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Asking the Wizard-of-Oz: How experiencing autonomous buses affects preferences towards their use for feeder trips in public transport

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ABSTRACT

Autonomous vehicles are expected to have a significant impact on the entire transport sector. With respect to public transportation, autonomous buses—as a means of small and flexible on-demand services—have the potential of increasing the accessibility of people and lower operational costs. As such services are not currently available, their acceptance by their prospective riders and their potential to boost public transportation are yet to be identified. The present study aims at shedding light on these issues by combining a Wizard-of-Oz experiment with a two-stage stated preference (SP) study. The participants of the study had the opportunity to try an ostensible autonomous bus, in the form of a feeder service, over a period of two to four weeks (Wizard-of-Oz experiment). Furthermore, they were confronted with the same hypothetical mode choice tasks, including two autonomous bus alternatives (SP experiment), before and after the Wizard-of-Oz experiment. The study took place in two cities in Germany, namely Berlin and Braunschweig. In this paper, we analyze the mode choices of the pooled sample of participants using a Mixed Logit model with random parameters in order to tackle respondents' heterogeneity of preferences. By estimating the model using the answers from the before and after experiments, we show that there is a positive effect in favor of the autonomous bus service for the feeder trip. In line with the expectations, the results indicate that the participants of the study have a preference for being the only passenger in the vehicle, while they prefer to call it just before their departure, rather than reserving it beforehand.

1. Introduction

The introduction of autonomous vehicles (AVs) is expected to have a disruptive impact on the transportation systems (see e.g. Fagnant and Kockelman, 2015; Milakis et al., 2018; Fraedrich et al., 2019). One of the most significant changes that AVs are likely to induce is enabling/facilitating the provision of highly flexible on-demand services, as the absence of a driver will result in a substantial reduction of the operational costs, and subsequently increasing the attractiveness of such services (Correia and van Arem, 2016; Bösch et al., 2018; Bahamonde-Birke et al., 2018). The advance of on-demand services, in turn, is expected to affect the way mobility

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requirements are perceived by the end-users and has the potential to revolutionize transport and urban systems (Fagnant and Kockelman, 2015; Bahamonde-Birke et al., 2018, etc.).

However, most of the aforementioned gains refer to a given point of time, when the integration of AVs and the development of on-demand services will have achieved a stationary status. The extensive adoption of both AVs and on-demand transportation is likely to take a long time. It is precisely this timeframe, when transportation and city planners will have the best chance to shape the transportation systems of the future and introduce regulation in order to steer transportation systems towards sustainability and social welfare optima (Smith, 2012; Bahamonde-Birke et al., 2018).

One of the most widely discussed issues regarding on-demand services and AVs concerns their integration into the public transportation system (Davidson and Spinoulas, 2015; Yap et al., 2016; Kolarova et al., 2019). This would ease the implementation of regulation, while, at the same time, avoiding that on-demand services cannibalize mass-transportation modes (which are the most efficient modes in terms of social costs) leading to the well-known Vicious Circle of the Decline in Public Transportation and Increased Urban Congestion (Ortúzar and Willumsen, 2011).

This study aims at evaluating the potential of AVs and on-demand services to improve the provision of public transportation services. To this aim, we analyze the preferences of individuals towards both autonomous buses and on-demand services in the context of modal choices. We follow an innovative research approach, which links stated-preferences (SP) experiments with the use of an AV in a "real context".

For this purpose, a three-stage experiment was conceived. First, an SP-experiment was developed and conducted, in which respondents were asked to state which transportation mode they would prefer to carry out a recent trip. The choice-set included potential on-demand autonomous bus services. On a second stage, the participants in the study had the opportunity to use an autonomous bus regularly over a period of two to four weeks. As the current use of autonomously driving buses only partially reflects future application scenarios (currently only very low speeds are permissible and the presence of a safety steward is required; furthermore, the operation is only rarely allowed in public road space), a so-called Wizard-of-Oz experiment (Kelley, 1984) was adopted for the test operation. Hereby, a conventional vehicle was modified in such a way that, firstly, the driver is not visible from the in- or outside of the bus and, secondly, the external appearance simulates an autonomously driving vehicle (e.g. by adding sensor equipment) leaving the passengers with the impression that they are traveling on an autonomous bus. After the completion of the Wizard-of-Oz experiment, the participants were asked to answer again the same SP-experiment they answered in the first stage in order to consider how experiencing autonomous bus services have affected their preferences towards them.

The presented paper reports the findings of the aforementioned study. Section 2 presents a brief review of the relevant literature regarding mode-choice behavior of autonomous buses as well as on Wizard-of-Oz experiments. Section 3 presents the details of the experimental setting, including both the SP-experiment as well as the Wizard-of-Oz experiment. Section 4 presents the methodological framework used to evaluate the results, while section 5 presents the results of the models and discusses the main findings of the study. Finally, section 6 summarizes the conclusions of the study.

