How Technology Commitment affects Willingness to Use AVs

Results from Realistic Mode Choice Experiment for a Self-Driving Shuttle Service

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Conference Paper STRC 2019

STRC | 19th Swiss Transport Research Conference
Monte Verità / Ascona, May 15-17, 2019

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April 2019

Abstract

Automation of vehicles will substantially change traffic and especially public transport as we know it. Ongoing implementations of test runs with self-driving vehicles offer the opportunity to assess future demand on this matter. Associated with the introduction of a self-driving bus service fully integrated into the local transport schedule on the Rhine Falls in Switzerland, we carried out a close to reality survey experiment. Making use of this example, we conducted a stated mode choice experiment drawn from a random sample in 2018. This stated choice survey aims to answer the question of willingness to pay and willingness to use self-driving bus services by making use of a realistic setting that provides high external validity. Respondents can choose among rental bike, walking and a self-driving bus service with varying costs, travel time, occupation and weather situations. By the inclusion of attitudinal questions regarding technology commitment into an integrated latent variable and choice model, we test how technology related attitudes of respondents explain their anticipated behaviour and whether individuals trade off technological scepticism with potential benefits. Results indicate that technology acceptance is a robust indicator for predicting self-driving bus usage, but that there is no interaction between technology commitment and time nor price.

Keywords

Mode Choice Experiment, Self-driving, Autonomous Vehicles, Stated Choice, Technology Commitment, Acceptance, Survey, Hybrid Choice Model, Willingness to Pay

1. Introduction

Autonomous vehicles (AV) will substantially change road traffic in the upcoming decades. The absence of a driver and manual steering is expected to have many positive effects. Among these are a) derived positive impacts from the combination and development with car sharing (Thomopoulos & Givoni, 2015), b) the reduction of space required for parking vehicles (Alessandrini et al., 2015), c) improvements in safety (Najm et al., 2010), d) reduced congestion through an increase in road capacity and efficiency improvement of the transport system (Fernandes & Nunes, 2012), e) environmental benefits through higher fuel efficiency (Ioannou, 1997) and f) issues of equity by allowing economically disadvantaged groups, younger people with no driving license, older people or those with disabilities access to personal mobility (Alessandrini et al., 2015; Bouton et al., 2015; Howard & Dai, 2014).

However, a transition to fully automated road traffic is only possible if AVs are accepted and used by society. These perceptions are driven by several challenges with self-driving cars. For example, there are various concerns about security and reliability of the self-driving vehicle and technology, system performance in poor weather conditions, interaction with pedestrians and bicycles, no driver controls available and AVs behaviour in unforeseeable circumstances (Bonnefon et al., 2016; Fagnant & Kockelman, 2015; Greene, 2016; Kyriakidis et al., 2015; Rietz, 2017). These are concerns that insecure people and hinder adaption and usage of this new technology (Fagnant & Kockelman, 2015; Kyriakidis et al., 2015). Therefore, technological innovations in the AV industry alone may not be sufficient to reform the current transportation system. It is thus necessary to evaluate and forecast users perceptions, acceptance and willingness to use for any emerging technology early in the design and development process (Davis et al., 1989; Fraedrich & Lenz, 2016). The execution of test runs with AVs offers a good opportunity to assess user preferences and intent to use in a realistic setting.

We do so by conducting a stated mode choice experiment with 761 residents from the canton of Schaffhausen, Switzerland. By applying an integrated choice and latent variable (ICLV) model, we consider aggregate consumer demand to be the result of a combination of several decisions made by each individual, where each decision consists of a choice made among a finite set of available alternatives (Ben-Akiva et al., 1985). In the case of the current study, these alternatives are a self-driving bus, rental bikes or walking with the attributes time, costs and occupancy. In addition, ICLV modelling allows us to integrate individual characteristics such as ability to walk and bike but also latent psychological factors such as attitudes and perceptions together with choice situation specific characteristics such as weather conditions into our model. We thus can check for a potential economic trade-off between technology scepticism and potential benefits (e.g. timesavings) for the individual. This leads to a more realistically explained individual choice behavior (Ben-Akiva et al., 2002).

The inclusion of general technology attitudes and perceptions as psychometric latent variables leads to a better understanding of choice behavior and increases the models predictive power (Ben-Akiva et al., 2002). We measure technology commitment with the short scale developed and validated by Neyer et al. (2012) to investigate how it affects willingness to use the self-driving shuttle. The scale is based on a model of technology readiness, which identifies three distinct facets as determinants of individually different readiness to use technology: Technology acceptance, technology competence and technology control convictions. Readiness to use technology is intended to predict the successful use of new technologies (Neyer et al., 2012, 2016).

The remainder of the paper is structured as follows. First, we discuss the current state of research on autonomous driving preferences and review scholarly work on choice preferences regarding self-driving vehicles. Second, important determinants of general behaviour derived from existing literature are discussed. Third, we describe the study and experimental design. Fourth, we elaborate methods used and our empirical model. We then present our results and finally yet importantly discuss possible implications.

2. What we know from existing research

Over the last decade, availability of new vehicle technology has been increasing (Zmud et al., 2016). According to the existing literature, usage and adaption of such technology is likely to depend on the specific perception of transport automation and individual attitudes towards technology in general. In recent years, various studies regarding perception of AVs were published (see Becker & Axhausen, 2017; Gkartzonikas & Gkritza, 2019 for extensive literature reviews). However, besides few studies applying modelling techniques trying to answer questions regarding travel demand, only little research has looked at realistic intent to use or even actual use behaviour (Zmud & Sener, 2017; Zmud et al., 2016). The following literature review thus concentrates on the general perception and acceptance of as well as on willingness to pay (WTP) for AVs as these are important determinants for user acceptance and thus general adoption. Regarding research on vehicle technology, acceptance can thereby be defined as the "the degree to which an individual intends to use a system and, when available, incorporates the system in his/her driving" (Adell et al., 2017, p. 477).

