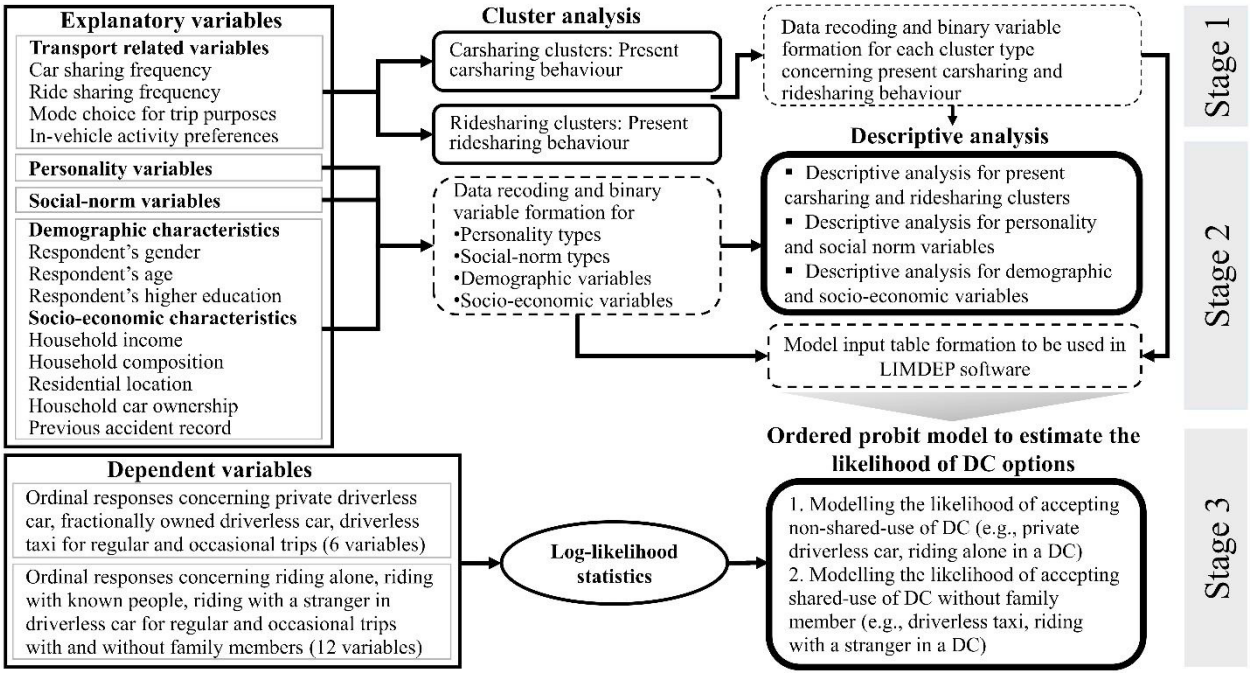

Fig. 1. Modelling framework.

Figure 1 depicts the analytical modelling framework applied in this paper. Leveraging the data from the online survey, we first identified clusters of respondents with different carsharing and ridesharing habits through a two-step cluster analysis, an exploratory technique based on the grouping of variables with a high degree of association, as Tan et al.(2014) described. We estimated ordered probit models to access the likelihood of the non-shared and shared DC usage options with their determinants, which are associated with a latent variable z_i^* As the following:

$$z_i^* = \boldsymbol{\beta} \mathbf{X}_i + \epsilon_i \quad (1)$$

Here, $\boldsymbol{\beta}$ is a vector of estimable parameters, $\mathbf{X}_i$ is the vector of the explanatory factors for observation i, and ϵ_i is an error term following a standard normal distribution. The predicted category y_i of each observation is defined as,

$$y_i = \begin{cases} 1 \text{ if } z_i \le \mu_0 \\ j \text{ if } \mu_{j-1} < z_i \le \mu_j, j > 1 \\ I \text{ if } z_i \ge \mu_{I-1} \end{cases} \quad (2)$$

With μ_j we are denoting the thresholds of the ordered probit model, which are also estimable parameters. We employed the Maximum Likelihood Estimation (MLE) process (Washington et al., 2011) for model estimation. Specifically, for each respondent i (i=1,2, 3….. n) of the sample, the log-likelihood function of the MLE process can be written as:

$$LL(\beta,\mu) = \sum_i \sum_j Z_{ij} \ln P(y_i = j) \quad (3)$$

Z_{ij} is the observed value of y_i in the jth category; otherwise, Z_{ij} is zero. To evaluate the statistical performance of the ordered probit model, we conducted a chi-square test of the differences between the final (i.e., with independent variables) and the base (i.e., without any independent variables, but with constant) model as follows:

$$\text{Chi-square } [\chi^2(df)] = -2[LL(\boldsymbol{\beta}) - LL(0)] \quad (4)$$