2. Literature review

User preferences and behavior play a relevant role regarding the adoption of autonomous vehicles. As the technology does not exist so far, except for some slow autonomous minibuses which are often escorted by a steward, stated preference experiments and user surveys are widely used to analyze future preferences in this regard. To increase the significance of these methods, they can be combined with a Wizard-of-Oz experiment, which is a well-established approach to evaluate users' interaction with future technical systems before they are implemented.

The Wizard-of-Oz approach itself is based on the idea of simulating a fully functional technical system in which a human operator (the wizard) takes over the tasks of the system (Dahlbäck et al., 1993). Originally developed for human–computer interaction research (Kelley, 1984), the approach is also used in the automotive industry, both for evaluation and iterative development of user interfaces for driver assistance and infotainment systems (e.g. Geutner et al., 2002; Lathrop et al., 2005; Martelaro and Ju, 2017; Rothenbücher et al., 2016) and for the analysis and evaluation of interactions in the deployment of autonomous driving vehicles (e.g. Lagstrom and Lundgren, 2015; Mok et al., 2015). In this context, several studies have reported that the methodology has been successfully used to investigate the interactions of other road users (mainly pedestrians) with autonomous driving vehicles (e.g. Habibovic et al., 2016; Lagstrom and Lundgren, 2015) or to study passengers' experiences of a robo-taxi service (Meurer et al., 2020) in real-world environments. However, researchers have raised ethical and methodological concerns (see e.g. Osz et al., 2018; Riek, 2012; Steinfeld et al., 2009) ranging from possible embarrassment of participants when they discover or are informed that they have been deceived, to test supervisors balancing what to tell participants, to concerns about how the environment might affect both the robot and the human.

Recent literature on acceptance and adoption of AVs in general was reviewed by Becker and Axhausen (2017), Gkartzonikas and Gkritza (2019) and Jing et al. (2020) concluding, that the attitude towards self-driving vehicles is driven by characteristics like gender and age as well as behavioral factors and perceptions including trust, safety expectations, social norms or environmental concerns. Furthermore, non-behavioral characteristics like comfort or costs, valuation of travel time and individuals' willingness to pay play an important role. Focusing on the introduction of AVs in public transport and especially as feeder mode to conventional public transport services a meta-analysis of existing literature was carried out by Zubin et al. (2020). The influential factors of adoption are clustered by Zubin et al. (2020) into the four categories sociodemographics, travel behavior, personality and operational characteristics. The results indicate, that regarding socioeconomics, age and income affect the willingness to adopt while the effect of gender seems to be irrelevant. Further, personality factors like the previous knowledge on AVs influences trust into the system and subsequently a low trust leads to a negative effect on adoption. Also, sharing the vehicle with strangers is often perceived negatively.

In the following, recent literature capturing user preferences when experiencing autonomous buses using SP-Experiments will be presented. This includes the experiments by Winter et al. (2019; the Netherlands and Germany) and by Wicki et al. (2019; Switzerland) who both conducted SP-Experiments after the introduction of an experimental autonomous minibus (operating at low speed) in the region of study as well as Smith et al. (2019; Australia) performing two SP-Experiment analyzing the change of behavior after experience.

Winter et al. (2019) conducted an SP-experiment on mode choices considering conventional and autonomous buses as well as a no-choice option. As variables, they included travel time, waiting time, and cost as well as surveillance, information, and type of service (scheduled vs. on-demand). Their results, based on a Mixed Logit model, indicate that preferences between respondents vary depending on travel time so that on longer routes the standard bus is more likely to be chosen. The value of travel time when using autonomous buses is higher than for the standard bus, which means that the travel time is perceived worse than on conventional buses. Another finding by Winter et al. (2019) is that scheduled services would be valued higher than a flexible on-demand system. Wicki et al. (2019) addressed mode choices among autonomous buses, walking, and rental bike and travel time, waiting time, costs, load factor (number of people in the bus), and weather as explanatory variables. They estimated a hybrid Mixed Logit model considering latent variables and panel effects. The results show that attitudinal traits have a significant impact on preferences. The attitude towards the technology does not correlate with time or cost, which harm the likelihood of choosing the alternative. Furthermore, bad weather increases the likelihood of opting for autonomous buses. However, the authors found that the willingness-to-pay for autonomous buses is rather low compared to other public transport modes.