Several studies conducted surveys within different contexts to identify relevant attitudes explaining AV perception and acceptance. Howard and Dai (2014) conclude that safety and liability concerns play a critical role in the adoption of AVs. Kyriakidis et al. (2015) argue that attitudes toward safety (e.g. privacy concerns, passengers' level of comfort and not being behind a wheel) are possibly related to individuals' perceptions about automation. Panagiotopoulos and Dimitrakopoulos (2018) find that safety concerns have a potentially negative effect on the intention to use. Hulse et al. (2018) argue that perceived risk (e.g. the potential for an accident to occur) together with different transportation modes has a negative influence on the intention to ride in AVs.

Regarding the preferred modes of operation for level 5 automation, Payre et al. (2014) conducted a survey among 421 drivers in France. Questions included general attitudes towards AVs, and intention to use an AV (Payre et al., 2014). 68% of respondents are concerned regarding the acceptance of AVs. In addition, older people are less likely to pay for such technologies even though they generally express acceptance towards them. Similarly, the study by Haboucha et al. (2017) shows that older people generally rather prefer private conventional vehicles and are indifferent regarding shared vs. privately-owned AVs. Furthermore, people with higher levels of education show a greater tendency towards AVs over private vehicles. Pakusch et al. (2018) conclude that people would still want to own a private vehicle (conventional or autonomous) after the introduction of AVs and private vehicles would still be the preferred transportation mode. In a panel survey conducted among 1408 Swiss citizens from the canton of Schaffhausen together with the implementation of a test run of a self-driving shuttle bus, Wicki and Bernauer (2018) find that respondents are generally sceptical regarding a transition towards fully automated road traffic, but are highly supportive of test runs. Concerns regarding a general transition focus on the possible misuse through third parties, for example through hacking attacks.

As an important indicator of acceptance, people's WTP for AV technology has attracted certain scholar attention. One reason would be that it could provide important insights for the valuation of this technology (Liu et al., 2019). Several studies investigate respondents' WTP for AVs, but find overall rather low WTP (Zmud et al., 2016). In a US based survey study by Bansal et al. (2016), respondents indicate that they were willing to pay around \$7000 more on average for a Level 5 and around \$3300 more for a Level 4. Moreover, as stated in Daziano et al. (2017), the average US household was found to be willing to pay \$3500 for partial automation and \$4900 for full automation. Yap et al. (2016) conducted a stated preference experiment exploring the role of attitudes in perceiving the utility of AVs. Results indicate that in-vehicle time in AVs is experienced more negatively than in-vehicle time in manually driven cars. In addition, travellers' attitudes regarding trust play an important role in AVs attractiveness (Yap et al., 2016). Furthermore, Jiang et al. (2018) argue that age, household size and trip purposes of AVs can influence the WTP. Shabanpour et al. (2018) find attributes such as purchase price, incentives, and policies on the liability to potentially increase the adoption and WTP. Similarly, Talebian and Mishra (2018) concluded that 'word-of-mouth' impacts the WTP and has the potential to drastically affect market share.

Regarding perceptions of various aspects of the technology and operation of AVs, several survey studies were conducted. Schoettle and Sivak (2014) conducted an online survey with 1533 respondents in the UK, US, and Australia on different aspects of and respondents' opinions. The survey included questions on level of familiarity, attitudes toward potential benefits, concerns about the emergence, and respondents WTP for AVs. Results showed that 43% of respondents expect travel time savings, but that over 50% do not want to pay more for advanced technologies and features installed on AVs.

Other studies focused more on behavioural characteristics and perceptions. The level of awareness of and general attitudes is the scope of a study based on an online survey among 4886 individuals in 109 countries (Kyriakidis et al., 2015). The study included questions regarding the acceptance and concerns of and respondents WTP for different levels of automation. The authors conclude that respondents who report higher vehicle miles travelled and who used cruise control in their personal vehicles were more likely to express a higher WTP. This indicates technology affiliation as an important determinant for AV acceptance (Kyriakidis et al., 2015). Similarly, Choi and Ji (2015) included questions on the external locus of control as driving-related personality factors and conclude that groups of people with difficulty in driving have a higher intention of using AVs. According to Hohenberger et al. (2016), emotional and affective reactions, in terms of willingness to use, differ by gender. Results indicate that woman are less likely to anticipate pleasure rather than anxiety when using AVs, which potentially influences the willingness to use.

While the current research on different aspects regarding acceptance of AVs spans a variety of methodological approaches, data sources and determinants, their findings appear to be somewhat conflicting and difficult to compare. In addition, the current research lacks of studies investigating acceptance in real world scenarios and are thus rather difficult to generalize and therefore impossible to determine individuals actual use behaviour regarding future usage as a potential transport mode.

3. Determinants of Mode Choice Behaviour

Travel mode choice has been widely discussed and analysed in the academic community over the past decades. Interest comes from a variety of disciplines such as economics, engineering, environmental sciences, geography, and transportation research. However, even though time and money are predominant, what affects travel mode choice most and why individuals prefer one travel mode over another in a specific situation is widely discussed in the academic community (Schwanen & Lucas, 2011). For a long time, the dominant framework to understand mode choice have been utility-based models. However, other cognitive mechanisms potentially predicting travel mode choice have caught scholarly attention too (see, for example, Hoffmann et al., 2017). We follow this approach, and argue that specific individual attitudes and characteristics as well as situational circumstances such as weather conditions are important determinants in explaining travel mode choice. In addition, we test whether a trade-off between attitudes and individual utility add to explaining decision-making approaches of individuals. By doing so, we add to the long lasting discussion of how consumers trade-off behavioural costs and individual benefits (see, for example, Verhallen & van Raaij, 1986).