Where χ^2 is the chi-square value, and df denotes the degrees of freedom that are equal to the difference of variables between the final and base models. Finally, the model's goodness-of-fit was assessed through the McFadden pseudo R^2, which is defined as:

$$R^2_{McFadden} = 1 - LL(\boldsymbol{\beta})/ LL(0) \quad (5)$$

McFadden Pseudo R^2 can take values from 0 to 1. The closer to 1 is the R^2 value, the better is the statistical fit of the model estimation, which means the model can better explain the variance of the data.

3. Model estimation results

The representativity of the sample is verified by a comparison with existing official data about the Edinburgh population in terms of age, gender, and car ownership. 69.54% of the respondents belong to working age (16 – 64 years) compared to 69.6% of the same for Edinburgh (City of Edinburgh, 2020). The sample gender ratio (male vs female) was nearly 2:1 compared to the 1:1 reported for the same in the National Records of Scotland (www.nrscotland.gov.uk). Concerning car ownership, 76.5% of the respondents owned one car versus the 71% of Scots that own at least one car, according to Transport Scotland (2019). The sociodemographic bias is not expected to affect the validity of the results reported below.

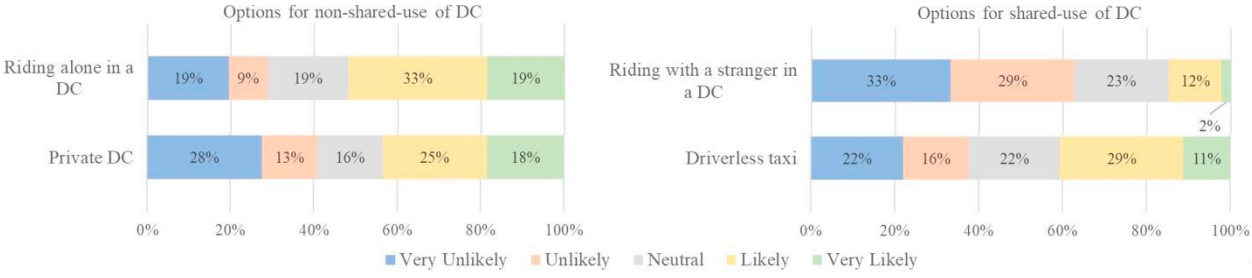

Fig. 2. Variations on levels of likelihood between individual-used and shared-used DC.

Demographically, 54% of the respondent's bare cooperative attitudes while 76% were influenced to preserve the environment. Nearly one third (29%) of the respondents were millennials, 44% belonged to higher income (>£500000) households. 55% of the households do not have any children, and 34% live within Edinburgh's city centre. Aside, the two-step cluster analysis distinguished three groups concerning present carsharing behaviour, namely 1) frequent users of household cars who use car rental (30.2%); 2) non-frequent users of household cars (33.4%); and 3) frequent users of household cars who do not use car rental (36.4%). Figure 2 shows that for non-shared-use DC, 43% of the respondents are "likely" or "very likely" to use a private DC for regular trips. The corresponding proportion is 52 %

for riding alone in a DC without family members. Regarding shared-use DC for regular trips, 40% of the respondents are "likely" or "very likely" for driverless taxi use, compared to 14% who prefer to ride with strangers in a DC. Table 1 reports the ordered probit model results obtained using the NLOGIT statistical package (Greene, 2016). The final models (including the explaining variables) are significantly more predictive than the base models (with only the constant) in terms of log-likelihood, thus proving the variations in perception among respondents concerning the likelihood of non-shared-use or shared-use DC.

4. Discussion

Firstly, we note that our modelling approach does not directly compare the preferences regarding different DC models. Instead, the results show what factors increase or decrease the likelihood of adopting each DC use model. When an explanatory factor has the same effect on models regarding opposing behaviour in terms of sharing – e.g. it increases the likelihood of both riding alone and sharing rides – we infer that effect is due to the driverless technology rather than to model the use of DC. We report statistics of significant determinants towards sharing DC in Table 1 along with other modelling results.

