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Consumers' expectations and attitudes towards owning, sharing, and riding autonomous vehicles

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ABSTRACT

It is still unclear whether autonomous vehicles will mainly bring benefits or not to the sustainable development of people's mobility. Opinion among various stakeholders diverge since autonomous driving may have different use cases, and potential impacts will depend on how consumers will deal with it: following an ownership-based or a consumption-based approach, using autonomous vehicles as individual (as a private car), shared (as a taxi service), or collective (as a public transport service) means of transport. This paper aims at shedding light on future mobility scenarios by investigating travelers' expectations, attitudes, and intentions towards adopting autonomous vehicles. The research method involves the estimation of hybrid choice models based on data collected through a Stated Intention survey. Results of an exploratory study conducted in Italy show that the willingness-to-adopt autonomous vehicles can be explained by both observable and latent traits of individuals, giving evidence of different policy implications. Moreover, the desire to experiment autonomous driving is on average very high, but consumers are more willing to share or ride autonomous vehicles, rather than purchasing them for personal use.

1. Introduction

In recent years, the mobility of people, especially in urban areas, has been characterized by a growing emergence of vehicle-sharing, ride-sharing and on-demand services. In the coming years, it is expected that disruptive technological innovations, enabled by connected and automated driving, could act as catalysts, facilitating the shift towards a green, smart, and fair mobility solutions. Automation could be the driving force for the widespread of the shared mobility, and for a more integrated and efficient Public Transport supply.

Despite car manufacturers' optimism, opinions in the scientific community are conflicting. Many authors warn that Autonomous Vehicles (AVs) will also generate negative externalities in terms of environmental, economic, and social sustainability. It is widely discussed in the literature whether the widespread diffusion of AVs could modify short-term travel behaviors (Levin and Boyles, 2015; Steck et al., 2018; Coppola and Silvestri, 2019) and long-term mobility choices (Gruel and Stanford, 2016; Wang et al., 2020), affect road safety (Chen et al., 2016; Diakaki et al., 2015), vehicle performance and traffic congestion (Talebpour and Mahmassani, 2016; Friedrich, 2016; Garg et al., 2021), transform land use and urban form (Carrese et al., 2019; Coppola and Silvestri, 2020; Kim et al., 2020; Duarte and Ratti, 2018), and have repercussions on the economy and environment (Fagnant and Kockelman, 2014; Milakis et al., 2017).

Opinion among various stakeholders diverge since autonomous driving may have different application and consumers could benefit from those in different ways. Studies in the literature return very different results depending on the focus of their analysis and the level of automation of vehicles being examined. In fact, the potential impacts of autonomous driving will depend on how people will adopt AVs: whether they will buy or not a vehicle, and whether they will make an individual, shared, or collective use. Moreover, vehicles can be equipped with diverse functionalities that offer different degrees of automation (SAE, 2021). In the present study we will refer to SAE Level 5 vehicles with Full Driving Automation.

The aim of this paper is to shed light on potential scenarios of autonomous driving by investigating potential users' attitudes and willingness-to-adopt AVs as:

- private cars (i.e. "willingness-to-own"),
- taxi services (i.e. "willingness-to-share"),

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- on-demand collective transport services with flexible routes (i.e. "willingness-to-ride").

Specifically, this paper describes an exploratory study conducted in Italy that aimed at answering the following research questions: i) what are individuals' perceptions, expectations, and concerns about autonomous driving? ii) what factors (observable and latent) most affect consumers' intentions to own, share, and ride autonomous vehicles?

The paper consists of 6 sections. After the introduction (Section 1), Section 2 provides an overview of the existing studies aimed at investigating the demand factors related to users' acceptance and intention to use of AVs. In particular, the section describes the different survey methodologies adopted by the previous authors, highlighting strengths, drawbacks, and the research gaps that this paper aims to fill in. Section 3 presents the method of analysis, including the survey carried out and the statistical metrics adopted. Section 4 includes a description of the sample and shows the results of the study, focusing on correlation analyses. These are discussed is Section 5, whereas conclusions are drawn in Section 6.

2. Literature review

Autonomous driving could cause significant changes in the transport sector in several respects. This paper focuses on investigating the potential impacts on mobility demand, highlighting how individuals' travel choices and behaviors have wider impacts on society and on the sustainable development of mobility in general. However, the impacts of autonomous driving have been also researched from different perspectives. Three main research streams can be identified in the literature:

1. studies focusing on governance, ethic, and liability issues
2. studies simulating effects on transport infrastructure
3. studies assessing potential impacts on the demand

The first stream includes research by (Taeihagh and Lim, 2019), (Soh and Martens, 2022) and (Papadimitriou et al., 2022) whose main contribution is related to the discussion of policy measures to address privacy, cybersecurity, liability, and ethical implications of the widespread of AVs in cities and more in general in the Society. The second stream of research papers includes studies assessing the changes that the advent of autonomous driving will bring to infrastructure capacity (mainly roads) and road intersections management and safety, such as in (Lu et al., 2020), (Neufville et al., 2022), (Zhao et al., 2021), and (Jiang et al., 2022). Finally, the third group of papers has focused on investigating the acceptance, preferences, and personal attitudes of potential users towards AVs, as, for example, by (Nordhoff et al., 2018), (Haboucha et al., 2017), and (Hudson et al., 2019).

In general, all these studies are often interdisciplinary and encompass different sectors that are recently becoming highly interconnected (e.g. ICT, transport policy, urban planning, psychology and sociology). What has emerged is that assumptions about future mobility scenarios cannot be conclusive because AVs are still in an early stage of implementation and deployment on the roads. The extent of their impacts will depend on numerous factors, such as predominant technologies, regulation, business and people's reactions. For example, the impacts on demand will inevitably depend on the affordability of new mobility services based on AVs; whether any incentives will be offered to individuals or public transit companies; what kind of regulations will be adopted by governments to manage the diffusion of autonomous driving and associated mobility services; furthermore, the capacity and level of service of infrastructure will depend on the level of driving caution that the artificial intelligences that control the AVs will be required to adopt, which in turn will depend on what levels of risk will be deemed acceptable; finally, there are still a number of ethical and liability issues that need to be addressed by the experts and policy makers.

Given the content of this paper, the rest of this section is focused on the third research stream, i.e. demand studies. Based on comprehensive literature reviews (Becker and Axhausen, 2017), (Gkartzonikas and Gkritza, 2019), and (Pigeon et al., 2021), a first element of classification relates to the objective of the analysis (see Table 1):

- investigating the level of acceptance and perception of AVs
- identifying individual attitudes towards autonomous driving
- estimating the likelihood of adoption of the AVs (i.e. the intention to use AVs)

A second element of classification relates to the methods of investigation (see Table 1):

- **Stated Intention (SI)**, i.e. survey designed according to the Likert's psychometric technique for measuring the attitude of individuals (Likert, 1932). With this methodology the respondents are asked to provide a score, based on how much they agree or disagree with some statements. In practice, an interviewee might be asked to provide a score from 1 to 5 (where 1 means totally disagree, and 5 means totally agree) with respect to the following example statement: "AVs will reduce the risk of road accidents".
- **Stated Preference (SP)**, i.e. survey constructed according to the experimental design approach (Kroes and Sheldon, 1988; Hensher et al., 1988). With this methodology the interviewees are presented with different choice alternatives, which differ in quantitative and qualitative attributes, and are asked to choose the one they prefer. For example, an experiment could consist of several choice situations to examine the modal choice between using a conventional vehicle or an autonomous vehicle to travel from home to the workplace, depending on the variation of some level of service attributes.