The traditional approach used in most studies to explain travel mode choice is based on utility theory. This means that, in certain circumstances, the travel mode with the highest (individual) utility will be chosen (Domencich & McFadden, 1975; McFadden, 1986, 2001). The utility is thereby based on travel costs and time. Time is thereby considered to be the scarce resource and has been identified as such in various studies ranging from economics, to sociology, and social psychology (Arkes & Ayton, 1999; Berning et al., 1976; Leclerc et al., 1995; Parasuraman & Riley, 1997; Soman, 2001). However, other factor have also been studied widely (Hoffmann et al., 2017), among which psychological factors play an important role (Gardner & Abraham, 2008). Several reviews have identified key determinants, concluding that travel time and cost, sociodemographics, and spatial characteristics are among the key factors explaining individuals travel mode choice (De Witte et al., 2013; Frank et al., 2008; Hoffmann et al., 2017).

Social-psychological theory has identified several mechanisms that are potentially key in explaining mode choice (Bamberg et al., 2011). Most famous, the theory of reasoned action (Fishbein & Ajzen, 1977) as well as the theory of planned behaviour (Ajzen, 1991) have both been discussed widely. The theory of reasoned action by Fishbein and Ajzen (1977) was introduced to test the relationship between attitudes and behaviour. Thereby, attitude can be defined as an individual's evaluation of an object, whereas behaviour is the respective result or intention (Fishbein & Ajzen, 1977). The theory of planned behaviour adds a third factor that is known as the perceived control behaviour, meaning the control which users perceive that may limit their behaviour (Ajzen, 1991). Subjective norms and attitudes are thereby products of underpinning beliefs (Hoffmann et al., 2017). In such attitude-behaviour relationships, individual variables (e.g. sociodemographics) are important determinants of these general attitudes (Verhallen & van Raaij, 1986).

What is also important in the theory of planned behaviour is past behaviour and experience (Bamberg et al., 2003). In general, prior experience is known to influence future purchase intentions and behaviour (Bentler & Speckart, 1979). Eagly and Chaiken (1993) suggested that the best predictor of future behaviour and intentions is the frequency of past behaviour directly related to the behavioural intentions being predicted. Thus, prior and initial experience of a product can potentially reinforce future behavioural intentions of individuals (Eagly & Chaiken, 1993, 2007).

Deriving from the literature review and the outlined theory, several factors explaining AV acceptance and usage need to be taken into account. Therefore, factors that need to be taken into account when conducting a mode choice survey including an AV are first of all mode specific characteristics such as travel costs, travel time, but also the occupancy of the vehicle when sharing a ride with other passengers. Second, individual ability (e.g. ability to walk and bike) as well as personal experience with an AV need to be accounted for. In addition, individual attitudes towards technology as well as the context (e.g. weather conditions) have to be controlled for.

4. Empirical Study Design

The implementation of a test trial for a self-driving shuttle bus contains societal as well as political challenges, but also enables the investigation of unanswered questions. Associated with the introduction of a self-driving bus in Neuhausen am Rheinfall (Route 12), we carried out a survey on the test run of Route 12 as well as autonomous driving in general, using 879 participants from a random sample. The survey was carried out in the context of the introduction of Route 12 in Neuhausen am Rheinfall in the three municipalities Neuhausen am Rheinfall, Stein am Rhein and Thayngen, all situated within the Canton of Schaffhausen, Switzerland.

4.1 Survey

We use data from a panel survey among residents of the Canton of Schaffhausen. In summer 2018, an invitation letter was mailed for the first part of an online survey (three waves in total) to a random sample of 8000 inhabitants aged 18 years or older of the Canton of Schaffhausen. The sample was randomly drawn from the registry of residents of the three municipalities Neuhausen am Rheinfall, Stein am Rhein and Thayingen. Thus, our survey population was sampled from the adult population, explicitly including non-Swiss citizens (Wicki & Bernauer, 2018). At the end of the first survey (Wicki & Bernauer, 2018), respondents were asked whether they wanted to participate in a second and third part.

Based on these responses indicating a willingness to partake in the survey, we invited 1080 individuals in November 2018. The participants received either a personal direct link to participate or an invitation letter with a web address and an individual access code for the online survey, which was conducted using a web service hosted by Qualtrics. Invitations to participate in the online survey were sent out via email and/or postal letter. Two and four weeks after the first invitation, reminder letters were sent out to those people who then had not completed the survey. The median response time for the total survey was 12.9 minutes. The final number of respondents in that wave, which is our data source here, was 879 individuals, consisting of completed and partial answers. This equals a response rate of 81.4% (The American Association for Public Opinion Research, 2016). However, as we only asked individuals who were already aware of the test case in Neuhausen am Rheinfall, this number reduces to 761 individuals. For details on survey methods and response behaviour, such as sample representativeness, please consult the respective field report of the second survey (Wicki & Bernauer, 2019).

4.2 Choice Experiment Design

Stated preference (SP) experiments are a way to gain information about hypothetical markets and products (Train, 2003). We conducted an SP experiment to determine the effect of different elements on the choice probability of specific transport modes (self-driving bus, rental bike, by foot). The experiment was combined with a survey to obtain socio-demographic information, information about mobility behavior (e.g. ability to walk and bike), and subjects' technology attitudes.

Figure 1: Example for Situation Description. Note: Everything but the weather and temperature stayed constant for every choice task.

