Measuring, analysing and explaining the value of travel time savings for autonomous driving

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‘*Nothing ... is ours, except time.*
We were entrusted by nature with the ownership of this single thing...
And yet time is the one loan, which even a grateful recipient, cannot repay.’

Lucius Annaeus Seneca
‘Letters from a Stoic: Epistualae Morales ad Lucilium’

Eidesstattliche Erklärung

Ich erkläre, dass ich die Dissertation selbständig und nur unter Verwendung der von mir gemäß § 7 Abs. 3 der Promotionsordnung der Mathematisch-Naturwissenschaftlichen Fakultät, veröffentlicht im Amtlichen Mitteilungsblatt der Humboldt-Universität zu Berlin Nr. 42/2018 am 11.07.2018 angegebenen Hilfsmittel angefertigt habe.

Berlin, 10.02.2021 Viktoriya Kolarova

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Abstract

Autonomous driving will potentially strongly affect preferences for time spent in a vehicle and, consequently, the value of travel time savings (VTTS). As VTTS is a key element of cost-benefit analysis for transport, these interrelations are crucial for analysing the potential impact of the technology on future travel demand. Despite the increasing number of simulation and empirical studies as well as position papers dedicated to this topic there are still many unanswered questions: first, no consensus has been reached so far on the potential extent and direction of changes in the VTTS by autonomous driving. Second, empirical studies have so far addressed only specific automated vehicle (AV) concepts or use cases. Third, potential determinants of the willingness to use AVs are addressed in several studies; however, their effect on travel time perception in an AV has not yet been quantified.

The focus of the thesis is therefore (1) to explore potential changes in the VTTS resulting from the introduction of autonomous driving and their determinants, (2) to measure these changes and (3) to quantify the effects of various factors that influence VTTS, including context-related characteristics, such as trip purpose and individual characteristics, especially psychological factors, such as attitudes and perceptions. The results contribute to developing more differentiated scenarios regarding the impact of the technology on travel demand as well as to the support of the development of policy and practice strategies for AVs.

As part of this cumulative thesis, three studies that built on each other were conducted. Qualitative approaches (focus group discussions and thematic qualitative text analysis) and quantitative methods (stated preference surveys and discrete choice models) were used. All the studies compared user preferences towards currently available transport modes (walking, bicycle, public transport, and conventional car) with two concepts of AVs: a privately-owned AV (PAV) and a shared AV (SAV), i.e. AV on demand.

The analysis results suggest lower VTTS for autonomous driving compared to manual driving. However, this applies only to commuting trips and not to leisure or shopping trips. A PAV is perceived as a more attractive option than an SAV, but user preferences for SAVs vary between the different studies. In the most recent study of the thesis, the time spent in an SAV is found to be perceived more positively when the vehicle is used individually compared to sharing the ride with other users. The perception of the SAV depend, among others, on how the concept is presented to respondents. Individual characteristics, such as experience with advanced driver assistance systems (ADAS), strongly affect the perception of time in an AV; other socio-demographic factors, such as age and gender, affect mode choices and the VTTS mainly indirectly by influencing the attitudes and perceptions of potential users. The perceived improvement in travel experiences due to autonomous driving and trust in the technology are important determinants of the perception of the travel time spent in an AV. However, enjoyment of driving and other perceived benefits of manual driving partially counterbalance the utility of riding autonomously. Last but not least, VTTS for different potential user segments depending on their socio-demographic characteristics and attitudes were calculated.

Overall, the results show that the VTTS for autonomous driving is lower than for conventional cars; however, this is applicable only for certain use cases, and it is strongly dependent on the individual characteristics of potential users. High variability in user preferences for SAVs was observed; therefore, further research with a focus on this alternative is needed. Policy implication derived from the results of the research is the need to actively shape the integration of AVs into the transport system, especially focusing on increasing the attractiveness of shared services. In conclusion, several development recommendations for AVs are derived from the findings, as well as recommendations for future studies and potential research avenues.