Using SP surveys, some authors (Krueger et al., 2016; Asgari et al., 2018; Pakusch et al., 2018; Stoiber et al., 2019; Webb et al., 2019) focused their research only on observable factors to estimate the likelihood of adoption of the AVs, such as level-of-service attributes, socioeconomic characteristics and travel habits. These factors are so-called observable since they are directly measurable. On the other hand, a large number of authors used a SI survey or a mixed SI/SP survey method to introduce latent factors into the analysis, such as personal attitudes of the respondents (Haboucha et al., 2017; Hudson et al., 2019; Lavieri and Bhat, 2019; Wang et al., 2020; Song et al., 2021) or their perceptions about autonomous driving (Hohenberger et al., 2016; Panagiotopoulos and Dimitrakopoulos, 2018; Montoro et al., 2019; Faber and van Lierop, 2020). These factors are so-called latent since they are not directly measurable but are rather inferred from other observable variables. Finally, a small number of researchers have explored all the factors related both to the acceptance of AVs, such as perceived usefulness, perceived ease-of-use, perceived safety, etc., and to the latent traits of individuals, such as aptitude for technology, propensity to share, risk aversion, etc., however focusing only on specific and not all AVs use cases, for example: (Becker et al., 2016; Cunningham et al., 2019a; Yuen et al., 2020) examined the users' approach towards individual and/or shared use of fully-automated vehicles; while (Zoellick et al., 2019; Chee et al., 2020) explored the collective use of AVs.

Some repeating patterns emerge from the review of the papers. On the one hand, many authors such as (Hohenberger et al., 2016; Liljamo et al., 2018; Cunningham et al., 2019a) have found that men are more enthusiastic about autonomous driving than women, just as (Haboucha et al., 2017; Hudson et al., 2019; Wang and Zhao, 2019) have pointed out a more positive attitude towards AVs in young people and in individuals with higher levels of education. On the other hand, some researchers have highlighted that the acceptance and intention to use AVs are more strongly influenced by latent factors, such as personal perceptions and attitudes, rather than by socioeconomic characteristics (Nordhoff et al., 2018; Cunningham et al., 2019b; Zoellick et al., 2019). With reference to perceptions, the latent constructs most often

Table 1
Summary of relevant studies on the analysis of mobility demand for AVs.

Author(s)	Method of investigation	Research objectives investigated			Users' approach investigated			Key finding(s)
		Acceptance & Perceptions	Personal Attitudes	Adoption	Individual use	Shared use	Collective use	
(Bansal et al., 2016)	SI survey	X	X	X	X	X		Higher-income, technology-savvy males, who live in urban areas, and those who have experienced more crashes have a greater interest in and higher willingness-to-pay for the new technologies, with less dependence on others' adoption rates.
(Hohenberger et al., 2016)	SI survey	X		X	X			Men in comparison to women will show a higher level of willingness to use automated cars. With increasing age, men compared to women, exhibit lower levels of emotional intensity towards automated cars.
(Krueger et al., 2016)	SP survey			X		X	X	Service attributes including travel cost, travel time and waiting time may be critical determinants of the use of shared AVs and the acceptance of dynamic ridesharing.
(Haboucha et al., 2017)	SI/SP survey		X	X	X	X		Currently, large overall hesitations towards autonomous vehicle adoption exist. Early AV adopters will likely be young, students, more educated, and individuals with longer commutes.
(Asgari et al., 2018)	SP survey			X	X	X		Most car users prefer single ride than shared ride with AVs regardless of whether it is on a daily or occasional basis. However, for transit users, shared rides showed higher potential than exclusive services.
(Liljamo et al., 2018)	SI survey	X	X		X			Men, highly educated individuals, people living in densely populated area and those living in households without a car had a more positive attitude to automated vehicles than the other respondents. traffic safety and ethical perspectives have a key role in the acceptance of automated vehicles.
(Nordhoff et al., 2018)	SI survey	X	X		X			Acceptance of driverless vehicles is more strongly determined by domain-specific attitudes than by sociodemographic characteristics.
(Pakusch et al., 2018)	SP survey			X	X	X	X	Private cars, whether conventional or fully automated, will remain the preferred travel mode. At the same time, carsharing will benefit from full automation more than private cars. However, the growth of carsharing will mainly be at the expense of public transport.
(Panagiotopoulos and Dimitrakopoulos, 2018)	SI survey	X		X	X	X		The constructs of perceived usefulness, perceived ease to use, perceived trust and social influence, are all useful predictors of behavioral intentions to have or use AVs, with perceived usefulness having the strongest impact.
(Brell et al., 2019)	SI survey	X	X		X			Autonomous driving is perceived as being beneficial in terms of efficiency and road and driver safety, as well as individual comfort. On the other hand, there are severe concerns, which especially regard the uncontrollable collecting of data, the fear of losing control, and the uncomfortable feeling of continuously being monitored.
(Cunningham et al., 2019a)	SI survey	X	X	X	X			Men tend to be more amenable to AV technology then women. Men tended to express lower levels of concern with AV-related issues, report a greater desire to use AVs in most conditions, and be more comfortable in allowing an AV to undertake all driving functions.
(Cunningham et al., 2019b)	SI survey	X	X		X	X		Attitudes and opinions relating to perceived benefits, level of comfort with an AV undertaking certain driving functions, and engagement in secondary activities were among the strongest predictors of willingness-to-pay, over and above key sociodemographic variables (e.g., age, salary), while the weakest were associated

(*continued on next page*)

Table 1 (*continued*)