In the choice experiment, respondents were presented with the decision to choose a transport mode for a single trip of 750 m. Respondents were told that the existing route of an autonomous bus within the city of Neuhausen will be extended to also drive between the 'Industrieplatz' to the 'Info Shop Rheinfall'. This route leads along the Rhine, offers a view of the Rhine Falls and is thus rather touristic. To avoid assumptions regarding the conditions, we randomly assigned three different weather situations to each of the choice tasks: rainy with 6°C, cloudy with 17°C and sunny with 28°C. The description was shown for every choice task (see Figure 1 for an example).

Figure 2: Images used to describe situation of bus occupation

As part of the choice experiment, subjects had to choose among three transport modes: the self-driving bus, by foot or by renting a bike. Each mode was described with a travel time (i.e. the time it will take to get from the Industrieplatz to the Info Shop Rheinfall). For the autonomous bus and the rental bike, we additionally varied waiting time (i.e. waiting time at the Industrieplatz for Route 12 or the set-up time you need to get the bike ready). In addition, the costs of the bus ride and the rental bikes varied. For the autonomous bus, the occupancy was displayed graphically. The bus has a capacity of 11 passengers. We attributed three different passenger situations to the choice experiment displayed in Figure 2. Respondents were confronted with an almost empty situation (two passengers), a medium occupancy rate (five passengers) or a nearly fully occupied bus (nine passengers).

The experiment contained 8 choice tasks with three generic alternatives (unlabeled experiment), which were divided into two blocks each containing 4 choice tasks. The attributes and the levels of the choice experiment are shown in Figure 3. The design was constructed as a D-efficient design in NGENE (the corresponding code can be found in Appendix A1, the overview of the 8 choice tasks is provided in Appendix A2).

			
Mode of transport	Autonomous bus	By foot	Rental bike
Travel time	[3 min.; 6 min.; 9 min.]	[12 min.]	[6 min.]
Waiting time	[0 min.; 1 min.; 8 min.; 15 min.]	[0 min.]	[2 min.]
Costs	[CHF 0; CHF 2; CHF 5]	[CHF 0]	[CHF 0; CHF 2; CHF 5]
Number of people on the bus	graphical, see *Figure 2* [empty; medium; full]		
What option do you choose?	☐	☐	☐

Figure 3: Attributes and attribute characteristics of conjoint tasks

4.3 Data

Table 1 provides an overview on the indicators included into the analysis. We measure the attitudinal constructs of technology commitment with the scale of Neyer et al. (2016). By introducing the concept of technology readiness, the primarily attitude-oriented technology acceptance model of Davis (1989) is extended by a broader personality psychological perspective. According to Neyer et al. (2012), the successful handling of technology depends on attitudes as well as on competence and control convictions. Our analysis comprises ‘technophily’ with these three latent constructs. The existent and validated scale that consist of multiple items as indicators of these psychological constructs measures the respective variables. Readiness to use technology is understood as a three-factor construct with the facets of technology acceptance, technology competence and technology control convictions. The measuring instrument contains items for recording three subscales (Neyer et al., 2016).

Table 1: Variables and indicators

Code	Variable	Description	Survey Question
X1	educ	Dummy variable for higher education based on responses for education	What is the highest level of education you have completed?
X2	Age	Age	What is your year of birth?
X3	Sex	Dummy for male	Please indicate your gender
X4	AB_weathCold	6°C and raining	Mode Choice Experiment
X5	AB_weathHot	28°C and sunny	
X6	AB_usedBus	Individual has used an autonomous bus before	
X7	AB_time	Travel time for autonomous bus	
X8	AB_waittime	Waiting time for autonomous bus	
X9	AB_cost	Cost for autonomous bus	
X10	AB_densitybus	People density in bus [low, medium, high]	
X11	B_cost	Cost for shared bicycle	
X12	B_abiBike	Ability to use bicylce	Can you ride a bike?
X13	F_abiWlk	Ability to walk more than more than 200 meters without stopping	Can you walk on your own (i.e. without help) 200 m or more without having to stop and without having severe problems?
X14	ASC_AB_RND	Alternative specific constant autonomous bus	
X15	ASC_F_RND	Alternative specific constant by foot	
I1	TecAcpt_1	Technology acceptance item 1	I am very curious about new technical developments.
I2	TecAcpt_2	Technology acceptance item 2	I rapidly enjoy new technical developments.
I3	TecAcpt_3	Technology acceptance item 3	I am always interested in using the latest technical equipment.
I4	TecAcpt_4	Technology acceptance item 4	If I had the opportunity, I would use technical products much more often than I do at the moment.

I5	TecCmpt_1	Technology competence item 1	When dealing with modern technology, I am often afraid of failing.
I6	TecCmpt_2	Technology competence item 2	For me, the handling of technical innovations is usually overstrained.
I7	TecCmpt_3	Technology competence item 3	I'm afraid of breaking new technical developments rather than using them properly.
I8	TecCmpt_4	Technology competence item 4	I find it difficult to deal with new technology - I just can't do it most of the time.
I9	TecCntr_1	Control over technology item 1	Whether I am successful in using modern technology depends largely on me.
I10	TecCntr_2	Control over technology item 2	It is in my hands whether I succeed in using new technical developments - it has little to do with coincidence or luck.
I11	TecCntr_3	Control over technology item 3	If I have difficulties in dealing with technology, it is ultimately up to me to solve them.
I12	TecCntr_4	Control over technology item 4	What happens when I deal with new technical developments is ultimately within my control.

5. Methods

In this section, we start by briefly describing the ICLV model. We then describe the model specification and discuss the empirical model that will be analysed in the result section.