Table 1. Ordered probit model estimation results

Variable descriptions	Mean	Private DC		Driverless taxi		Riding alone in a DC		Ridesharing with a stranger	
		Coeff.	T-stat	Coeff.	T-stat	Coeff.	T-stat	Coeff.	T-stat
Sociodemographic indicators									
Millennial (1 if the respondent is 24 - 43 years old, 0 otherwise)	0.29			0.339	2.515	0.256	1.933	0.334	2.943
Generation X (1 if the respondent is 44 - 55 years old, 0 otherwise)	0.22			0.370	2.369				
Baby boomer (1 if the respondent is 56 -74 years old, 0 otherwise)	0.37	-0.607	-5.283			-0.256	-1.940		
Masters or higher degree holder (1 if respondent hold a master's degree or higher, 0 otherwise)	0.46	-0.222	-2.060						
Household with at least one child (1 if the respondent lives in a household with at least one child, 0 otherwise)	0.37			-0.281	-2.144	-0.262	-2.254		
Household without a child (1 if the respondent lives in a household with no children, 0 otherwise)	0.42							-0.177	-1.673
Higher income (1 if the respondent earns more than £50000/year, 0 otherwise)	0.43			0.290	2.416				
City centre (1 if the respondent lives in the city centre, 0 otherwise)	0.34							0.206	1.904
Car ownership (1 if the respondent has at least one car, 0 otherwise)	0.82	0.634	4.208						
Existing carsharing behaviour indicators									
Frequent household car user (1 if the respondent is a frequent household, but do not use car rental, 0 otherwise)	0.34	0.199	1.691			0.274	2.343		
Personality trait indicators									
Agreeableness (1 if the respondent is cooperative, and trusting, 0 otherwise)	0.28			0.274	2.250			0.244	2.145
Social-norm indicators									
The social expectation for preserving the environment (1 if the respondent has feelings for social expectation to preserve the environment, 0 otherwise)	0.76	0.295	2.314			0.334	2.686		
The social expectation for sharing (1 if the respondent has feelings for social expectation to share resources, 0 otherwise)	0.09			0.311	1.665			0.495	2.810

Model fitting statistics				
Model statistics	Private DC	Driverless taxi	Riding alone in a DC	Ridesharing with a stranger
Final model log-likelihood (β)	-605.78	-558.79	-612.28	-607.84
Base model log-likelihood (0)	-634.90	-574.9	-626.44	-624.08
Chi-square (χ^2)	58.24	32.22	28.31	32.47
ρ-value	0.000	0	0.000	0.000
$R^2_{McFadden}$	0.046	0.028	0.023	0.026
Degrees of freedom (df)	5	7	6	5
Number of observations in the model	405	439	408	440

4.1. Likelihood of accepting non-shared-use options of DC

Among generations, baby boomers (age range 55– 74) are less open to private DC and less likely to ride alone in DC. This behaviour can be explained by a reluctance to accept new technology. Highly educated respondents (holding a master's degree or higher) have shown negative attitudes towards private DC for regular trips. In support of this finding, the study of Dias et al. (2017) suggested that highly educated people are more inclined to use DC sharing than private DC. Families with at least one child are less willing to ride alone in DC, probably because they are more used to share their car with people around them. Regular car trips made by members of larger households are likely to accommodate the needs of more than one member. Interestingly, the study of Haboucha et al. (2017) found that individuals from multimember households are more inclined to share the ride in DC. Current ownership of at least one car is also associated with a greater tendency towards private DC. The observed propensity to private DC for car owners can be attributed to their habitual patterns stemming from the current car use behaviour (Wachenfeld et al., 2016). In this context, Menon et al. (2019) proved that people are keen on the car ownership culture and its benefits in their everyday life. Therefore, they are reluctant to accept shared DC readily. Car-owning individuals are also more inclined to ride alone in DC due to the joy they may get from the sense of driving (Lee et al., 2019). Following previous research (Kyriakidis et al., 2015) results, it can be proved that past habits can explain the future acceptance of private DC. Specifically, respondents who frequently use the household car but do not use car rental are more optimistic about private DC and likely to ride alone in DC. Partly, this variation is associated with car dependency and psychological disposition of car use, as mentioned in earlier studies (Lee et al., 2019). In line with these findings, Zmud et al.(2016) found that people prefer to use private DC rather than carsharing with DC. The same tendency was observed for riding alone in DC. People who own a private car and drive their car are more likely to own private DC or ride alone in DC in the future (Becker and Axhausen, 2017). The variable representing social expectation to preserve the environment is likely to affect the DC preferences significantly. Respondents who acknowledge the social expectation to preserve the environment are more receptive to private DC use and more likely to drive alone in a DC for their regular trips. This result may be driven by public expectations for low-emission technologies to be incorporated in DC. However, these findings need to be further investigated since the impact of social norms in accepting DC has not been fully identified to date. Prior research showed that pro-environmental attitude is an essential factor in determining the acceptance of shared DC use (Haboucha et al., 2017).