Author(s)	Method of investigation	Research objectives investigated			Users' approach investigated			Key finding(s)
		Acceptance & Perceptions	Personal Attitudes	Adoption	Individual use	Shared use	Collective use	
								with awareness of AV technologies and perceived concerns.
(Hudson et al., 2019)	SI survey		X		X			Old, retired, unemployed, less well-educated people and women tend to be more hostile to AVs. There are also differences based on localities, with those in large towns and cities most in favor.
(Lavieri and Bhat, 2019)	SI survey		X	X	X		X	Users are less sensitive to the presence of strangers when in a commute trip compared to a leisure-activity trip. The travel time added to the trip to serve other passengers may be a greater barrier to the use of shared services compared to the presence of a stranger. The potential to use travel time productively may help overcome this barrier especially for high-income individuals.
(Montoro et al., 2019)	SI survey	X		X	X			Individuals with a higher educational level tend to appraise AVs more positively, not only perceiving them as safer transportation means when compared to conventional vehicles, but also because they are thought to improve the transport dynamics and the overall road safety.
(Jiang et al., 2019)	SI/SP survey	X		X	X			Young people tend to avoid owning AVs, which contrasts with the elderly group. Effects of the number of different household members and driving purposes on the ownership of AVs are mixed. Intention to improve driving safety seems irrelevant to the ownership of AVs. People who have experienced risks in long-distance driving and who drive frequently prefer owning AVs.
(Stoiber et al., 2019)	SP survey			X	X	X	X	Respondents preferred the pooled-use autonomous taxis (auto-taxis) and autonomous public transport shuttles (auto-shuttles), over privately owned autonomous cars (auto-cars).
(Wang and Zhao, 2019)	SI/SP survey	X		X	X			Young, high-income, fully employed individuals with higher education are the most risk-seeking social group, while older and lower income individuals are more risk-averse in the adoption of new technology.
(Webb et al., 2019)	SP survey			X	X	X		Wealthier participants, commuters and married couples were now more likely to adopt autonomous self-driving vehicles. But those with children and those who loved driving became less likely to do so. Younger people and those who lived closer to the CBD were shown to be less likely to reject autonomous vehicles.
(Zoellick et al., 2019)	SI survey	X	X	X			X	Close relationships exist between the following constructs: acceptance, perceived safety, trust, and intention to use AVs. Age significantly predicts intention to use AVs. There is a tendency for gender differences in many constructs. Acceptance is the strongest predictor for intention to use AVs followed by perceived safety and age.
(Chee et al., 2020)	SI survey	X	X	X			X	Passengers' intentions to use an automated bus service is greatly influenced by the frequency of the service and ride comfort. Perceptions of service quality vary according to age, income, existing travel modes, tech-savviness, and familiarity with automated driving technology.
(Faber and van Lierop, 2020)	SI survey	X		X	X	X	X	Older adults have a strong interest in using AVs in their daily life to overcome current accessibility and mobility barriers. Costs and payment are a strong determinant among participants in their preference for existing transport modes and different AV service models to meet their daily mobility demand.
(Tan et al., 2020)	SI/SP survey	X		X	X	X		Personal monthly income, driver's license, driving confidence, preference for AVs and

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Table 1 (*continued*)

Author(s)	Method of investigation	Research objectives investigated			Users' approach investigated			Key finding(s)
		Acceptance & Perceptions	Personal Attitudes	Adoption	Individual use	Shared use	Collective use	
								convenience of arriving at public transport stations will affect the purchase decision of autonomous vehicles; teenagers, long-distance travelers, students and employees of enterprises and institutions, those who believe that traditional taxis/taxi-hailing are unsafe, and those who lack confidence in driving have a higher probability of choosing AVs.
(Topolšek et al., 2020)	SI survey	X			X			Car safety, buyer age and level of education, perceived social influence, anxiety and performance expectancy are significantly correlated to purchasing intention of Autonomous cars.
(Wang et al., 2020)	SI survey		X		X	X	X	Early adopters of technology and those who support stricter traffic regulations are more likely to have a positive attitude about AVs, whereas those who avoid risky behavior were more likely to have a negative attitude.
(Wu et al., 2020)	SI survey	X		X	X			Respondents found the potential for environmental-friendly transport, increased accessibility of travel for non-drivers, and reduced driving fatigue as the most attractive aspects of electric AVs. Conversely, respondents were most concerned about vehicle safety, legal liability, and charging issues.
(Yuen et al., 2020)	SI survey	X	X	X		X		Perceived behavioral control has the largest direct effect on user adoption of shared autonomous vehicles. This is followed by attitude and perceived norm. As for the determinants of attitude, hedonic motivation has the largest effect, followed by performance expectation, effort expectation, price value and habit.
(Song et al., 2021)	SI survey		X				X	Technology-savvy people have higher willingness to try AV technologies, but they also tend to have more concerns about potential problems brought by AVs and their disruption to transit.
This paper	**SI survey**	**X**	**X**	**X**	**X**	**X**	**X**	**See Section 5**

investigated and generally resulting significant predictors of the behavioral intention to use AVs are related to perceived usefulness, perceived ease-of-use, perceived safety and security, perceived norm and perceived behavioral control (Panagiotopoulos and Dimitrakopoulos, 2018; Yuen et al., 2020). While with regard to personal attitudes the most affecting latent traits are related to technology-savviness (Bansal et al., 2016; Song et al., 2021) and risk aversion (Wang and Zhao, 2019; Wang et al., 2020). Finally, two further evidences are confirmed by several authors: (Bansal et al., 2016; Liljamo et al., 2018; Hudson et al., 2019) found that people living in densely populated urban areas are more likely to own or share AVs than people living in small towns or rural areas; (Jiang et al., 2019; Stoiber et al., 2019) found that individuals (especially young ones) prefer the pooled-use of robo-taxis and self-driving public transport minibuses over privately owned autonomous cars, but other researchers warn that this may be true for current transit users, since private cars will remain the preferred travel mode for today's car users (Asgari et al., 2018; Pakusch et al., 2018).

A third element of classification concerns users' approach to autonomous driving and the type of service provided (see Table 1). Many authors have studied AVs as personal cars for individual transport (in literature this type of studies of AVs are commonly referred to as: private autonomous vehicles, driverless car, self-driving car, etc.). Others, albeit to a lesser extent, have carried out studies focusing on vehicles for shared mobility services (commonly referred to as: shared autonomous vehicles, self-driving taxi, robo-taxi, etc.). Very few have explored the dynamics of demand in relation to the use of AVs for public and collective transport (commonly referred to as: automated public transport, driverless shuttle, self-driving minibus, etc.).

It should also be noted that many, but not all, of those studies model respondents' stated preferences on the basis of psychological theories. For example, some authors refer to the Theory of Planned Behavior (TPB) in order to link personal attitudes, subjective norms, and perceived behavioral control, to individual's behavioral intentions. Other authors instead make use of the Technology Acceptance Model (TAM) to model how users come to accept and use a new technology. These theories, although widely and frequently used in scientific research, are not yet well established and are subject to criticism of various kinds. In particular, these theories ignore individuals' needs and current habits and do not properly consider some individuals' expectations and concerns, such as the perceived safety and the perceived monetary cost of adopting a certain behavior. In this study, instead of relying on a single theory, we conducted a comprehensive literature to identify the factors that have been found relevant in previous research. This approach allowed us to design and administer a survey capable of capturing all the latent traits that significantly affect individuals' behavioral intentions regarding the adoption of AVs.

This paper aims at bridging up these research gaps, proposing a cross-sectional study that explores the preferences and perceptions of consumers with respect to the different approaches towards autonomous driving (i.e. ownership-based or consumption-based) according to which users could adopt AVs (i.e. in individual, shared, or collective

use), and estimate the likelihood of adoption of autonomous driving, considering both individuals' expectations, concerns, and attitudes towards AVs. In addition, the proposed methodology is applied to a case study of a geographical area poorly investigated in the literature, providing evidence resulting from an exploratory survey on a sample of over 400 potential Italian users.