5.1 The integrated choice and latent variable (ICLV) model

The ICLVM is a method for including latent variables in choice models (Ben-Akiva et al., 2002). Latent variables such as attitudes and perceptions cannot be measured directly; they can only be measured with indicators. These indicators are assumed manifestations of the effect of the latent variables. Similar to the well-known structural equation modelling (SEM) framework, the model's equations are comprised of measurement equations and structural equations that are simultaneously estimated using maximum likelihood techniques. The structural model relates observable casual variables X (and other latent variables) with latent variables (here denoted as γ and β). The structural model denotes as follows:

$$tecAcpt = X_1\gamma_1 + X_2\gamma_2 + X_3\gamma_3 + \eta_{tecAcpt}$$

$$tecCmpt = X_1\gamma_1 + X_2\gamma_2 + X_3\gamma_3 + \eta_{tecCmpt}$$

$$tecCntr = X_1\gamma_1 + X_2\gamma_2 + X_3\gamma_3 + \eta_{tecCntr}$$

$$U_{AB} = ASC_{AB} + tecAcpt\,\beta_{tecAcpt} + tecCmpt\,\beta_{tecCmpt} + tecCntr\,\beta_{tecCntr} + \sum_{i=4}^{10} X_i\,\beta_{X_i} + \varepsilon$$

$$U_B = X_{11}\,\beta_{X_{11}} + X_{12}\,\beta_{X_{12}} + \varepsilon$$

$$U_F = ASC_F + X_{13}\,\beta_{X_{13}} + \varepsilon$$

The measurement model specifies the relationship between latent variables and their indicators I (denoted as α). The choice model (i.e. the relationship between the latent utilities U and the observed choice y) can potentially take a number of forms. In this paper, a logit model is used. The measurement model is specified as follows:

$$I_r = tecAcpt\,\alpha_r + \nu_r, r \in \{1,..,4\}$$

$$I_r = tecCmpt\,\alpha_r + \nu_r, r \in \{5,..,8\}$$

$$I_r = tecCntr\,\alpha_r + \nu_r, r \in \{9,..,12\}$$

$$y_i = \begin{cases} 1, if\ U_i = \max U_j \\ 0, otherwise \end{cases}$$

The maximum likelihood estimation of ICLV models requires solving multidimensional integrals, which is computationally expensive. Thus, estimation of the models usually relies on simulation methods that require a large number of draws for consistent results. The implementation of these methods should thus be computationally efficient. In this paper, a tool developed by Molloy et al. (2019) is used for the estimation.

5.2 Model specification

A graphical representation of the model specification is shown in *Figure 4*. The latent variables technology acceptance (*tecAcpt*), technology competence (*tecCmpt*) and perceived control over technology (*tecCntr*) are measured by four indicators each (I1 to I12). X4 to X10 indicate the choice situation specific variables. X11 is a dummy variable indicating whether the individual has already used a self-driving shuttle. X12 is the ability to use a bicycle, X13 the ability to walk. X14 is the alternative specific constant for the autonomous bus, X15 the alternative specific constant by foot. Age, gender and education (X1 to X3) are assumed to be casually related to the latent variables. The variable codes are also listed in Table 1.

