Robotaxis or autonomous shuttles? The role of urban representations and mobility habits in tomorrow's mode choice in France

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Short abstract: Autonomous vehicles (AVs) will profoundly modify our mobility habits. The collective impact of AVs will differ according to the autonomous mode choice. In this paper, we apply a simultaneous-equation model to a database from an original 2017 survey of French mobility users to analyze their acceptance of two forms of autonomous transport mode: autonomous shuttles and robotaxis (N=3,297). Our results show that the intention to use autonomous shuttles is on average greater than robotaxis. Gender and age influence autonomous mode choice, as well as the current transport mode. In addition, location and urban representations play a central role.

Keywords: robotaxi ; autonomous shuttle ; autonomous vehicle ; intention to use ; autonomous mode choice; transport mode; simultaneous-equation model; discrete choice model

Research goals

Autonomous Vehicles (AVs) are expected to profoundly modify our mobility habits within the coming years. These impacts (Fagnant and Kockelman 2015; Berrada and Leurent 2017; Orfeuil and Leriche 2019) will vary according to the autonomous modes of transport: (1) autonomous shuttles, (2) privately-owned self-driving cars and (3) robotaxis.

Much is expected of autonomous modes of transport: enhancing mobility for impaired drivers (Becker and Axhausen 2017), reducing congestion (Payre et al. 2014; Berrada and Leurent 2017), cutting greenhouse-gas and noise emissions (given the fact that autonomous vehicles are also electric), improving road safety (Schoettle and Sivak 2014; Lang et al. 2016). Last, AVs will provide useful time during trips.

We in this paper focus on the determinants of modal shift. We first consider a transport mode that is expected to encourage car-owners to give up their personal vehicle: on-demand mobility in the form of robotaxis. We then consider a collective autonomous mode of transport, autonomous shuttles. We analyze the intention to use one of those transport modes by mobility users, were they to be available. To our knowledge, this is the first analysis comparing the results regarding on-demand *versus* collective autonomous mobility.

Most of the literature on the determinants of autonomous mode choice is quite recent. A number of explanatory variables of the intention to use AVs commonly appear: sociodemographic (gender, age, marital status, number of children, education and income), technophilia characteristics, attitudes (happiness score and the perception of the future) and mobility variables (having a driver's license, driver experience, the number of crashes and current travel mode).

Considering in this empirical research a majority of the previous variables, we also include, using a simultaneous-equation model, the current transport mode(s) used and the individual's representations of the city resulting from a factor analysis to establish novel relationships with the intention to use robotaxis or autonomous shuttles.

Materials and method

Data

The data used for our analysis come from an online survey on French mobility use and representations towards future transport modes. 3,297 usable questionnaires were completed online in 2017 (Chronos and L'ObSoCo 2017). The respondents' declared intention to use on-demand (robotaxi) and/or collective autonomous vehicles (autonomous shuttle) is the central variable. Respondents' answers come from the following question: "*If the following services were to become available where you live, would you have the intention to use them?*", with one question for autonomous shuttles, and another for robotaxis.

Beyond the socio-demographic characteristics, respondents' urban representations were analyzed using ten questions answered on a ten-point scale: "*To what extent do you consider that the city is good place to [...]?*" The first factor pools six variables (Work, Earn a living, Fulfill your professional life, Enjoy activities, Study and Shop) and the second four variables (Grow, Live, Raise children and Age). Following the factor analysis, we construct two variables for urban representations by calculating the mean values of the items contained in each factor; these are positively correlated. We consider the first factor as an instrumental representation of the city and the second as the city as a way of life.