Smith et al. (2019) collected their data by asking actual users of an autonomous shuttle bus that was used in the context of a pilot study on the campus of the University of Western Australia. The bus shuttle was allowed to drive at a low speed of 5 km per hour and was used on two fixed routes. They conducted SP-experiments, before using the bus on-board to capture eventual differences in preferences caused by experiencing the bus. The choice task considered the options autonomous bus and walking while distance, costs, travel (walking) time, waiting time, and weather conditions were considered as explanatory variables. The results suggest that the willingness-to-pay for the ride decreases after experiencing the bus, which is explained by the low operational speed (Smith et al., 2019). Furthermore, it is revealed that the weather and cost are key drivers for choosing the autonomous bus. Finally, Smith et al. (2019) raise the question of whether the parameters derived from experiments in pilot studies reveal the proper indicators for future use of AV and whether these parameters are biased by self-selection. Another approach to estimate longitudinal effects of experiencing autonomous buses is presented by Chee et al. (2021). In contrast to the aforementioned studies, a Structured Equation Model is used instead of a SP-Experiment. The used dataset consist of 185 respondents and the timeframe between the two surveys was four months. The results of Chee et al. (2021) show that after experiencing the autonomous bus for a longer time, the willingness-to-use stays relatively constant while the reason for the usage changes from the basic needs of safety and travel time reliability to ride comfort.

Beside the presented literature, several studies have aimed at offering a broader perspective on the user's behavior and usage of autonomous vehicles (Fagnant and Kockelman, 2015; Thomopoulos and Givoni, 2015; Milakis et al., 2018; Bahamonde-Birke et al., 2018). There seems to exist a wide consensus regarding the barriers to adoption of AVs, such as cybersecurity or privacy concerns, but the same cannot be said regarding the evolution of the demand for mobility services and the broader impacts of this development (Gkartzonikas and Gkritza, 2019).

3. Experimental setting

The experimental setting of the study consists of three-steps. First, an SP-experiment was developed and conducted in order to capture mode choice preferences ex-ante. In a second step, a Wizard-of-Oz experiment was developed and conducted. Finally, the SP-experiment was repeated to capture preferences ex-post.

3.1. *Wizard-of-Oz experiment*

The Wizard-of-Oz experiment offered the participants the possibility of experiencing autonomous bus services during a certain period of time. They were told that the bus will drive autonomously while a safety engineer will remotely observe the systems and can be reached by the passengers via intercom in urgent emergencies[1]. The aim was to enable users to experience the use of autonomous buses, in particular the absence of a driver who, in addition to controlling the vehicle, is also responsible for providing information, selling tickets, assisting persons with reduced mobility, and ensuring safety in the vehicle. In order to make these changes perceptible, the aim was to operate the bus as realistically as possible. At present, however, the use of autonomous buses is only possible with a number of restrictions, such as very low speeds or the need for a safety driver on board. For this reason, a conventional, electrically driven, and manually controlled bus was modified for the experiment in such a way that it gave the appearance of an autonomously driving vehicle. This included the driver not being visible from the outside or inside, attached parts for sensors, and slogans related to research on autonomous driving vehicles. That means the driver compartment was completely separated from the passengers as well as all windows of the driver cabin were darkened. This enabled the vehicle to be used under real conditions in public road space and in accordance with the existing speed limits. In addition, the drivers received special training to ensure that the vehicle is driven as expected by AVs, such as anticipating and driving smoothly, staying in lanes and making few lane changes, approaching obstacles

[1] The participants were also told, that in very rare occasions, an engineer may indeed be in the cabin in order to avoid problems in the very unlikely case that the travelers note a human presence in the cabin (e.g. because of sneezing or the like), but the standard was digital monitoring

slowly. Furthermore, the users were informed in advance that an autonomously driving service would be offered, but only after the experiment was completed, they were informed about the actual setup. A picture of the outside and inside of the used vehicle is shown in Fig. 1.

The experiment was carried out in two cities in Germany, namely Berlin (big-sized city; ca. 3.7 M inhabitants) and Braunschweig (medium-sized city; ca. 0.28 M inhabitants). In Braunschweig, the experiment was carried out in August 2019 for a total of two weeks and in Berlin, it was conducted in November 2019 for a total of four weeks. Bus services were provided on the so-called first/last mile as a connection from the origin or destination to the next mass transportation mode station, reflecting a favored field of application for autonomous buses in public transport. In Berlin, services were offered in a residential area located near the campus of the Freie Universität Berlin (in Dahlem), and providing connections to two subway stations. In Braunschweig, the services were offered connecting an industrial area near the airport with the central station.

3.2. SP-experiment

The SP-experiment represents a modal choice situation and were carried out twice per city, before and after the Wizard-of-Oz experiment. The setting of the modal choice is supposed to represent the last feeder trip from home to a mass transportation mode station. Feeder trips were selected as they most closely resemble the setting, in which the Wizard-of-Oz experiment with autonomous buses was conducted. For the purposes of the feeder trip, individuals were offered five transportation alternatives, namely:

a) Conventional public transport (bus), including the attributes walking time to the bus stop, waiting time at the bus stop, and travel time in the vehicle
b) Walking, including the attribute walking time to the mass transportation mode station
c) Biking, including the attribute travel time as well as walking time representing the additional walking time required to park/secure the bike at the mass transportation mode station
d) Autonomous on-demand bus (two different alternatives were shown in each choice situation), including the attributes walking time to the pick-up point, waiting time (considered to be at home), travel time in vehicle, as well as information regarding whether further passengers were on-board or has to be picked up after and whether it was possible to reserve a given pick-up time in advance (in this case the users still faced a waiting time, which only applies if they do not reserve in advance)

Regarding the cost attribute, it was considered that the price of conventional public transport (CPT) was included in the price of mass transportation mode. Consequentially, neither conventional public transport, nor walking or biking resulted in an increase of the costs faced by the user. The autonomous on-demand bus, in turn, considered a premium to be paid on top of the price of the mass transportation mode ticket. It ranged between 0€ and 1€. Finally, every choice situation included five alternatives, as two alternatives offering autonomous on-demand bus services were included. The reason behind it is that autonomous on-demand bus services included more attributes than conventional services and, consequentially, more options were required to depict this higher degree of internal variability.