Zusammenfassung

Autonomes Fahren wird potenziell die Präferenzen für die im Auto verbrachte Zeit stark beeinflussen und dementsprechend den Wert der Reisezeit, der ein Schlüsselelement von Kosten-Nutzen-Analysen im Verkehr ist. Die Untersuchung dieses Aspekts des autonomen Fahrens ist daher entscheidend für die Analyse potenzieller Auswirkungen der Technik auf die zukünftige Verkehrsnachfrage. Trotz der steigenden Anzahl an simulationsbasierten und empirischen Studien, sowie Positionspapieren zum oben genannten Thema gibt es noch folgende Forschungslücken: (1), es herrscht noch kein Konsens über die Höhe und Richtung der Änderungen des Werts der Reisezeit im Fahrzeug durch das autonome Fahren; (2), bisherige empirische Studien haben oft nur bestimmte Konzepte oder Anwendungsszenarien von autonomen Fahrzeugen (AF) adressiert; (3), potenzielle Determinanten der Nutzungsbereitschaft für AF wurden bereits in diversen Studien untersucht, aber ihr Effekt auf die Wahrnehmung der Zeit in einem AF wurde bislang noch nicht quantifiziert.

Der Fokus der Dissertation ist daher: (1) die potenziellen Änderungen des Reisezeitwerts, die durch das autonome Fahren entstehen, und ihre Determinanten zu erforschen, (2) diese Änderungen zu messen und (3) den Effekt verschiedener Faktoren, die sie beeinflussen, einschließlich kontextspezifische Charakteristiken, wie Wegezweck, und individuelle Charakteristiken, besonders psychologische Faktoren, wie Einstellungen und Wahrnehmungen, zu quantifizieren. Die Ergebnisse tragen für die Entwicklung differenzierter Szenarien über die Auswirkungen der Technik auf die Verkehrsnachfrage bei und unterstützen die Entwicklung von Politik- und Praxisstrategien für AF.

Im Rahmen der vorliegenden kumulativen Dissertation wurden drei aufeinander aufbauende Studien durchgeführt. Dabei kamen sowohl qualitative Ansätze (Fokusgruppendiskussionen, thematische qualitative Analyse), als auch quantitative Methoden (Stated Preference Befragungen, diskrete Entscheidungsmodelle) zur Anwendung. In allen Studien wurden Nutzerpräferenzen für aktuell verfügbare Verkehrsmittel (zu Fuß, Fahrrad, öffentlicher Verkehr und konventionelles Auto) mit Präferenzen für zwei Konzepte von AF verglichen: privates AF und geteiltes AF bzw. Fahrzeug auf Abruf.

Die Ergebnisse der Analysen zeigen, dass der Wert der Reisezeitersparnis beim autonomen Fahren niedriger als beim konventionellen Fahren ist. Das trifft allerdings nur auf Pendelwegen und nicht auf Freizeit- oder Einkaufswege zu. Das private AF wird als eine attraktivere Option im Vergleich zum geteilten Fahrzeug wahrgenommen, die Nutzerpräferenzen für geteiltes AF unterscheiden sich jedoch stark zwischen den Studien. Die letzte Studie in der Thesis zeigt, dass die in einem geteilten AF verbrachte Reisezeit positiver wahrgenommen wird, wenn man das Fahrzeug individuell nutzt im Vergleich zu einer mit anderen Nutzern geteilten Fahrt. Die Nutzerpräferenzen für ein geteiltes AF hängen unter anderem von der Art der Präsentation des Konzepts ab. Individuelle Charakteristiken, wie Erfahrung mit fortgeschrittenen Assistenzsystemen, beeinflussen stark die Wahrnehmung der Zeit im AF; andere sozio-demographischen Faktoren, wie Alter und Geschlecht haben vor allem einen indirekten Effekt auf den Reisezeitwert indem sie Einstellungen der potenziellen Nutzern beeinflussen. Die wahrgenommene Verbesserung des Fahrterlebnisses durch das AF und das Vertrauen in die Technik sind wichtige Determinanten der Wahrnehmung der im AF verbrachte Reisezeit. Fahrvergnügen und andere wahrgenommene Vorteile vom manuellen Fahren dagegen gleichen in einem gewissen Ausmaß den Nutzen vom autonomen Fahren aus. Nicht zuletzt wurden Reisezeitwerte für unterschiedliche potenzielle Nutzersegmente, definiert anhand ihrer soziodemographischen Charakteristiken und Einstellungen, berechnet.