Econometric model

We hypothesize that the probability of using robotaxis and autonomous shuttles may be explained by a number of variables: socio-demographic characteristics (external and individual variables), attitudinal variables and technophilia characteristics, the main transport modes respondents use, and the urban representations from the factor analysis. Moreover, the representations of the city as an instrument and as a way of life are simultaneously considered as a function of the socio-demographic characteristics. The resulting simultaneous-equation model estimates the standard errors taking into account the contemporaneous correlations of the representations of the city as an instrument and as a way of life.

$$C_i = \alpha + \beta X_i + \varphi H_i + \gamma T_i + \delta V_i + \theta U_i + \varepsilon_i \quad (1)$$

$$I_i = \mu + \pi X_i + \chi H_i + \tau T_i + \varsigma V_i + \zeta U_i + \omega_i \quad (2)$$

$$U_i = \nu + \eta X_i + \vartheta_i \quad (3)$$

$$V_i = \psi + \xi X_i + o_i \quad (4)$$

with C_i and I_i being the answers to the autonomous shuttle and robotaxi questions, which vary between the individuals *i*. As Eq.(1) & (2) reflect linear ordered probability equations, they will be estimated through ordered Probit models. The assumption here is that *C* and *I* are determined by underlying continuous variables (C^* and I^*). When C^* and I^* take values between certain thresholds, the corresponding observable outcomes *C* and *I* take the values of 1, 2, 3 and 4. X_i is a vector of socio-demographic characteristics, H_i a vector of attitudinal variables (except for the representations of the city) and technophilia characteristics, T_i a vector of mobility variables, and U_i and V_i vectors reflecting the representations of the city as an instrument and a way of life respectively. Last, $\alpha, \beta, \varphi, \gamma, \delta, \theta, \mu, \pi, \chi, \tau, \varsigma, \zeta, \nu, \eta, \psi$ and ξ are the corresponding parameters to be estimated and ε_i, ω_i, υ_i, and o_i are the residual error terms. The model is estimated via quasi-maximum likelihood.

Results and discussion

The detailed results are presented in Table A1.

Socio-demographic characteristics

Age and gender both turn out to influence the intention to use the two autonomous transport modes (Models (1) and (2) in Table A1). Men are more prone to this use than women, as are the older (45 years and over) relative to the younger. These results are globally consistent with previous studies. The only other socio-demographic characteristic that stands out is that higher education is associated with a greater intention to use autonomous shuttles, but not robotaxis.

Living in a city or in the countryside likely determines the intention to use on-demand or collective autonomous modes of transport. Our results reveal a distinction between highly and mediumly-populated areas on the one hand, be they major urban centres or their surrounding areas, and lightly-populated areas (small towns and their surroundings, and isolated municipalities). Multipolar areas form a third geographic group. Living in a low-density area reduces the intention to use autonomous shuttles, compared to highly- or mediumly-dense urban areas, although no significant difference is found for robotaxis. Multipolar areas (which are mostly low-density, as they are not themselves major urban centres) are positively associated with both autonomous transport modes, compared to highly- or mediumly-dense areas.

This distinction between rural and urban areas regarding AV acceptance is consistent with that in other work (for example, König and Neumayr 2017) showing that individuals in rural areas do not feel concerned by AVs, as the infrastructure may not be adapted there (Bel et al. 2019), which constitutes unfavorable external conditions (Venkatesh et al. 2003).

Attitudinal variables and technophilia characteristics

Positive attitudes towards the future are associated with a greater intention to use both autonomous transport modes, as is owning a smartphone or a tablet. On the contrary, environmental sensitivity has no significant impact on the intention to use either autonomous mode, including the most environmentally-friendly autonomous shuttle (which is public transport). We have not found any work in which technophilia characteristics reduced the intention to use autonomous technology.

Regarding our specific explanatory variable, urban representations, 'City as an instrument' reduces the intention to use both autonomous transport modes, while 'City as a way of life' increases both. 'City as an instrument' is more common for older and highly-educated respondents and falls with neighborhood density (Model (3) in Table A1); 'City as a way of life' is also more common for the highly-educated, but less so for the middle-aged, those in couples and in low-density or multipolar areas (Model (4)).

The city considered as a way of life is positively associated with both autonomous transport modes (Models (1) and (2) in Table A1). AV acceptance may be part of a positive representation of the future associated with middle-aged, highly-educated mobility users. Even so, the "gadget-effect" of these vehicles should not be overlooked, and it would be useful to test AV acceptance over time, i.e. both the "acceptance to use" and "appropriation to use" stages of the acceptance process.