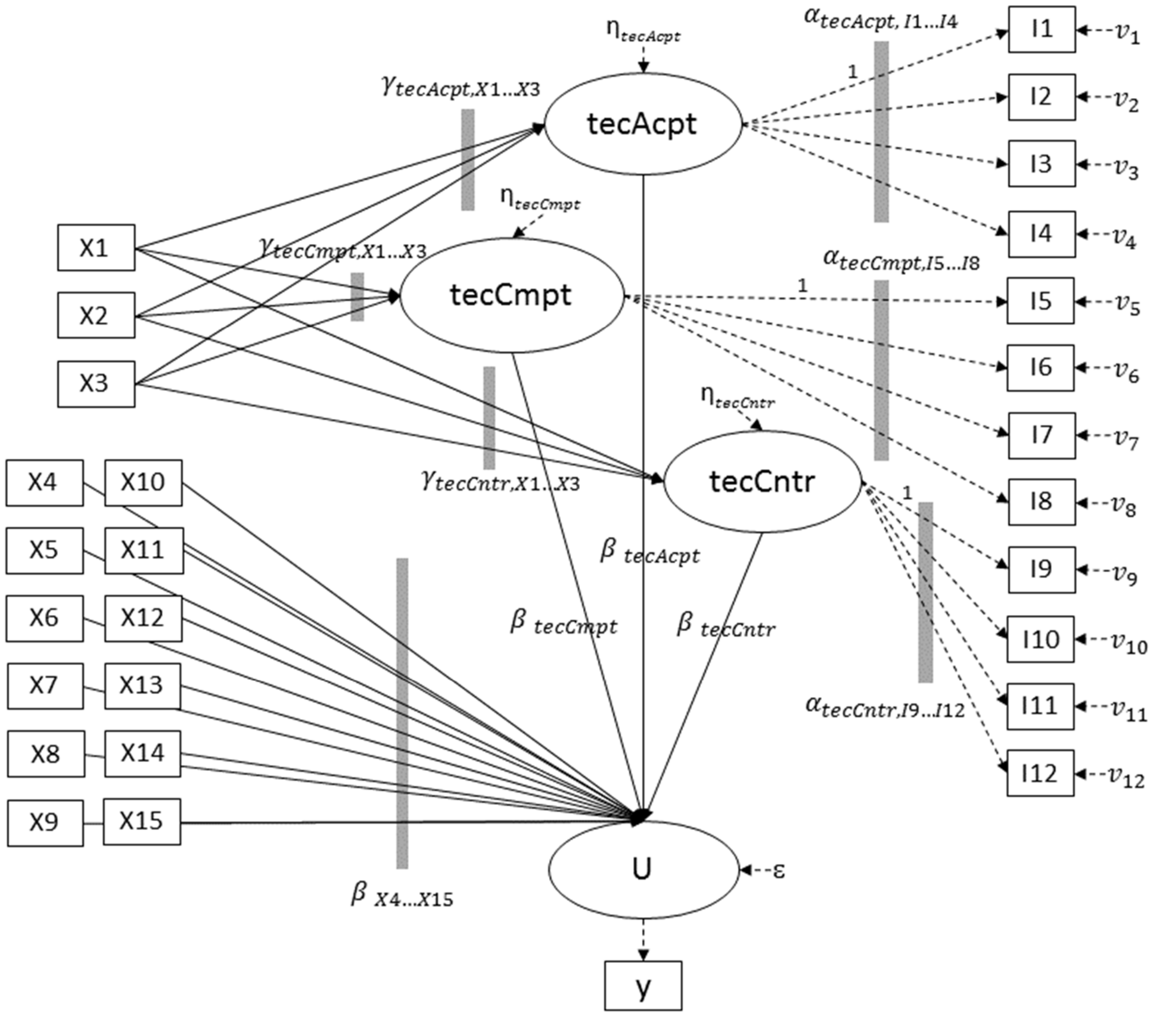

Figure 4: Empirical Model

6. Empirical Results

Table 2 presents the estimation results for the structural part of the latent variable model. In summary, the sociodemographic measures included in the analysis appear to be robust predictors for the mediation of the technology commitment scale on the estimated utility of the different models. However, some findings appear to be of specific interest.

Regarding age, technology acceptance is lower among relatively elderly individuals, whereas the same effect can be observed for the case of technology competence indicating that older individuals may feel less secure when it comes to technology. In addition, older individuals appear to be slightly more self-sceptical when it comes to control over technology, indicating that they allocate failures in handling technology rather to themselves then to the technology.

Furthermore, the models indicate rather robust gender differences. Male participants are somewhat surprisingly less technology accepting than woman. However, men indicated higher technology competence as well as technology control.

Education appears to be the weakest predictor among the three sociodemographic variables. Whereas technology competence is indeed higher among better educated participants, the sign for technology acceptance is not surprisingly positive, but not statistically significant in all three models. In addition, no effect of education on technology control can be observed.

Table 2: Estimation results: latent variable model (structural part)

	ICLVM 1 Coef. (SE)	ICLVM 2 Coef. (SE)	ICLVM 3 Coef. (SE)
LV_tecAcpt_age	-0.01^{***} (0.00)	-0.01^{***} (0.00)	-0.01^{***} (0.00)
LV_tecAcpt_male	0.63^{***} (0.07)	0.63^{***} (0.07)	0.62^{***} (0.07)
LV_tecAcpt_educ	0.15^{+} (0.07)	0.16^{+} (0.07)	0.13^{+} (0.06)
LV_tecCmpt_age	0.01^{***} (0.00)	0.01^{***} (0.00)	0.01^{***} (0.00)
LV_tecCmpt_male	-0.45^{***} (0.07)	-0.45^{***} (0.07)	-0.49^{***}(0.06)
LV_tecCmpt_educ	-0.32^{***} (0.06)	-0.32^{***} (0.06)	-0.32^{***}(0.06)
LV_tecCntr_age	0.00^{*} (0.00)	0.00^{*} (0.00)	0.00^{+} (0.00)
LV_tecCntr_male	0.22^{***} (0.06)	0.22^{***} (0.06)	0.20^{***} (0.06)
LV_tecCntr_educ	-0.02 (0.05)	-0.02 (0.05)	-0.03 (0.05)

***p < 0.001, **p < 0.01, *p < 0.05, +p < 0.1

To analyze the results of the choice experiment, logit models were estimated.[1] The results of the models' estimation are summarized in *Table 3*. It can be seen that the model fit according to McFadden's R-Squared and AIC remain relatively stable among the four models. However, the inclusion of the technology commitment scale improves the model slightly (*MMNL* to *ICLVM 1*). Contrary, interaction effects between technology commitment and costs (*ICLVM 2*) and time *(ICLVM 3*) are neither statistically significant nor improve the model fit. Besides that, all predictors remain stable and significant among all four models, even though the alternative specific constant by foot (*ASC_F*) is not statistically significant on traditional thresholds, but remains within a 10% level. In what follows, results for the four models will be discussed jointly if not drastically different.

Not surprisingly, the estimates for the attributes of the autonomous bus all have negative signs and are highly significant. In other words, individuals were less likely to choose the shuttle bus

[1] The factor loadings for the latent construct of technology commitment are presented separately in Table A1 to A4 for the four respective choice models presented in *Table 3*.

when travel time (*AB_time*) as well as waiting time (*AB_waittime*) were relatively longer. In addition, passenger density has a negative effect on the choice probability for the self-driving shuttle bus. This is also the case for costs of the bus ride (*AB_cost*). The same result can be found for costs of the rental bikes (*B_cost*). Overall, values of travel time savings (*VTTS*) are lower for travel time (between CHF 10.2 and 10.8 per hour[2]) then for waiting time (between CHF 15.6 and 16.8 per hour), which was expected. In general, VTTS are slightly lower but in line with other studies investigating VTTS for Switzerland, even though the route distance is rather short and thus only comparable to a limited extent. More specifically, VTTS for travel time in the case of leisure activities for public transportation is in other cases at around CHF 20 per hour (see, for example, Axhausen et al., 2008).