Insgesamt zeigen die Ergebnisse, dass der Reisezeitwert beim AF niedriger als bei konventionellen Autos ist; allerdings nur bei bestimmten Anwendungsfällen und er ist stark abhängig von individuellen Charakteristiken der Nutzer. Es gibt große Präferenzunterschiede bei geteilten AF und daher sind weitere Forschungen mit einem spezifischen Fokus auf dieser Alternative nötig. Politische Implikation, abgeleitet von den Ergebnissen, ist die Notwendigkeit für eine aktive Gestaltung der Integration von AF in das Verkehrssystem, die sich besonders auf die Erhöhung der Attraktivität von geteilten Angeboten fokussiert. In der Dissertation werden abschließend Empfehlungen für die Entwicklung von AF abgeleitet sowie Empfehlungen für künftige Studien und potenziellen Forschungsgebiete diskutiert.

Overview of the thesis

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List of Abbreviations

AD	Autonomous driving
ADAS	Advanced driver assistance systems
AV	Automated vehicle
BMVI	Bundesministerium für Verkehr und digitale Infrastruktur
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
HCM	Hybrid Choice Model
ICLV	Integrated choice and latent variable
LC	Latent class
LV	Latent variable
LVLC	Latent variable latent class
MiD	Mobilität in Deutschland
MIMIC	Multiple Indicator Multiple Cause
ML	Mixed Logit
MNL	Multinomial Logit
PAV	Privately-owned automated vehicle
SAE	Society of Automotive Engineers
SAV	Shared automated vehicle
SC	Stated choice
SP	Stated preference
VoD	Vehicle-on-demand
VoT	Value of time
VTTS	Value of travel time savings

1 Introduction, motivation and scope of the thesis

What would happen if, in the future, our cars could drive fully autonomously so that we were no longer required to focus on the traffic and the driving task, and we could undertake other activities while riding more comfortably? How would this change our perception of time spent in the car? Finally, would our preferences for certain transport modes change?

In recent years, rapid technology development and further trends towards digitalisation have led to ever-increasing automation and connectivity in all areas of daily life, including transportation. Road vehicle automation is among the most discussed future transformations in transportation. The vision of automated or self-driving cars has existed since the 1920s (Kröger, 2014, Kröger, 2016). However, recent technological advancements have led to the expectation that fully automated vehicles might soon become a reality on the roads, changing individual mobility, the transport system and, in the long term, land use, infrastructure and society (Trommer et al., 2016, Litman, 2018, Milakis et al., 2017, Anderson et al., 2014).

Due to the increasing environmental challenges as well as demographic and urbanisation trends, it is becoming increasingly important to anticipate the impacts of this new technology and identify development pathways that will shape a more sustainable future transport system. The first step towards this is understanding how the technology will potentially change user preferences, mode choices and vehicle usage in the future, as this is crucial in evaluating the impact of the technology on the transport system and society.

1.1 Potential impacts of autonomous driving on travel behaviour and the transport system

Autonomous driving is associated with several societal and individual benefits, and these are cited as the main reasons for developing and deploying this technology. It is expected that road vehicle automation will increase road safety, road capacity and efficiency as well as increase energy efficiency through optimised driving performances (Fagnant and Kockelman, 2015, Litman, 2018, Anderson et al., 2014, Fraedrich et al., 2015). These aspects can be viewed as potential direct (positive) effects of vehicle automation.