Mobility characteristics, habits and representations

Holding a driving license is not associated with the intention to use either autonomous shuttles or robotaxis. Household number of cars is associated with a greater intention to use autonomous shuttles, but not robotaxis. Respondents may here consider autonomous shuttles as a complement to private cars (to go to certain congested areas at peak hours), whereas robotaxis may be viewed as a substitute for a second car. Alternatively, cost could be at play, with autonomous shuttles being seen as cheaper than robotaxis. Last, autonomous shuttles and robotaxis may be considered respectively, as current public transport (buses) and current on-demand mobility offers with reservation systems (like Uber). As the former (public transport) is older than the latter (on-demand mobility offers), individuals' social representations of buses are more anchored than those of on-demand mobility. This may lie behind the greater intention to use autonomous shuttles than robotaxis (cf. Planned Behavior Theory, Ajzen 1991).

The mobility habits of respondents are expected to affect both the intention to use automated vehicles in general and their preferred autonomous transport mode. We find that the current transport mode significantly affects the intention to use autonomous modes. Walking is significantly associated with the intention to use both autonomous modes, but this is not the case for cycling, which is insignificant. Unsurprisingly, current use of public transport increases the intention to use autonomous shuttles as public transport in the future.

We last have information on the respondent's ideal trip (without considering automated vehicles): (1) public transport, (2) private car and (3) active modes. Respondents who view private cars or active modes as this ideal mode are strongly opposed to the two autonomous transport modes, whereas, this time, public-transport proponents do not consider that autonomous shuttles will suit their mobility requirements.

Conclusions – Policy recommendations

This empirical paper contributes to the recent and scarce work on the intention to use fully-automated vehicles. Our results render policy recommendations complex and challenging. First, any benefit of autonomous shuttles in low-density areas (essentially to bring first-mile mobility users to mass transport nodes such as railway stations) does not appear in our analysis, although the conclusions are less clear for robotaxis. The situation may be the opposite in multipolar areas, where we find an intention to use both autonomous modes. While the key challenge in these areas remains the relevant routes for autonomous shuttles (where should they go?), this could indicate an opportunity for robotaxis, which can likely cover many destinations that the local authority will not have to define *a priori*.

Second, the statements of acceptance in our survey only deal with the first stage of the process (i.e., when individuals have a number of representations of the potential technology and its use). As a result, recommendations have to be made with caution: these here come from an initial analysis and may not be valid once individuals (start and) continue to use the service.

As car drivers do not intend to use any of the autonomous modes, it is also not clear how to effect a sizeable modal shift between the main current transportation mode and future autonomous modes. The results regarding the ideal transport mode do not correspond to the intention to use AVs, as mobility users who consider the car as the ideal way to travel daily very likely do not intend to use any of the future autonomous modes.

As pedestrians and public transport users claim that they would use autonomous shuttles if available, we can conclude that autonomous technology will retain the current users of public transport, whether there is a driver is behind the wheel or not. For autonomous shuttles (and robotaxis), the emphasis is on the autonomous aspect of the object. While the technology is innovative, the use is not. With respect to the use, an autonomous shuttle has the same features as a current bus (and a robotaxi has the same functionality as a current on-demand mobility offer). We have shown that, under certain conditions, current users would be inclined to use these new autonomous transport modes. This is unsurprising, as individuals stick to their existing habits (Bel 2016). For privately-owned self-driving cars (not analyzed here), the underlying technology is innovative but, unlike the two other new forms of mobility, so is the use: the driver will change his/her activity during this interaction with the autonomous vehicle. He/she will be able to do something else inside his/her vehicle. On the contrary, in shuttles or robotaxis, users do not change their habits or their use. There is no paradigm shift in this case (Bel et al. 2019).

Last, some explanatory variables that were not available in our dataset should be considered: trip purpose and distance to be covered. This is left for further research.