3. Data and methods

The methodological approach proposed in this research has been applied to the Italian case study and consists of the following two main phases:

1. **Stated Intention (SI) survey design and data collection.** Considering that AVs with full driving automation features have not yet been introduced on the roads, a SI survey was designed to probe future behavioral intentions of respondents in hypothetical AVs mobility scenarios.
2. **Data analysis and Hybrid Choice Models (HCMs) estimation.** The collected data were analyzed with descriptive statistics and respondents' stated intentions were further investigated through HCMs, which combine a discrete choice model with latent construct measurement models.

These two phases are described in detail in the next sub-sections.

3.1. Stated intention (SI) survey design and data collection

The SI survey was implemented on "Limesurvey" (Limesurvey GmbH, 2021) and was randomly distributed on-line to individuals belonging to the Italian population. The respondents voluntarily participated in the survey, without receiving any monetary or other compensation in return.

All the answers and information gathered were anonymous. The survey instruction informed the respondents about the scientific research aim of the questionnaire and about the approximate time to complete it (i.e. 12 min). Moreover, an introductory video about autonomous driving was provided: this showed AVs (both private car/taxi and minibus/shuttle type) driving in urban context, allowing the participants to see the interior of the vehicle, passenger's location and how these can be used in everyday actions (for instance, to accompany children to school or to go to the airport with suitcases).

The survey probed the following macro-areas: socioeconomic and personal information about the respondent, expectations about AVs, personal attitudes, and intentions about adopting AVs in future scenarios characterized by the presence of innovative mobility solutions.

With reference to socioeconomic and personal information, the following data were collected: gender, age group, household type (i.e. living with parents, with partner and/or children, with other housemates, or alone), educational level, income level, size of the city (i.e. number of inhabitants) where the respondent lives.

With reference to the expectations regarding AVs, interviewees were asked how much they agreed with some statements (see Table 2, statements from S1 to S9). For each of the statements, answers on a Likert scale from 1 ("Strongly disagree") to 5 ("Strongly agree") have been collected.

Statements about personal attitudes were then proposed (see Table 2, statements from S10 to S19): interviewees were asked to rate on a Likert scale from 1 ("Very untrue") to 5 ("Very true") how accurately certain statements described themselves.

Note from Table 2 that some of the statements derive from existing studies in the literature and were therefore already used and tested for the identification of some latent traits. Other statements were created specifically for the present study, to verify the existence of additional potential latent traits of individuals able to improve the modeling of their decision-making processes. A preliminary pilot survey was conducted on a small sample to validate the consistency of the respondents' answers and to understand if such statements could have been functional to the research to be conducted.

Finally, in order to understand how much respondents were willing to experiment, own, share or ride AVs, interviewees were asked how much they agreed with the following statements: "I will get into an autonomous vehicle to test its features" was proposed to measure their willingness-to-experiment AVs (S20), "I will buy an autonomous car" for their willingness-to-own AVs (S21), "I will use autonomous taxi services" for their willingness-to-share AVs (S22) and "I will use public transportation services with autonomous buses" for their willingness-to-ride (S23). For each of the statements, answers on a Likert scale from 1 ("Strongly disagree") to 5 ("Strongly agree") have been collected.

Table 2
Summary of the proposed statements in the SI survey.

	Statements	Source
Expectations about AVs	S1 - You can engage in other activities (working, reading a book, sleeping, etc.)	Adapted from (Acheampong and Cugurullo, 2019)
	S2 - You will not spend time looking for a parking space	Adapted from (Cunningham et al., 2019a)
	S3 - Places that are currently hard to be accessed by public transport will be easier to be reached	Created for the present study
	S4 - Vehicles will be more subject to cyber-attacks	Created for the present study
	S5 - There will less travel data privacy (e.g. departure and arrival times, geolocation, routes, etc.)	Adapted from (Cunningham et al., 2019a)
	S6 - There will not be fewer road accidents	Adapted from (Acheampong and Cugurullo, 2019)
	S7 - Taxi services will be more expensive than now	Adapted from (Yuen et al., 2020)
	S8 - Vehicles will be too expensive to be purchased	Created for the present study
	S9 - Vehicle repair/maintenance costs will be higher than now	Created for the present study
Personal attitudes	S10 - I do not prefer to pay in cash, but rather with electronic payment tools (for example: credit card, app, etc.)	Created for the present study
	S11 - My family and friends often ask for my advice when they have a technical/IT issue	Adapted from (Haboucha et al., 2017)
	S12 - I like living in an apartment with other roommates (people who do not belong to the household)	Created for the present study
	S13 - I frequently use shared mobility services (car-sharing, bike-sharing, car-pooling, etc.)	Created for the present study
	S14 - I prefer to drive a car with a manual transmission rather than a car with an automatic one	Created for the present study
	S15 - Whenever I can, I prefer to drive the car myself instead of having someone else drive it	Adapted from (Haboucha et al., 2017)
	S16 - I do not feel comfortable traveling with collective means of transport	Adapted from (Haboucha et al., 2017)
	S17 - I find public transport not convenient for traveling	Adapted from (Song et al., 2021)
	S18 - When I install a new mobile app, I check all the permissions (e.g. access to contacts, access to location, etc.)	Created for the present study
	S19 - I never publish posts and personal photos (with friends or family) on social networks	Created for the present study

3.2. Data analysis and hybrid choice models (HCMs) estimation

In the second step of the proposed methodology, the collected data were preliminary analyzed with descriptive statistics to evaluate the sociodemographic characteristics of the sample and respondents' expectations, attitudes and intentions towards AVs.

The stated intentions of the respondents were further investigated through HCMs, to quantitatively assess the factors that most explain their willingness-to-own, -share or -ride AVs. Hybrid choice modeling is a well-consolidated framework in transportation studies that combines behavioral choice models with latent psychological variables to better understand decision-making processes. HCMs were first introduced by (Ben-Akiva et al., 2002) and have found applications with both discrete choice models (Bolduc et al., 2008; Dumortier et al., 2015; Hess et al., 2018) and ordered choice models (Bahamonde-Birke and Ortúzar, 2017; Saeidi et al., 2020; Piras et al., 2021). HCMs consists of two main components: the choice model and the latent variables model. A schematic representation of the overall HCM is shown in Fig. 1.

The choice model assumes that each individual n has well-defined preferences in choosing between different alternatives, which can be measured by means of a random utility function. In particular, this research aims at investigating individuals' willingness-to-adopt AVs, i.e. the decision-making process that led respondents to declare a certain score (among the possible alternatives) with respect to the willingness-to-own, -share or -ride AVs. The dependent variable in the choice model is therefore the general willingness-to-adopt AVs, as users participated in three specific choice situations where they were asked to declare their behavioral intentions on a Likert scale regarding the statements: "I will buy an autonomous car", "I will use autonomous taxi services", and "I will use public transportation services with autonomous buses". To this end, given the ordinal nature of the dependent variable, ordered choice models were used for which it is assumed that the individuals have a continuous, albeit unobservable, range of preferences y_n^* that they could express if they were not forced to provide an integer score from 1 to 5 (i.e. the Likert scale used in this research). Thus, the continuous latent utility of an individual may be expressed by the latent regression:

$$y_n^* = \delta + \boldsymbol{\beta_X X_n} + \boldsymbol{\beta_L L_n} + \varepsilon_n$$

where δ is the intercept (i.e. a constant), X_n is a vector of observed variables (e.g. the level of service attributes and the individual characteristics), L_n is a vector of latent variables (e.g. the individual personal attitudes and perceptions about AVs), β_X and β_L are vectors of unknown parameters to be estimated, and ε_n is the error term (independently and identically distributed). Note that the differences between the responses to the three choice situations are captured by the level of service attributes that identify the autonomous driving use cases. In the case of willingness-to-own, a "Ownership" dummy variable takes on the value of 1, and a "Individual use" dummy variable takes on the value of 1. In the case of willingness-to-share, these dummy variables take on the value 0 and 1 respectively. In the case of willingness-to-ride, these dummy variables take on the value 0 and 0 respectively.