The attribute selection is based on qualitative analysis, which was specially conducted in the context of the experiments (Stark

Fig. 1. Used vehicle from outside and inside; passenger compartment shown down right.

et al., 2019). An overview of the attributes and their levels is given in Table 1 and a representation of a choice situation is shown in Fig. 2. The SP design, the attribute levels and the understanding of the experiment by the respondents were considered and improved by means of personal interviews (which also included the collection of choices to estimate prior-model) and the final design was defined by maximizing the D-efficiency relying on the aforementioned priors (Rose and Bliemer, 2009). We also checked for dominance as proposed by Bliemer et al. (2017) and we found no alternative dominating any of the proposed choice-sets.

3.3. Data

The dataset received from the SP-experiment consists of 65 individuals, 14 from the city of Braunschweig while the others are from Berlin. All individuals answered the experiment ex-ante, while only 33 of them answered the experiment ex-post, from which twelve are from Braunschweig and 21 from Berlin. In each wave, each individual provided answers to twelve choice situations. In total, the experiment yielded 1 176 observations (780 ex-ante and 396 ex-post). Given the short duration of the experiment, it was considered that the outside conditions remained stable and no control group was considered. The key attributes in terms of the sociodemographic composition are shown in Table 2 disaggregated by city and time. For a better comparison, the statistics of the overall population are also shown where available (Gerike et al., 2019; Amt für Statistik Berlin Brandenburg, 2021; Braunschweig, 2021; WVI GmbH, 2011). The majority of participants of the study in Berlin are male, while in Braunschweig males represents 50% of the sample. The average (mean) age is about 30 years in Berlin and slightly under 30 in Braunschweig. Regarding education and income levels, in both cities most of the participants hold a university or college degree and have a relatively high income above 2 000 € per month; overall, the income of the participants in Braunschweig is slightly higher than in Berlin. In Braunschweig, over 90% of the sample has a driving license while only roughly 40% is in possession of a public transport season or monthly pass. In contrast, about two-thirds of the respondents in Berlin have a seasonal public transport ticket and only three-quarters are allowed to drive a car. The average commuting time to work with their current mode is similar in both cities taking ca. thirty minutes one way.

4. Methodological approach

The modeling approach combines the ex-ante and ex-post choices of the participants, in order to evaluate the changes in the user preferences after experiencing the on-demand autonomous-bus service. As multiple observations are collected from the same individual (pseudo-panel data) they are likely to be correlated. Here, we present a Mixed Logit model formulation (ML; Cardell and Dunbar, 1980; Ben-Akiva and Bolduc, 1996), allowing to account for correlation among the choices provided by the same respondent, as well as for unobserved inter-respondent heterogeneity (e.g. Bhat, 1995; Walker et al., 2007). In what follows we delineate the model specification and the estimation approach.

4.1. Model specification

The general form of the utility functions of alternatives i ∈ {1: bus, 2: walk, 3: bike, 4: AV1, 5: AV2} for individual q ∈ {1, 2,…, Q} in choice task t ∈ {1, 2,…, T_n} is given by

$$U_{1qt} = \widetilde{ASC}_{1q} + \widetilde{\beta}\,{}^{*}X_{1qt} + \delta^{*}Z_q + \epsilon_{1qt} = ASC_{1q} + \sigma_{ASC1q} + (\beta + \mu_{1q})^{*}X_{1qt} + \delta^{*}Z_q + \epsilon_{1qt}$$

$$U_{2qt} = \widetilde{ASC}_{2q} + \widetilde{\beta}^{*}X_{2qt} + \delta^{*}Z_q + \epsilon_{2qt} = ASC_{2q} + \sigma_{ASC2q} + (\beta + \mu_{2q})^{*}X_{2qt} + \delta^{*}Z_q + \epsilon_{2qt}$$

$$U_{3qt} = \widetilde{ASC}_{3q} + \widetilde{\beta}^{*}X_{3qt} + \delta^{*}Z_q + \epsilon_{3qt} = ASC_{3q} + \sigma_{ASC3q} + (\beta + \mu_{3q})^{*}X_{3qt} + \delta^{*}Z_q + \epsilon_{3qt}$$

Table 1
Attributes and levels.