For users, this technology can improve travel quality, as it enables the driver to take their hands off the steering wheel and engage in other activities whilst travelling more comfortably (Cyganski et al., 2015, Fraedrich et al., 2016, Trommer et al., 2016, Dungs et al., 2016). Thus, autonomous driving will potentially make travelling in a vehicle less costly for travellers, and the value of saving travel time will decrease. In other words, people will be unwilling to pay for saving travel time, as they will be able to use it more efficiently and/or pleasurably (Trommer et al., 2016, Fosgerau, 2019). This will potentially change travel behaviour, as the value of time is considered an important determinant of mode choices. Anticipating changes in the value of time due to vehicle automation is crucial for travel demand projection because time savings '*continue being the single most important benefit of transport improvement projects'* and *'in spite of its importance, a consensus has not been reached about the size and nature of the values to be used in project evaluation'* (Ortúzar and Willumsen, 2011). Furthermore, fully automated vehicles enable users who are currently unable or unwilling to drive to use a vehicle. It is expected that shared automated mobility services will blur the distinction between private and public transport, as they combine the benefits of both: door-to-door mobility that is accessible and available to people who do not own or drive a car. Together, both trends contribute towards making personal travel increasingly *'passengerised'* with implications for travel behaviour, transport and daily life. The magnitude and effect of these potential changes are currently highly uncertain. Simultaneously, it is important to analyse and discuss them appropriately (Mokhtarian, 2018).

The implications of autonomous driving will depend on the use cases and how they are implemented into the existing transport system. However, the preferences, decisions and behaviour of potential users of such vehicles and services will shape the impact of the technology on the transportation system, society and land use (Trommer et al., 2016, Gruel and Stanford, 2016, Bahamonde Birke et al., 2018).

Assuming that vehicle automation will make vehicle use more attractive and accessible to new user groups, the traffic volume may increase (Bahamonde Birke et al., 2018). This could lead to rebound effects that counterbalance the above-mentioned potential positive effects of the technology or even create new issues. These potential systemic effects highlight that implementing road vehicle automation requires more in-depth analyses of the outcomes of the complex systemic processes. Based on the results of these analyses, suitable measures and strategies can be created to shape desirable technology development, implementation and deployment pathways (Bahamonde Birke et al., 2018, Gruel and Stanford, 2016, Milakis et al., 2017).

1.2 Motivation and scope of the thesis

The above discussion clarifies two aspects: much uncertainty is associated with the user preferences for autonomous driving; simultaneously, individual travel-related decisions are key to determining the impact of the technology on the transport system and society. From this background, it is crucial to analyse how vehicle automation affects the mode choices of potential users and which factors are essential for evaluating automated vehicles (AVs). This thesis is therefore dedicated to measuring and analysing potential changes in the value of travel time savings (VTTS) for autonomous driving compared to manual driving. It explores the phenomenon from the user perspective, analysing the complex psychological processes when evaluating a new option for vehicle use, such as autonomous driving. The value of time for autonomous driving is, from a research perspective, worth exploring more deeply for two reasons.

Firstly, motives behind car use remain highly interesting to researchers because of the enormous impact of passenger cars on travel behaviour and land use (in the past) as well as the negative external effects of their use, such as the environmental impact. Previous research on the motives for car use postulates, for instance, a more important role of the affective (e.g. driving pleasure) and symbolic (e.g. as a status symbol) functions of cars than instrumental (and rational) ones, such as cost or as a means to travel from A to B (Steg, 2005, Steg et al., 2001). As regards autonomous driving and evaluating the time spent in a vehicle, it might be important to consider all relevant aspects related to car use today and explore how an increase in automation may change car use and meaning.