The continuous latent utility y_n^* is observed in discrete form through a censoring mechanism (Greene and Hensher, 2010):

$$\begin{cases} y_n = 1 & if\ y_n^* \le \tau_1 \\ y_n = 2 & if\ \tau_1 < y_n^* \le \tau_2 \\ y_n = 3 & if\ \tau_2 < y_n^* \le \tau_3 \\ y_n = 4 & if\ \tau_3 < y_n^* \le \tau_4 \\ y_n = 5 & if\ y_n^* > \tau_4 \end{cases}$$

where y_n is the observed stated intention of the willingness-to-adopt AVs of respondent n, and τ_s are the threshold unknown parameters to be estimated. Estimates are obtained by the Maximum Simulated Likelihood Estimation (MSLE) method since the overall model involve both fixed and random parameters. Moreover, panel ordered choice models were specified to consider the non-independence of the observations associated with the same respondent, since interviewees were asked about the willingness-to-adopt AVs in three distinct moments of the questionnaire relating to three different use cases of the AVs (owning, sharing, or riding).

As regards the latent variables model, this consists of j latent variables measured by k psychometric items. The structural equation associated with a latent variable L_n may be expressed in general as:

$$L_n = \gamma + \boldsymbol{\beta_Z Z_n} + \omega_n$$

$$\boldsymbol{I_n} = \alpha + \boldsymbol{\lambda} L_n + \nu_n$$

where γ is the intercept, Z_n is a vector of observed variables (e.g. the individual characteristics), $\boldsymbol{\beta_Z}$ is a vector of unknown parameters to be estimated, ω_n is an error term (distributed with zero mean and standard deviation σ_ω), I_n is a vector of psychometric indicators that are associated with the latent variable through the measurement equation, α is the intercept, $\boldsymbol{\lambda}$ is the vector of unknown parameters (i.e. factor loadings) to be estimated, and ν_n is an error term (normally distributed with zero

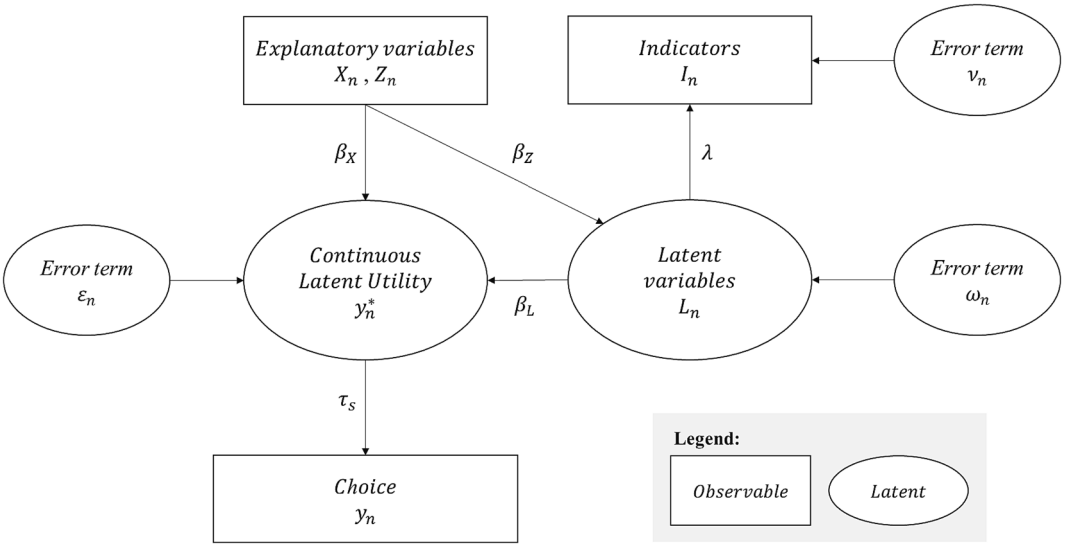

Fig. 1. Schematic representation of the hybrid choice model.

mean and standard deviation σ_v). Note that the psychometric indicators are the statements introduced in the previous section (coded through the Likert scales) and the structural equation modeling is based on ordered choice models.

The estimation procedure adopted in this research follows the simultaneous approach, i.e. the parameters are estimated by maximizing the joint likelihood of observed sequence of choices (with respect to the willingness-to-own, -share, or -ride AVs) and the observed answers to the psychometric questions (respondents' expectations and personal attitudes towards AVs).

4. Results

4.1. Sample description

The survey yielded responses from a total of 460 individuals within one month (from December 22nd 2020 to January 22nd 2021). Respondents who did not fully complete the survey were removed from the survey sample. This filtering process led to a final sample of 406 individuals. Sociodemographic breakdowns of the sample are presented in Table 3. This is made up of 39.2 % women and 60.8 % men, with 56.4 % of the sample being less than 34 years old. Regarding the educational level, 61.3 % declare to have a bachelor's degree or higher. From the employment status viewpoint, more than a half (58.6 %) is employed, 27.6 % are students, 8.1 % are retired, while negligible percentages are among the unemployed, looking for employment or others. Moreover, with reference to the income, 48.5 % of the sample receive a monthly net salary between € 1,000 and € 2,499, while 27.8 % do not receive any revenue. Finally, as regards the extension of the city in which the interviewees live, it is observed that around 20 % live in a small municipality (less than 10,000 inhabitants), almost 38 % live in a small town (10,000–100,000 inhabitants), around 14 % live in a medium-sized city (100,000–400,000 inhabitants), and the remaining 28 % live in a large city (more than 400,000 inhabitants).

From the comparison of the sample with the population in terms of distributions by gender, age group, personal monthly income, employment status, and educational level, some limitations of the sampling method emerge. Having disseminated the questionnaire on-line has led to a sample made up of a higher percentage of young respondents with respect to the characteristics of the population.

Table 3
Sociodemographic characteristics of the sample. *Source: ISTAT (Census of Italian population).