4.2. Likelihood of accepting shared-use options of DC

Amongst generations, millennials are more influential in preferring driverless taxi use and accepting strangers in their rides for regular trips. These results align with the study of Menon et al. (2019), where millennials were found more likely to accept shared DC use. One-third of our survey sample are millennials, who represent the dominant living generation in contemporary society (Fry, 2016), the leading supporters of innovative technology solutions (Smith, 2013), and the adopters of alternative transport modes (Circella et al., 2016). Generation X (age range: 44 – 55) also shows a statistically significant tendency towards driverless taxi use but not any observable pattern towards shared DC use. Families with at least one child are unwilling to use a driverless taxi, which probably indicates their preference to travel with family members. This finding is consistent with earlier research demonstrating that the likelihood of shared DC use by single-person households is higher (Lavieri and Bhat, 2019). Another recent study suggested that a family without a child is unwilling to accept shared DC (Barbour et al., 2019). Similarly, Table 1 shows that a family without a child is less interested in DC sharing with strangers. This result is consistent with recent research that identified the unwillingness of sharing a confined space with a stranger (Wang et al., 2020). Overall, these findings do not reflect any clear connotation for the family composition with shared-use DC. Table 1 also shows that a higher income level increases the propensity for driverless taxi use, which can be used as a second car to serve their leisure travel or when the family car is occupied. These findings echo previous findings suggesting higher-income individuals' willingness to share DC (Lavieri and Bhat, 2019). Disparities for sharing a DC with and without a stranger were observed among financially affluent people who are psychologically attached to enjoying private space inside cars and, therefore, unwilling to share a driverless taxi with a stranger (Wang et al., 2020). City-centre dwelling respondents are willing to share the ride with a stranger, reflecting their familiarity with ride-sourcing services extensively provided in urban areas and city centres. This result contradicts recent research showing that sharing with a stranger is less evident for urban trips (Rahimi et al., 2020). Respondents with cooperative attitudes and belief in

social harmony demonstrate a higher inclination towards driverless taxi use for regular trips and a higher likelihood of accepting strangers in DC trips. This result is supported by the finding of Kyriakidis et al. (2015) and deemed as plausible since respondents with this type of personality are generally submissive, pro-environmental (Hirsh, 2010), and likely to adopt sustainable transport modes (Kim et al., 2014). Respondents who exhibited a general tendency for sharing are willing to use driverless taxis and share their rides with strangers for their regular urban trips. These results indicate that social norms promoting the shared use of resources may help enhance the reach of DC sharing schemes.

5. Conclusion

This study provides an exploratory analysis of likelihoods towards non-shared and shared DC options across respondents. Using data collected through an online survey in Edinburgh, UK, ordered probit models were estimated to identify the factors affecting these likelihoods for various DC options for regular urban trips. The statistical analysis results showed that millennials are likely early adopters of shared-use DC, while ageing seniors (baby boomers) are indifferent in their choices for non-shared DC use. Present car ownership and respondents' behaviour to follow social expectations to preserve the environment increase the willingness for non-shared DC use. The model results reflect the heterogeneity of respondents' attitudes towards DC sharing, especially regarding age, car ownership, and social norm attitudes. Overall, shared DC use is likely to be enhanced by respondents' cooperative attitudes with a general tendency towards sharing. Interestingly, this study reveals the unwillingness to switch for DC in exchange for conventional cars despite technological innovation. Therefore, the insights relating to the impact of present car ownership and sharing behaviour on future DC sharing options should be further investigated to understand how the switch from private to the shared mode of transport can be facilitated through the emergence of DC.

We found substantive variations between the factors determining driverless taxi use and sharing DC with a stranger. 'Sharing with a stranger' is the intrinsic feature of a shared driverless car use bearing a promising potential to reduce traffic from the road network, but convincing people to share the ride with a stranger is a crucial barrier to overcome (Parkhurst and Seedhouse, 2019). Such variations set new challenges for transport planners and policymakers relating to the policy measures needed to facilitate the modal shift from non-shared-use DC to shared-use DC. For example, possible privacy concerns and pricing options in a shared DC may constitute an array of issues hampering this modal shift. Future policy interventions may encourage DC service providers to design privacy-preservative DC interiors and subsidised pricing schemes to attract private, concerned individuals to use shared DCs.

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