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Appendix

Table A1. Estimation results

	Intention to use		Urban representations	
	Autonomous shuttles	**Robotaxis**	**City as an instrument**	**City as a way of life**
	(1)	**(2)**	**(3)**	**(4)**
Socio-demographic characteristics				
Female	-0.145***	-0.111***	0.096	-0.026
	(0.039)	(0.039)	(0.073)	(0.069)
Age (ref. Under 30)				
Between 30 and 44	0.038	0.070	0.156	-0.337***
	(0.061)	(0.062)	(0.121)	(0.106)
Between 45 and 54	0.135**	0.152**	0.268**	-0.161
	(0.065)	(0.066)	(0.128)	(0.113)
55 and over	0.152**	0.162**	0.421***	0.107
	(0.064)	(0.063)	(0.117)	(0.106)
Couple (vs. single)	-0.015	-0.040	0.099	-0.249***
	(0.049)	(0.049)	(0.087)	(0.085)
Child(ren) at home	0.020	-0.025	-0.004	0.048
	(0.046)	(0.046)	(0.088)	(0.085)
Education (ref. Primary**)**				
Secondary	0.098	0.003	0.231	0.353**
	(0.085)	(0.084)	(0.166)	(0.156)
Bachelor	0.132	0.040	0.675***	0.523***
	(0.087)	(0.086)	(0.166)	(0.157)
Master or PhD	0.198**	0.044	0.641***	0.669***
	(0.092)	(0.091)	(0.181)	(0.166)
Type of municipality (Ref. Highly or mediumly-dense urban area)				
Low-density urban area	-0.136*	-0.059	-0.312**	-0.869***
	(0.070)	(0.070)	(0.129)	(0.131)
Multipolar area	0.112*	0.099*	-0.071	-0.942***
	(0.060)	(0.058)	(0.109)	(0.101)
Attitudinal variables and technophilia characteristics				
Perception of the future	0.065**	0.085***		
	(0.031)	(0.030)		
Environmental sensitivity	0.173	0.094		
	(0.110)	(0.103)		
Urban representations				
	(0.040)	(0.040)		
City as an instrument	-0.033***	-0.037***		
	(0.012)	(0.011)		
City as a way of life	0.039***	0.043***		
	(0.011)	(0.011)		
Technophilia characteristics				
Has a Smartphone	0.148**	0.166***		
	(0.063)	(0.061)		
Has a tablet	0.183***	0.199***		

Mobility characteristics, habits and representations				
Has a driving license	0.046	-0.065		
	(0.084)	(0.080)		
Household number of cars	0.058*	-0.022		
	(0.030)	(0.028)		
Main modes of transport				
On foot	0.166***	0.164***		
	(0.047)	(0.046)		
Bicycle	0.021	-0.017		
	(0.072)	(0.070)		
Two-wheeled vehicle	-0.009	0.160*		
	(0.100)	(0.094)		
Micro-mobility objects (hoverboards etc.)	0.045	0.167		
	(0.141)	(0.141)		
Public transport	0.299***	0.048		
	(0.056)	(0.055)		
Private car (driver)	0.027	0.064		
	(0.047)	(0.046)		
Private car (passenger)	0.067	0.063		
	(0.049)	(0.047)		
Shared mobility (other forms) or on-demand	0.064	0.142		
	(0.101)	(0.106)		
Daily perceived mobility satisfaction	-0.031***	-0.035***		
	(0.011)	(0.011)		
Ideal daily trip (ref. Different possibilities combined)				
Exclusively by collective modes of transport	0.077	-0.021		
	(0.063)	(0.061)		
Exclusively car	-0.344***	-0.179***		
	(0.055)	(0.054)		
Exclusively active modes of transport	-0.104**	-0.135***		
	(0.052)	(0.051)		
Constant			6.404***	5.800***
			(0.189)	(0.170)
Observations	3,297			
Log pseudo-likelihood	-22037.554			

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: Chronos and L'ObSoCo, 2017