As expected based on our theoretical arguments, individuals who have already used the self-driving shuttle bus (*AB_usedBus*) were more likely to choose it as a mode in the stated choice experiment. The utility is also statistical significantly higher for individuals who are able to walk (*F_abiWlk*) and bike (*B_abiBike*).

Regarding weather, results are somewhat mixed. With 17°C and cloudy weather as baseline, we find statistically significant different coefficients for rainy weather with 6°C (*AB_weathCold*) but not for sunny weather with 28°C (*AB_weathHot*). This indicates that individuals were more concerned with rain rather than temperature as both the baseline and the sunny weather situation did not indicate any precipitation.

As already mentioned, including measures for individual technology commitment somewhat adds to the understanding of the choice models. Technology acceptance (*AB_LV_tecAcpt*) is highly significant in all three ICLV models. This indicates that individuals with a high technology acceptance are also more likely to use a self-driving shuttle bus. In contrast, technology competence appears to be not statistically significant (*AB_LV_tecCmpt*). This is not surprising as passengers have no need to interact with the shuttle bus and thus their choice is not dependent on their ability to cope with technology. Technology control (*AB_LV_tecCntr*) is negative and significant in the ICLVM 1 model, but is not stable between the other two ICLV models. In summary, readiness to use technology appears to be helpful when explaining mode choice situations including AVs.

[2] At the time of the study, 1 CHF is equivalent to 0.9 Euro or 1 Dollar.

Table 3: Estimation results choice models

	MMNL Coef. (SE)	ICLVM 1 Coef. (SE)	ICLVM 2 Coef. (SE)	ICLVM 3 Coef. (SE)
ASC_AB	4.2*** (0.84)	4.15*** (0.82)	4.16*** (0.82)	4.09*** (0.83)
SIGMA_AB	1.75*** (0.15)	1.52*** (0.14)	1.52*** (0.14)	1.64*** (0.16)
ASC_F	2.08+ (1.19)	1.98+ (1.17)	1.99+ (1.17)	2.17+ (1.16)
SIGMA_F	2.25*** (0.15)	2.09*** (0.14)	2.10*** (0.14)	2.08*** (0.14)
AB_time	-0.05* (0.02)	-0.05* (0.02)	-0.05* (0.02)	-0.05* (0.02)
AB_waittime	-0.08*** (0.01)	-0.08*** (0.01)	-0.08*** (0.01)	-0.08*** (0.01)
AB_cost	-0.29*** (0.03)	-0.29*** (0.03)	-0.29*** (0.03)	-0.29*** (0.03)
AB_densitybus	-0.49*** (0.07)	-0.48*** (0.07)	-0.48*** (0.07)	-0.49*** (0.07)
B_cost	-0.32*** (0.06)	-0.32*** (0.06)	-0.31*** (0.06)	-0.30*** (0.06)
AB_usedBus	0.98*** (0.26)	0.92*** (0.25)	0.91*** (0.25)	0.98*** (0.25)
F_abiWlk	2.48* (0.92)	2.42* (0.92)	2.41* (0.92)	2.33* (0.90)
B_abiBike	1.78* (0.82)	1.76* (0.8)	1.76* (0.80)	1.79* (0.81)
AB_weathCold	1.85*** (0.16)	1.79*** (0.16)	1.80*** (0.16)	1.80*** (0.16)
AB_weathHot	-0.01 (0.15)	-0.02 (0.15)	-0.02 (0.15)	-0.01 (0.15)
AB_LV_tecAcpt	-	0.83*** (0.14)	0.77*** (0.16)	0.82***
AB_LV_tecCmpt	-	0.05 (0.14)	-0.02 (0.16)	-0.12
AB_LV_tecCntr	-	-0.57* (0.21)	-0.47 (0.24)	-0.07
AB_LV_tecAcpt* AB_cost	-	-	0.03 (0.04)	-
AB_LV_tecCmpt* AB_cost	-	-	0.04 (0.05)	-
AB_LV_tecCntr* AB_cost	-	-	-0.06 (0.06)	-
AB_LV_tecAcpt* AB_time	-	-	-	-0.02
AB_LV_tecCmpt* AB_time	-	-	-	0.01
AB_LV_tecCntr* AB_time	-	-	-	-0.02
VTTS (travel time) [CHF/h]	10.2	10.2	10.8	10.8
VTTS (waiting time) [CHF/h]	16.8	16.2	15.6	15.6
McFadden R2	0.39	0.39	0.39	0.39
Individuals	761	761	761	761
Choice Observations	3044	3044	3044	3044
Log Likelihood (null)	-3344	-3344	-3344	-3344
Log Likelihood (final)	-2026	-2027	-2026	-2026
Akaike Inf. Crit.	4080	4154	4154	4154

***p < 0.001, **p < 0.01, *p < 0.05, +p < 0.1

7. Discussion

In this paper, we examine the intention to use a self-driving shuttle bus in a realistic and close to reality setting providing high external validity. We conducted a stated mode choice experiment with 761 participants drawn from a random sample among three municipalities in the Canton of Schaffhausen, Switzerland, in late 2018. Respondents had to perform three choice task deciding between the modes of walking, biking and the use of a self-driving bus. Weather conditions and mode specific attributes such as costs, occupation, travel and wait time varied. By using additional questions for technology commitment, integrated latent variable and choice models are used to test how the technology related attitudes of respondents explain their anticipated behaviour. This approach also allowed us to test whether and how individuals trade off technological scepticism with potential benefits.

Overall, the results were in line with the expectations derived from the literature. Longer travel time as well as wait time, higher costs and a denser occupancy of the bus all lower individuals' latent utility and thus the choice probability for the self-driving shuttle. A similar result can be observed for the costs of the rental bike. In addition, individuals who are able to walk and bike end up with a higher utility compared to individuals without one of these abilities. In addition, in the case of cold and rainy weather, individuals rather choose the bus compared to situations without any precipitation. These results are all robust among the different estimated models.