Variable	Number of respondents	Sample (%)	Italy* (%)
Gender			
Male	247	60.8	48.7
Female	159	39.2	51.3
Age group			
Less than 25	95	23.4	22.7
25 to 34	134	33.0	10.6
35 to 44	34	8.4	13.0
45 to 54	66	16.3	16.1
55 to 64	49	12.1	14.1
More than 64	28	6.9	23.2
Monthly income			
No income	113	27.8	29.2
Less than 1,000 €	37	9.1	
1,000 € to 2,499 €	197	48.5	43.7
2,500 € to 3,999 €	45	11.1	22.3
More than 3,999 €	14	3.5	4.8
Employment status			
Student	112	27.6	11.8
Employed	238	58.6	58.1
Unemployed	7	1.7	6.5
Looking for employment	8	2.0	7.2
Retired	33	8.1	16.4
Other	8	2.0	
Educational level			
Elementary school diploma	1	0.3	4.7
Middle school diploma	18	4.4	35.5
High school diploma	138	34.0	42.5
Bachelor's degree	84	20.7	17.4
Academic diploma in art, music, and dance	7	1.7	
Master's degree	146	36.0	
PhD	12	3.0	
City extension			
Small municipality (less than 10,000 inhabitants)	80	19.7	31.9
Small towns (10,000–100,000 inhabitants)	153	37.7	45.0
Medium-sized city (100,000–400,000 inhabitants)	59	14.5	11.1
Large cities (more than 400,000 inhabitants)	114	28.1	12.0

4.2. Expectations, attitudes and intentions towards AVs

Fig. 2 and Fig. 3 provide an overview of the observed scores of the different indicators used to assess the latent traits of the interviewees.

The results show that on average AVs are perceived as a useful technology (see mean scores of S1, S2, and S3), but at the same time there are high concerns regarding safety-related and cost-related issues. In particular, with regard to safety, it is thought that the use of AVs can somehow reduce the number of road accidents (S6), but it could expose vehicles more to threats of cyber-attacks (S4) and also endanger the confidentiality of personal data (S5). While for the costs, it is generally believed that the AVs will cost too much to be purchased and used individually (S8 and S9). Moreover, the majority of respondents believe that driverless taxi services will not cost more than traditional taxi services (S7). As far as personal attitudes are concerned, some statements differ significantly from the central value of the Likert scale, for example it emerges that the sample generally is inclined to use electronic payment channels (S10), not very oriented towards sharing goods or services (S12 and S13), at ease in traveling by collective means of transport (S16) and quite attentive to take care of the confidentiality of personal data.

To obtain a general understanding of the intention to use AVs according to the different use cases, the survey envisaged a section with four questions aimed at probing interviewees willingness-to-experiment, -own, -share, and -ride vehicles equipped with full driving automation functionalities. Fig. 4 shows the percentage distributions of the responses relating to the different willingness in a Likert scale, where 1 corresponds to a low and 5 to a high intention in the adoption of AVs.

The desire to experiment an autonomous vehicle is on average very high (4.2 out of 5), the distribution has a negative skew (i.e. the left tail of the distribution is longer, and the mass is concentrated on the right of the figure). The same cannot be said for the willingness-to-own AVs, where mean, median, and mode almost coincide in an approximately symmetrical distribution. Interviewees responded with uncertainty to the intention to purchase a self-driving vehicle. Willingness-to-share and the willingness-to-ride respectively have an average score of 3.3 and 3.6 out of 5.

4.3. Estimated models

The overall estimated hybrid choice model is shown in the following tables. Table 4 shows the estimated parameters related to the latent utility function (i.e. the willingness-to-adopt AVs, as extensively explained in Section 3.2) of the ordered choice model, while Table 5 shows the estimated parameters of the measurement models of the latent variables. The estimates are based on 1218 observations and 1000 Modified Latin Hypercube Sampling (MLHS) draws were used to perform the Maximum Simulated Likelihood Estimation (MLSE) method, under the assumption that the random parameters follow a normal distribution.

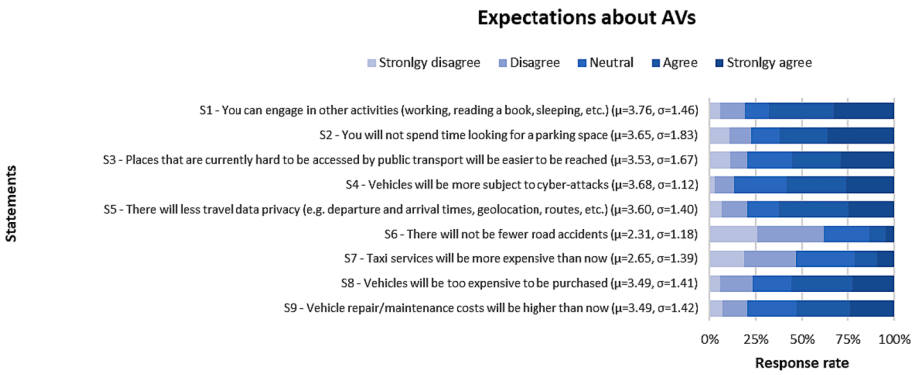

Fig. 2. Descriptive statistics of respondents' expectations about AVs.

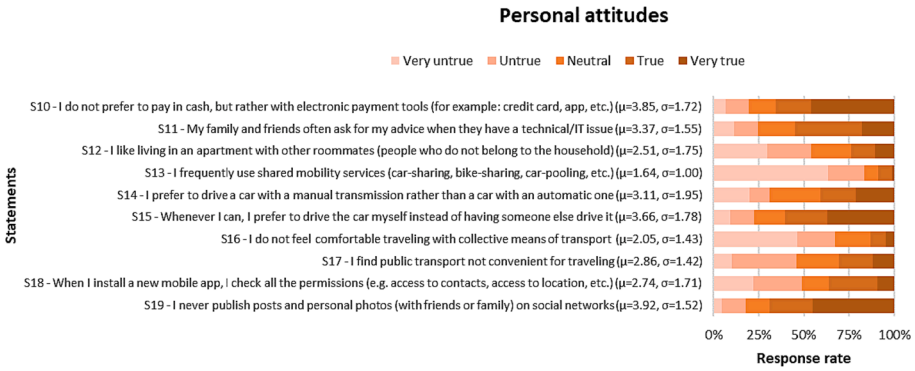

Fig. 3. Descriptive statistics of respondents' personal attitudes.