Attribute	*Alternative*	*Levels*	
Premium Price	*AV1, AV2*	*0, 0.5, 1*	*Euro*
Walking Time	*Walking*	*20, 25, 30*	*Minutes*
	Bike	*2, 5*	*Minutes*
	CPT	*5, 10*	*Minutes*
	AV1. AV2	*2, 5, 10*	*Minutes*
Waiting Time	*CPT*	*5, 10*	*Minutes*
	AV1, AV2	*5, 10, 15, 20*	*Minutes*
Travel Time	*Bike*	*12,15, 20*	*Minutes*
	CPT	*7, 10, 15*	*Minutes*
	AV1, AV2	*7, 10, 12, 15*	*Minutes*
Further Passengers in Bus	*AV1, AV2*	*0, 1*	
Last Passenger to Board	*AV1, AV2*	*0, 1*	
Reservation Possible*	*AV1, AV2*	*0, 1*	

if reservation is used, waiting time will reduce to 0

	Bus	Walk	Bike	AV On-Demand Bus (1)	AV On-Demand Bus (2)
Premium Price				1 Euro [Premium price, additionally to the usual public transport ticket]	0 Euro [Premium price, additionally to the usual public transport ticket]
Walking Time	10 Min	30 Min	2 Min	2 Min	2 Min
Waiting Time	10 Min			10 Min	0 Min (10 Min)*
Travel Time	10 Min		20 Min	7 Min [Travel time in vehicle, incl. detours to pick up other passengers]	12 Min [Travel time in vehicle, incl. detours to pick up other passengers]
Further Passengers				No, **I am the only passenger**	Yes, there are **further passengers**
Last Passenger					Yes, I am the last passenger to board
Reservation				**No**	**Yes**
Your Choice	○	○	○	○	○

* If you make a reservation, **you do not need to wait.** If you **do not** make a reservation, you may have to wait. **The waiting time in this case is shown in the brackets**

Fig. 2. Representation of a choice task (translated into English, experiment originally in German).

Table 2
Key characteristics of participants.

Attribute	*Level*	*Berlin*			*Braunschweig*		
		Pre	*Post*	*Population*	*Pre*	*Post*	*Population*
Gender	*Male*	*63%*	*76%*	*49%*	*46%*	*55%*	*50%*
Age	*Years*	*31*	*34*	*41*	*28*	*29*	*43*
Income per month	*0 € - <900 €*	*32%*	*29%*	*10%*	*23%*	*27%*	*n/a*
	900 € - <2000 €	*14%*	*24%*	*40%*	*0%*	*0%*	*n/a*
	2000 € - <2600 €	*29%*	*14%*	*13%*	*54%*	*46%*	*n/a*
	2600 € - <3200 €	*20%*	*33%*	*13%*	*23%*	*27%*	*n/a*
	>3200 €	*4%*	*0%*	*24%*	*0%*	*0%*	*n/a*
Education	*University, College*	*75%*	*67%*	*24%*	*92%*	*91%*	*22%*
	Professional Training	*6%*	*5%*	*51%*	*0%*	*0%*	*50%*
	Other	*19%*	*28%*	*25%*	*8%*	*9%*	*28%*
Driving License	*Yes*	*75%*	*76%*	*84%*	*92%*	*91%*	*87%*
Public Transport Season Pass	*Yes*	*65%*	*67%*	*51%*	*38%*	*45%*	*n/a*
Commuting Time	*Minutes*	*31*	*34*	*24*	*32*	*31*	*n/a*

$$U_{4qt} + U_{4qt,ex-post} = \widetilde{ASC}_{4q} + \widetilde{\beta}^{*}X_{4qt} + \left[\widetilde{ASC}_{4q,ex-post} + \widetilde{\beta}_{ex-post}{}^{*}X_{4qt}\right]{}^{*}I_{ex-post} + \delta^{*}Z_{q} + \epsilon_{4qt} = ASC_{4q} + \sigma_{ASC4q} + \left(\beta + \mu_{4q}\right){}^{*}X_{4qt} + \left[ASC_{4q,ex-post} + \sigma_{ASC4q,ex-post} + \left(\beta_{ex-post} + \mu_{4q,ex-post}\right){}^{*}X_{4qt}\right]{}^{*}I_{ex-post} + \delta^{*}Z_{q} + \epsilon_{4qt}$$

$$U_{5qt} + U_{5qt,ex-post} = \widetilde{ASC}_{5q} + \widetilde{\beta}^{*}X_{5qt} + \left[\widetilde{ASC}_{5q,ex-post} + \widetilde{\beta}_{ex-post}{}^{*}X_{5qt}\right]{}^{*}I_{ex-post} + \delta^{*}Z_{q} + \epsilon_{5qt} = ASC_{5q} + \sigma_{ASC5q} + \left(\beta + \mu_{5q}\right){}^{*}X_{5qt} + \left[ASC_{5q,ex-post} + \sigma_{ASC5q,ex-post} + \left(\beta_{ex-post} + \mu_{5q,ex-post}\right){}^{*}X_{5qt}\right]{}^{*}I_{ex-post} + \delta^{*}Z_{q} + \epsilon_{5qt}$$