Our results provide some of the first data on how people would be willing to use an automated vehicle in a realistic choice situation. By including the technology commitment scale, we add an important personality psychological perspective to research about intent to use AVs. Indeed, the results presented in this paper indicate that technology acceptance is a robust indicator for predicting self-driving bus usage, but that there is no interaction between technology commitment and time nor price. Thus, individuals appear to not trade-off their attitudes with potential benefits regarding timesavings. However, technology acceptance appears to be indeed an important predictor with regard to intention to use as well as actual use behaviour.

These results bear some interesting business and policy implications. First, general technology acceptance is not only a predominant determinant for AV acceptance, but also for the intent to use AVs. Therefore, to motivate individuals to adopt AV technology and thus foster a transition to automated road traffic, it is important for both policy-makers and businesses to increase individual technology acceptance. More specifically, it is of high importance to educate comparably technophobe individuals in questions regarding technology to increase technology acceptance and thus perception of AVs. Second, our study shows that individuals are indeed willing to pay for AV technology and usage. Even though comparably lower than in other studies, VTTS for travel time at around CHF 11 and for waiting time at around CHF 16 indeed offer potential business opportunities for transport agencies but also others that go beyond the current test runs, which are predominantly for free.

There are many opportunities for further research. As our study is limited to a specific test case within a rather narrow setting, the generalizability of our results is rather limited. Thus, to begin with, a replication of our survey experiment within a larger population would be very valuable to determine whether the findings remain consistent with a more diverse population. However, this is conditional on the awareness of individuals on such test runs. Therefore, the replication of our study in the context of other test operations could be a second possibility to increase the generalizability of the results. In addition, follow-up surveys specifically among individuals who did not yet ride on such a bus but will do so in the near future could potentially allow to study how a change in experience might affect individual willingness to use an AV. This would also allow to assess how determinants perform over time as adoption is potentially conceived as an experience factor and thus determinants eventually change when AVs become available to the larger public.

8. References

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9. Appendix

A1 NGENE Experiment Design

;alts = alt1, alt2, alt3

;rows = 8

;block = 2

;eff = (mnl, d)

;model:

*U(alt1) = b0 + b1*time[3,6,9] + b2*waitTime[0,1,8,15] + b3*cost[0,2,5] + b4*densSitBus[1,2,3] + b5*time*waitTime + b6*time*densSitBus /*

*U(alt2) = b7*cost[0,2,5] /*

U(alt3) = b8 $

A2 Experimental Design Overview

Choice situation	alt1.time	alt1.waittime	alt1.cost	alt1.denssitbus	alt2.cost	Block	alt1.time*alt1.waittime	alt1.time*alt1.denssitbus
1	3	1	2	3	0	2	3	9
2	9	15	0	2	2	2	135	18
3	3	1	2	1	2	1	3	3
4	6	8	5	2	5	1	48	12
5	6	8	5	1	0	2	48	6
6	3	15	0	2	2	1	45	6
7	6	0	0	1	5	2	0	6
8	9	0	2	3	0	1	0	27

Note: D error: 0.080496; A error: 1.554539; B estimate: 100

A3 Additional Tables

Table A1: Factor loadings (unstandardized)

	tecAcpt	tecCmpt	tecCntr
I1	1.00		
I2	0.99 (0.04)		
I3	0.92 (0.04)		
I4	0.82 (0.04)		
I5		1.00	
I6		0.95 (0.05)	
I7		0.92 (0.05)	
I8		0.97 (0.05)	
I9			1.00
I10			1.03 (0.08)
I11			1.07 (0.09)
I12			1.05 (0.08)

Table A2: Factor loadings of ICLVM 1 (unstandardized)

	tecAcpt	tecCmpt	tecCntr
I1	1.00	-	-
I2	0.99^{***} (0.04)	-	-
I3	0.92^{***} (0.04)	-	-
I4	0.82^{***} (0.04)	-	-
I5	-	1.00	-
I6	-	0.95^{***} (0.05)	-
I7	-	0.92^{***} (0.05)	-
I8	-	0.97^{***} (0.05)	-
I9	-	-	1.00
I10	-	-	1.03^{***} (0.08)
I11	-	-	1.07^{***} (0.09)
I12	-	-	1.05^{***} (0.08)

Table A3: Factor loadings of ICLVM 2 (unstandardized)

	tecAcpt	tecCmpt	tecCntr
I1	1.00	-	-
I2	0.99^{***} (0.04)	-	-
I3	0.92^{***} (0.04)	-	-
I4	0.82^{***} (0.04)	-	-
I5	-	1.00	-
I6	-	0.95^{***} (0.05)	-
I7	-	0.92^{***} (0.05)	-
I8	-	097^{***} (0.05)	-
I9	-	-	1.00
I10	-	-	1.03^{***} (0.08)
I11	-	-	1.07^{***} (0.09)
I12	-	-	1.05^{***} (0.08)

Table A4: Factor loadings of ICLVM 3 (unstandardized)

	tecAcpt	tecCmpt	tecCntr
I1	1.00	-	-
I2	0.99^{***} (0.04)	-	-
I3	0.92^{***} (0.04)	-	-
I4	0.82^{***} (0.04)	-	-
I5	-	1.00	-
I6	-	0.95^{***} (0.05)	-
I7	-	0.92^{***} (0.05)	-
I8	-	0.98^{***} (0.05)	-
I9	-	-	1.00
I10	-	-	1.01^{***} (0.08)
I11	-	-	1.02^{***} (0.08)
I12	-	-	1.04^{***} (0.08)