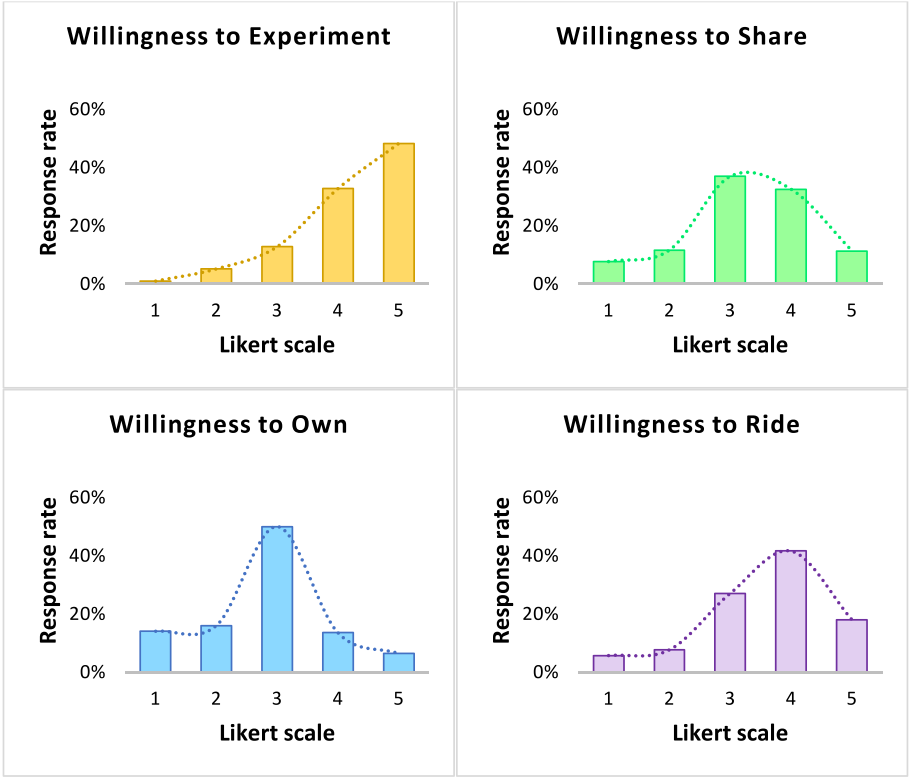

Fig. 4. Summary of respondents' willingness-to-adopt AVs.

Table 4
Estimations results of the hybrid choice model.

Sample size:	406		
Number of observations	1218		
Null log likelihood:	−18806.0		
Final log likelihood:	−10419.2		
Rho-square	0.45		
Akaike Information Criterion:	20954.5		
Number of draws:	1000		
Types of draws:	Normal, MLHS		
Observable Variable	**value**		***t*-test**
Constant	2.91	***	8.71
Ownership (Yes = 1, No = 0)	−0.71	***	−5.38
Individual use (Yes = 1, No = 0)	−0.60	***	−4.72
Gender (Female = 1, Male = 0)	−0.15		−1.34
Age (More than 45 y.o. = 1, otherwise = 0)	−0.38	***	−2.72
Education (PhD or Master's degree = 1, otherwise = 0)	−0.02		−0.20
Personal Monthly Income (More than 2.500 € = 1, otherwise = 0)	−0.03		−0.26
Household type (Live alone = 1, otherwise = 0)	−0.63	***	−3.14
City extension (More than 100.000 inhabitants = 1, otherwise = 0)	0.11		0.91
Travel frequency (More than 4 times per week = 1, otherwise = 0)	−0.11		−0.90
Latent Variable	**value**		***t*-test**
Perceived usefulness	0.21	***	5.50
Safety concerns	−0.14	**	−2.55
Cost concerns	−0.17	***	−3.55
Technology-savviness	0.15	***	5.74
Propensity for sharing	0.08	**	2.31
Aversion to Public Transport	−0.20	***	−4.16
Thresholds Parameter	**value**		***t*-test**
Tau(01)	0.00		
Tau(02)	1.46	***	28.07
Tau(03)	2.97	***	35.05
Tau(04)	4.69	***	37.96

***, **, * Significance at 1%, 5%, 10% level.

As can be seen in Table 4, many individuals' socio-economic characteristics are not statistically significant (see the *t*-test values), apart from the dummy variables relating to the *Age* and *Household type* of the interviewees. The sign of these estimated parameters informs that those who live alone and/or are over 45 years of age have on average a lower willingness-to-adopt AVs. The dummy variables *Ownership* and *Individual use* are statistically significant, and the negative sign of both parameter is consistent with what could be expected. In fact, as shown in the previous section, respondents stated a greater interest in the consumption of AV-based services rather than in the ownership of such vehicles and, furthermore, they are also generally more oriented towards collective rather than individual use.

All the latent traits of the individuals considered in this specification are statistically significant (see Table 5 for the item-construct correspondence assumed in this specification), explaining part of the variability of the respondents' stated intentions towards AVs, and consistent in the sign. The parameters of latent variables with a positive sign increase behavioral intentions to use autonomous driving. Indeed, as one might expect, when *Perceived usefulness*, *Technology-savviness,* and *Propensity for sharing* increase, the willingness-to-adopt AVs also increases. On the other hand, parameters with a negative sign decrease behavioral intentions to use autonomous driving. In fact, as *Safety concerns*, *Cost concerns,* and *Aversion to Public Transport* increase, the willingness-to-adopt AVs decreases. The values of these parameters provide information about the magnitude of their influence on the willingness to adopt AVs. However, it is noteworthy that all the values fall within the range of −0.20 to 0.21, indicating a substantial balance in terms of importance between factors related to perceptions and personal attitudes. Note that the model presented in Table 4 is the result of one of several estimation iterations, through which some statements and potential latent traits that did not appear to be statistically significant as well as returning non-robust models were excluded from the analysis. As an example, those latent traits whose indicators yield a poor value of the Cronbach's alpha (Cronbach, 1951) were not included in the final estimated hybrid choice model. This applies to statements S14 and S15, aimed at identifying individuals' *Enjoyment in driving* (with a Cronbach's alpha of 0.60), and statements S18 and S19, aimed at identifying individuals' *Sensitivity to privacy* (with a Cronbach's alpha of 0.48). On the other hand, the remaining latent traits are characterized by an acceptable value (greater than 0.70) of the Cronbach's alpha, as can be seen in Table 5.

In Table 5 the estimation results of the parameters of the measurement models of the latent variables are reported. For each latent variable, a reference indicator was chosen for which the intercept α equal to 0, the factor loading λ equal to 1 and the error term ν equal to 1 were set. Although all the parameters are statistically significant and the factor loadings assume values greater than 0.4, i.e. threshold commonly accepted as a cut-off rule, in some cases the intercept and the error term assume preponderant values with respect to the factor loading. This result highlights some limitations of this research regarding the use of a

Table 5
Estimation results of the measurement models of the latent variables.

	α			λ			ν			γ			ω			Cronbach's Alpha
Latent variable / *Item*	**value**		***t*-test**	**value**		***t*-test**	**value**		***t*-test**	**value**		***t*-test**	**value**		***t*-test**	**value**
Perceived usefulness										3.63	***	24.55	2.09	***	13.82	0.84
Item S1	0			1			1									
Item S2	0.95	***	2.58	0.74	***	7.62	2.54	***	15.51							
Item S3	2.00	***	6.09	0.70	***	4.38	2.45	***	17.07							
Safety concerns										3.43	***	26.63	1.52	***	13.25	0.75
Item S4	0			1			1									
Item S5	1.19	***	3.46	0.63	***	6.56	1.91	***	17.29							
Item S6	0.53	*	1.74	0.48	*	1.95	1.83	***	18.39							
Cost concerns										1.69	***	15.27	1.7	***	13.76	0.77
Item S7	0			1			1									
Item S8	2.85	***	14.15	0.54	**	2.09	2.07	***	18.71							
Item S9	2.83	***	13.73	0.78	**	2.19	2.11	***	18.38							
Technology-savviness										4.29	***	22.28	2.82	***	15.53	0.79
Item S10	0			1			1									
Item S11	2.07	***	8.77	0.59	***	4.18	2.12	***	18.59							
Propensity for sharing										1.28	***	9.46	2.44	***	13.41	0.71
Item S12	0			1			1									
Item S13	−1.47	***	−6.04	0.45	***	5.64	2.40	***	13.11							
Aversion to PT										0.32	**	2.22	2.34	***	13.23	0.81
Item S16	0			1			1									
Item S17	1.91	***	16.60	0.48	***	8.47	1.66	***	17.85							

***, **, * Significance at 1%, 5%, 10% level.

small number of indicators to derive reliable latent constructs. However, the decision to design a survey with a small number of questions aimed at measuring psychometric indicators arises from having to deal with the trade-off that exists between the need to increase the reliability of the constructs and the need to limit the duration of the interview.