where $\widetilde{ASC}_{iq} \sim N(ASC_{iq}, \sigma_{ASCiq})$ are individual- and mode/alternative-specific constants with mean ASC_{iq} and standard deviation σ_{ASCiq}; $\widetilde{\beta} \sim N(\beta, \mu_{iq})$ are random parameters with mean β and standard deviation μ_{iq}, associated with X_{iqt} the vector of the level of service attributes of alternative i; δ denotes the parameters associated with Z_q the vector of the socio-economic characteristics of the respondents. $I_{ex-post}$ is a dummy variable equal to one, if the observation is associated with the ex-post experiment, and zero otherwise. The specification of the last two equations allows to estimate the changes in the sensitivities associated with the attributes of the autonomous bus after experiencing the service. Finally, ϵ_{iqt} are independent and identically distributed (i.i.d.) EV1 error terms.

4.2. Model estimation

The random parameters are assumed to be normally distributed across individuals, that is $\widetilde{ASC}_{iq}$ and $\widetilde{\beta}_i$ are common to all answers provided by the same individual, while the i.i.d. EV1 error terms ϵ_{iqt} are different in each choice-situation (Walker et al., 2007). It is then possible to estimate the variability of these individual-specific perturbations relative to the variability of ϵ_{iqt}.

Under these assumptions, the likelihood function of the sample can be expressed as follows

$$L = \int \gamma \Pi_q \Pi_t P\left(y_{iqt} | X_{iqt}, Z_q; \gamma, \delta\right) * f(\gamma|\theta) * d\gamma$$

where the first term stands for the usual multinomial logit probabilities - with $y_{iqt} = 1$ taking a value of one, if alternative i is chosen in choice situation t, and 0 otherwise - while the second term represents the density of the random parameters, with γ denoting the joint vector of random coefficients to be estimated, that is $\widetilde{ASC}_{iq}$ and $\widetilde{\beta}$, and θ denoting collectively the parameters of the distribution, in this case the mean and the variance of γ. As this representation of the likelihood does not lead to a closed-form expression for the probabilities, it is integrated over the domain of the stochastic components and estimated using maximum simulated likelihood techniques (McFadden, 1986; Train, 2009). Evidently, the integration over the domain of the random components must be conducted at individual rather than at the observation level.

5. Results and discussion

The model is estimated in Biogeme (Bierlaire, 2003) using 2000 MLHS draws on the pooled sample of participants from Berlin and Braunschweig. This number of draws produced results that were deemed as highly stable across simulations. Table 3 presents the estimation results of the Mixed Logit model as well as the results from a previously estimated MNL-Model. In the modelling process,

Table 3
Model Estimates.

Variable	*Utility Equation*	*Model 1: MNL Estimate*	*t-test*	*Model 2 ML Estimate*	*t-test*
ASC Bike	*Bike*	**0**	*fixed*	**0**	*fixed*
σ ASC Bike				**(3.82)**	*9.13*
ASC Conventional Public Transport (CPT)	*CPT*	**0.432**	*1.56*	**2.02**	*3.46*
ASC Walking	*Walking*	**0.00439**	*0.00929*	**0.128**	*1.54*
σ ASC Walking				***(2.21)***	***5***
ASC AV BS	*AV1, AV2*	**0.33**	*1.17*	**1.13**	*1.89*
ASC AV B	*AV1, AV2*	**1.01**	*4.71*	**2.26**	*4.42*
σ ASC AV B				**(1.66)**	*6.28*
Premium Price	*AV1, AV2*	**−1.49**	*−10.3*	**−3.01**	*−9.16*
σ Premium Price				**(1.84)**	*7.88*
Travel Time BS	*Bike, CPT, AV1, AV2*	**−0.174**	*−6.86*	**−0.369**	*−6.56*
σ Travel Time BS				**(0.148)**	*3.73*
Travel Time B	*Bike, CPT, AV1, AV2*	**−0.127**	*8.26*	**−0.259**	*−9.36*
σ Travel Time B				**(0.0795)**	*3.26*
Walking Time BS	*All Alternatives*	**−0.223**	*−8.27*	**−0.47**	*−8.38*
Walking Time B	*All Alternatives*	**−0.151**	*−8.55*	**−0.337**	*−9.76*
σ Walking Time B				**(0.0634)**	*3.93*
Waiting Time BS	*CPT, AV1, AV2*	**−0.241**	*−6.39*	**−0.351**	*−5.13*
σ Waiting Time BS				**(0.132)**	*2.03*
Waiting Time B	*CPT, AV1, AV2*	**−0.105**	*−4*	**−0.242**	*−4.86*
σ Waiting Time B				**(0.222)**	*5.54*
Waiting Time when reserved	*AV1, AV2*	**−0.011**	*−0.872*	**−0.038**	*−1.84*
σ Waiting Time when reserved				**(0.092)**	*6.76*
High Income CPT	*CPT*	**−0.702**	*−3.32*	**−2.1**	*−3.75*
High Income Walk	*Walking*	**−0.769**	*−2.37*	**−2.55**	*−3.11*
Change in ASC AV ex-post	*AV1, AV2*	**1.56**	*3.76*	**1.69**	*2.76*
σ Change in ASC AV ex-post				**(1.28)**	*3.55*
Change in Premium Price ex-post	*AV1, AV2*	**−1.03**	*−3.8*	**−1.21**	*−2.09*
σ Change in Premium Price ex-post				**(2.08)**	*3.96*
Change in Reservation ex-post B	*AV1, AV2*	**−0.407**	*−1.53*	**−1.05**	*−2.7*
Change in Further Passengers ex-post BS	*AV1, AV2*	**−1.32**	*−2.7*	**−1.79**	*−2.51*
Change in Further Passengers ex-post B	*AV1, AV2*	**−0.677**	*−1.83*	**−0.627**	*−1.22*
Change in Last Passenger ex-post BS	*AV1, AV2*	**−1.19**	*−2.79*	**−1.22**	*−1.93*
Change in Last Passenger ex-post B	*AV1, AV2*	**−0.554**	*−1.64*	**−0.415**	*−0.945*
Log-likelihood		**−1224.097**		**−902.3708**	
Mc Fadden ρ^2		**0.353**		**0.523**	

city specific parameters, denoted by B and BS, respectively for Berlin and Braunschweig, were first estimated for all attributes and maintained only when significant, otherwise replaced by generic parameters for both cities. Similarly, differences between parameters ex-ante and ex-post (denoted in the table as "change in") are only included when found to be statistically significantly different from zero, or when deemed relevant for the analysis. Also, distributed parameters to account for preference heterogeneity were tested for all parameters and maintained only when significant. No further parameter was found to be statistically significantly different from zero. No alternative specific parameters were considered as they were not found to be statistically significantly different from each other. Furthermore, we considered correlation among different alternatives in our experiment on the basis of an NL-kernel (Williams, 1977; Daly and Zachary, 1978), but we did not find any statistically significant correlation structure.

The parameters associated with travel costs as well as with travel, waiting, and walking time exhibit the expected signs. Similarly, in line with the hypothesis, walking time is perceived more negatively than travel time in both cities. The ratio between walking and travel time lies between 1.27 and 1.30 which is lower than a common assumed factor of 2 (Wardman, 2004; Small, 2012) but comparable to the 45% estimated in a meta-analysis by Wardman et al. (2016). Also, in both cities, waiting time is perceived as less negative than travel time with a ratio of 0.93 to 0.95. While these results may seem surprising, it is important to consider that, in the context of the experiment, the waiting time for autonomous buses was assumed to be at home instead of at a station or bus stop.

The magnitude of the time parameters in Berlin is smaller than in Braunschweig. A comparison between the marginal utility of travel time and the marginal utility of price this yields a value of time for the average individual of 7.36 €/hr in Braunschweig and 5.16 €/hr in Berlin. After exposure, we observe a significant change in the price attribute, which was also the case in Smith et al. (2019). Consequentially, the value of travel time decreased to 5.25 €/hr in Braunschweig and 3.68 €/hr in Berlin. As a possible explanation can be postulated that the willingness-to-pay to use a novelty decreases after experiencing it. The estimates for the value of travel time align with previous studies in Germany (Ehreke et al., 2015; Wardman et al., 2016; Steck et al., 2018).

When reserving a given pick-up time was possible, the waiting time was found to be not statistically significant in both cities. In this case, the waiting time reflects how long individuals would have to wait if they did not previously reserve a pick-up time; hence, the insignificance of the parameter means that the individuals were willing to reserve a vehicle and forgo the waiting time. The necessity of having to reserve a vehicle was also found to be statistically insignificant prior to the experiment. After exposure, no changes in the valuation of waiting time when reserving a given pick-up time were identified, but a significant disutility was identified in association with the necessity itself of reserving a vehicle (in order to avoid waiting times) in Berlin. It remained an insignificant factor in Braunschweig. The disutility of reservation amounts to 2:30 min of waiting time when reservation is not possible. That means that a person would prefer the need for a reservation upfront if the waiting time would be otherwise longer than 2:30 min.

Furthermore, before exposure it was found that being the last passenger boarding the vehicle or traveling with further passengers had no significant impact. However, in Braunschweig after exposure the disutility of traveling with other people was found statistically significant at a significance level of 5%, while the estimate associated with being the last passenger after exposure is also negative (which may be associated with having troubles finding a desired place to sit, which may be accentuated due to the small size of the vehicles to which the individuals were exposed) and significant at 10% level. For Berlin, both estimates show the same negative effect without being significant.