5. Discussion and conclusions

This section discusses key findings, highlighting those that have already been reported (or not) by other authors in the literature, policy recommendations, limitations of the study and conclusions.

Firstly, from the descriptive statistics of the indicators, it emerges that future mobility solutions involving the use of vehicles equipped with full driving automation functionalities for passenger transport are perceived as a very useful option, capable of solving common everyday problems. Primarily, because they allow travelers to engage in other activities (such as working, reading a book, sleeping, etc.) instead of driving, as it was also found by (Panagiotopoulos and Dimitrakopoulos, 2018) and (Wu et al., 2020). AVs are perceived beneficial even in terms of road safety, but there are concerns about possible hacker tampering attacks that could affect cyber-security of vehicles, and the uncontrollable collecting of data that could undermines the protection of personal travel data (Brell et al., 2019).

Secondly, the existence of a slight relationship between consumers' (observable) socioeconomic characteristics and their willingness-to-own, -share, or -ride AVs was measured in the estimated HCM. As confirmed by several authors (Hohenberger et al., 2016; Cunningham et al., 2019a; Hudson et al., 2019), younger age groups have in general a greater intention to adopt AVs. But unlike other studies, no significant relationships were found between the intentions and the educational level or personal income of respondents, nor with respect to the size of the cities in which individuals live, as reported by (Bansal et al., 2016; Liljamo et al., 2018; Hudson et al., 2019). On the other hand, the estimated HCM showed that consumers' latent traits turn out to be statistically significant in explaining the intentions to adopt AVs. In particular, the modeling of the choices of respondents made it possible to validate the existence and quantitatively evaluate the relative weight of the *Perceived usefulness, Safety concerns, Cost concerns, Technology-savviness, Propensity for sharing, and Aversion to Public Transport* in their decision-making processes. Therefore, this research is part of the existing studies in the literature, such as (Nordhoff et al., 2018; Zoellick et al., 2019; Cunningham et al., 2019b), that have found that individuals' perceptions and personal attitudes significantly affect the willingness-to-own, -share or -ride AVs. However, it should be noted that some indicators and hypothesized latent traits were not found to be statistically significant, in particular those related to driving and privacy attitudes, and others have not proved to be very reliable, probably due to the limitations of the investigation relating to the number of indicators pertaining to each hypothetical construct.

Finally, descriptive statistics showed that, even if the willingness-to-experiment the new autonomous driving technology is very high, a lower willingness-to-own private AVs exists; and their individual use is perceived more expensive in relation to current repairing and maintenance costs of conventional vehicles. Conversely, it is believed that driverless taxi services may be cheaper than traditional taxi services and people were found to have a higher willingness-to-adopt AVs in shared or collective mode. These expectations give hope for a consumer orientation towards the consumption-based, rather than ownership-based, approach.

Indeed, future potential impacts of this new disruptive technology will strongly depend on how people will adopt AVs: whether they will buy or not a vehicle, and whether they will make an individual, shared, or collective use.

If users buy and make an individual use of AVs, then it is reasonable to expect that little will change compared to the current scenario, in terms of vehicle kilometers traveled. In fact, these could even increase due to a reduction in the value of time, as found by (van den Berg and Verhoef, 2016; Kolarova et al., 2019). While if the private AVs will be shared within the family, a reduction of the motorization rate would be obtained, but there could also be an increase of empty vehicle kilometers traveled (Saleh and Hatzopoulou, 2020), i.e. vehicles sent with no one on board across the city to be available to other members of the family.

On the other hand, the consumption-based logic could be implemented as cars performing taxi services, in this way the users would share the vehicles with the rest of a community but would not share the same rides. It is worth noting that there is also a non-negligible risk that travelers might be diverted from public transport to autonomous taxi solutions, giving rise to an unsustainable modal shift and generating potentially an increase of empty vehicle kilometers traveled (Moreno et al., 2018), energy consumption, and polluting emissions. Otherwise, the most desirable implementation is that AVs could be collective means of transport, for example minibuses with 4–6 seats, able to meet the demand of more travelers at the same time. In this case, AVs could be deployed as shuttle services with fixed-route and fixed-timetable feeding the mass rapid transit network, or as demand-responsive transit solutions, i.e. on-demand services with flexible-route. The consumption-based approach with the use of collective means of transport is likely to result in fewer negative impacts on environment, economy, and society, since there would be a greater aggregation of the demand of several individuals on a single vehicle (Coppola and Silvestri, 2020).

It is therefore evident that travel behaviors of individuals should be oriented and guided towards the latter use case, through transport policies that may act on several aspects, not least the latent traits of individuals:

- increase the overall attractiveness of transit infrastructure, vehicles, and services, in order to reduce the latent aversion of individuals to Public Transport
- foster a greater individuals' propensity for sharing goods and services through sustainability awareness campaigns
- promote monetary incentives to keep transit fares of autonomous minibuses far cheaper than those of driverless taxi services, also through governmental subsidies for Public Transport operators
- encourage the design of Public Transport lines with self-driving shuttle vehicles that transversally connect residential districts with the main railway and metro stations, in order to increase the catchment areas of the latter and encourage the use of autonomous road vehicles on short distances while rapid mass transit over long distances.
- reassure individuals (especially the elderly) about the ease of use of this technological innovation
- reassure people about the increased reliability and road safety that autonomous driving will provide
- manage accesses in the most congested areas of cities through restrictions and pricing, to avoid the widespread use of private AVs that may travel many empty vehicle kilometers

In conclusion, the contribution of this exploratory study conducted in Italy is all-in-one research, giving an overall understanding of users' expectations and personal attitudes affecting different approaches towards autonomous driving (i.e. ownership-based or consumption-based; individual, shared, or collective use). Future research could be addressing some limitations related to the sample size and to the fact that the interviewees have been recruited only through an on-line survey, in order to guarantee that all socioeconomic categories of consumers are well represented in the sample by a higher number of observations. Furthermore, the use of only 2 indicators for measuring personal attitudes poses problems of reliability in the identification of latent constructs, which can however be easily overcome by using at least 3–4 indicators for each latent construct. Finally, future developments will be focused on the design of a Stated Intention survey with also Stated Preference experiments in order to take into

consideration other level of service attributes that may differentiate the AVs use cases and to assess the influence of the latent variables on the perceived value of time and individuals' willingness-to-pay for owning, sharing or riding AVs.

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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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