Also, several socioeconomic variables were tested in the model including age, gender, education and income. However, only a high income revealed a significant effect influencing the choice of walking and public transport negatively, which matches expectations and earlier literature results (e.g. Paulley et al., 2006).

Finally, for both cities, the ASC of the alternative AV was found to significantly increase after exposure. This means that the individuals were more likely to use the alternative AV, after having taking part in the experiment. Along these lines, it is important to note that the ASC of autonomous buses is higher than the ASC of conventional public transport.

The most important takeaway from the results is that experiencing autonomous buses results in a clear positive effect towards the acceptance of AV feeder trips. This finding differs from the results presented by Smith et al. (2019), who also considered changes after exposure. The reason behind these divergent results may be given by the characteristics of the vehicles considered in the experimental setting: while Smith et al. (2019) considered actual AVs offering a very low level of service (very low operational speed), in our experiment the level of service was much higher and close to the level of service expected from AVs once they are permitted to operate. Hence, we consider that these results offer clear insights on how preferences may be affected by experience, once fully capable AVs are available.

However, exposure to AVs does not only results in a higher valuation of the alternative in general, but also in stronger apprehension to travel with further passengers (most likely due to the small size of the vehicles compared with conventional buses) and being the last passenger (the last to be confirmed with a larger sample). Along these lines, exposure also increases the disutility associated with the premium paid to use the autonomous feeders. Consequentially, the impact of experiencing the actual services will also depend on their characteristics. Nonetheless, it must be pointed out that the general valuation of AVs is higher than the valuation of conventional public transport services, which offers a significant opportunity for public transport.

Finally, the results indicate that experiencing AVs results in increased awareness regarding the disutility of having to reserve pick-up times in advance when using on-demand services. This disutility amounts to a$<$3 min, which indicates that an optimized on-demand service (from a user perspective) should either reduce waiting times to less than three minutes or otherwise allow reserving pick-up times.

6. Conclusions

The study reports the results regarding preferences towards the use of on-demand autonomous buses for the purposes of feeder trips in the cities of Braunschweig and Berlin. The results show that experiencing autonomous bus services positively impacts the propensity of using such services in the future. Furthermore, the results indicate that the experience increased the negative disutility associated with having to reserve a pick-up time a priori, which may have been neglected *ex-ante*, given the hypothetic nature of SP-experiments. Also traveling with further passengers becomes negatively significant in the propensity of using the new services in both cities. A similar tendency is observed for being the last passenger but without the certainty of highly statistical significance.

Regarding the typical attributes considered in mode choice models, we observe that the disutility of travel time as well as waiting and walking time remain constant after exposure. The disutility of paying a premium price to use autonomous feeders, however, increases after the experiment and a slight decrease is observed in the value of travel time. This may be explained by novelty effects.

From a policy perspective, the most important finding of the study is that, in contrast to previous studies, experiencing autonomous buses increases the propensity of using such services. Similarly, AVs seem to be better perceived by the users than conventional bus services. This represents a significant opportunity for public transport; however, it is important to take into account that autonomous buses are likely to be introduced together with smaller vehicles meant for individual use (be they private or shared), which relativizes this advantage. Concerning the (technology) adoption of AVs, it is important to mention, that initial doubts may be overcome after the experience of an AV and therefore, well run pilot operations as well as incentives like reduced fares may help to exploit advantages. Finally, it was estimated that the disutility of reserving a pick-up time in advance amounts to a little bit less than three minutes. It implies that, from a demand perspective, this possibility should be offered if waiting times are longer than this amount of time, which may be the case in many applications.

Notwithstanding, it is important to acknowledge that the results are neither representative for the German society nor for any of the two cities, as the sampling is affected by location and self-selection issues. For this reason, we centered the analysis upon changes after experiencing the vehicles and not upon the basal levels. We, however, acknowledge that changes after experiencing the vehicles may also be user-group specific, although we hypothesize that these differences are much more limited than differences in basal levels (in fact, we were not able to identify any differences in the way preferences are affected by experience in association with socio-demographic variable, while we were indeed able to identify how these variables impact basal preferences, which aligns with our hypothesis). Notwithstanding, results are limited by the sample size and, eventually, a larger sample may have enabled to identify difference among user groups regarding the way their preferences are affected by experience, among other differences e.g. mode specific time parameters or the influence of unobservable individuals' characteristics (which could be considered by including latent variables). However, the main results of the study, such as the value of travel time are consistent with the average for the German population as reported by previous studies and the estimates align with the working hypothesis. Further research is necessary in order to confirm these results with larger sample

CRediT authorship contribution statement

Jan Weschke: Writing – original draft, Data curation, Formal analysis, Methodology, Software. **Francisco J. Bahamonde-Birke:** Writing – original draft, Conceptualization, Data curation, Methodology, Formal analysis. **Kay Gade:** Writing – review & editing, Conceptualization, Funding acquisition, Project administration. **Evanthia Kazagli:** Writing – review & editing, Conceptualization, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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