Secondly, besides the importance of the value of time (and of travel time savings) in transport research and planning, no consensus has been reached on the size and nature of these values for current modes of transport (Ortúzar and Willumsen, 2011). This implies that defining these aspects for future transportation options, such as automated vehicles, could be even more challenging. A group of experts in the transport research field are exploring the potential positive utility of travel and the link between travel and subjective well-being (Mokhtarian and Salomon, 2001, Mokhtarian, 2019). These aspects might become increasingly important when addressing autonomous driving (Mokhtarian, 2018, Singleton, 2018), and they question the applicability of the concept of value of time to the era of autonomous driving as it is currently understood.

1.3 Overview of the thesis

This cumulative thesis encompasses three studies that address the topic of mode choices and the VTTS for autonomous driving. The studies are connected: each study addresses a specific aspect of the topic and is related to the previous one. Together, they aim to provide a comprehensive picture of the addressed research topic. Table 1 overviews the studies, their specific research focus and the corresponding chapter in the thesis.

Table 1: Overview of the studies conducted within the thesis

Study Nr.	Focus of the study	Chapter
Study 1	**Exploration** of potential determinants of the value of time for autonomous driving	Chapter 6
Study 2	**Measurement** of value of travel time savings for autonomous driving	Chapter 7
Study 3	**Analysis** of the effect of psychological factors on the value of travel time savings for autonomous driving	Chapter 8

The remainder of the thesis is organised as follows: Chapter 2 defines vehicle automation in terms of automation levels and mobility concepts. Chapter 3 summarises the state of the art and knowledge about the VTTS and mode choices for autonomous driving. Chapter 4 introduces the research questions addressed in this thesis. Chapter 5 overviews the methodology used to address the research questions. While each further chapter, i.e. paper of the thesis, includes a section on the methodology used in the particular study, Chapter 5 introduces the general methodological framework used in the thesis, identifies the relationship between the methods used in the single studies and provides a basic theoretical background to the applied methodology.

The chapters 6–8 include the three studies described in the cumulative thesis. Chapter 6 provides insights from an explorative study on potential determinants of the value of time for autonomous driving as opposed to driving manually. Chapter 7 focuses on the measurement and VTTS for autonomous driving. Chapter 8 is dedicated to analysing the effect of selected psychological factors on mode choices and the VTTS for autonomous driving.

Chapter 9 summarises the main results for all three studies. Chapter 10 compares the results to the knowledge in the literature. It discusses their implications for policy, vehicle and service development as well as recommendations for further empirical studies and future research avenues related to autonomous driving.

During the thesis period, I performed further research work related to the topic of mode choices and the VTTS for autonomous driving, the results of which were published in journal papers or other research publications but are not included directly in the thesis. An overview of these works is provided in the Annex II.

2 Definition of vehicle automation: levels and mobility concepts

Before discussing in more detailed potential changes of the individual travel behaviour that result from vehicle automation, first we have to define what automated or autonomous driving means and how it will potentially change the characteristics of the vehicles and the way they can be used. Following an existing classification of the Society of Automotive Engineers (SAE International), vehicle automation ca be defined by six levels: from no automation (Level 0), through low or partly automation (Level 1 and 2), conditional automation (Level 3) and high (Level 4) to full automation, i.e., driverless (Level 5) (SAE, 2018). While Level 1 and 2 are only driver support features, systems from level 3 on are automated driving features, which means that the car user do not have to drive – under limited or under all conditions depending on the automation level.

Figure 1 gives an overview of driving automation the levels including the task of the driver, the functions of the system features and examples for such feature for each level. It can be expected that main changes in the travel behaviour of users arise from the automation Level 4 on, because these features allows drivers to switch their attention from the traffic to other activities and travelling in a more comfortable way and this will change the quality of travel with a vehicle (Trommer et al., 2016). For Level 3, there are still high uncertainties whether it will provide significant benefits to the users because on the one hand, it allows avoiding driving in demanding conditions (e.g. traffic jam). On the other, however, the driver has to be ready to take back the control over the vehicle on a request by the system. Such situation can be more overwhelming for the vehicle user than being concentrated at the driving task all the time. As from Level 4 on the vehicle can drive fully autonomously, I will refer on these levels in the thesis using the term 'autonomous driving'.

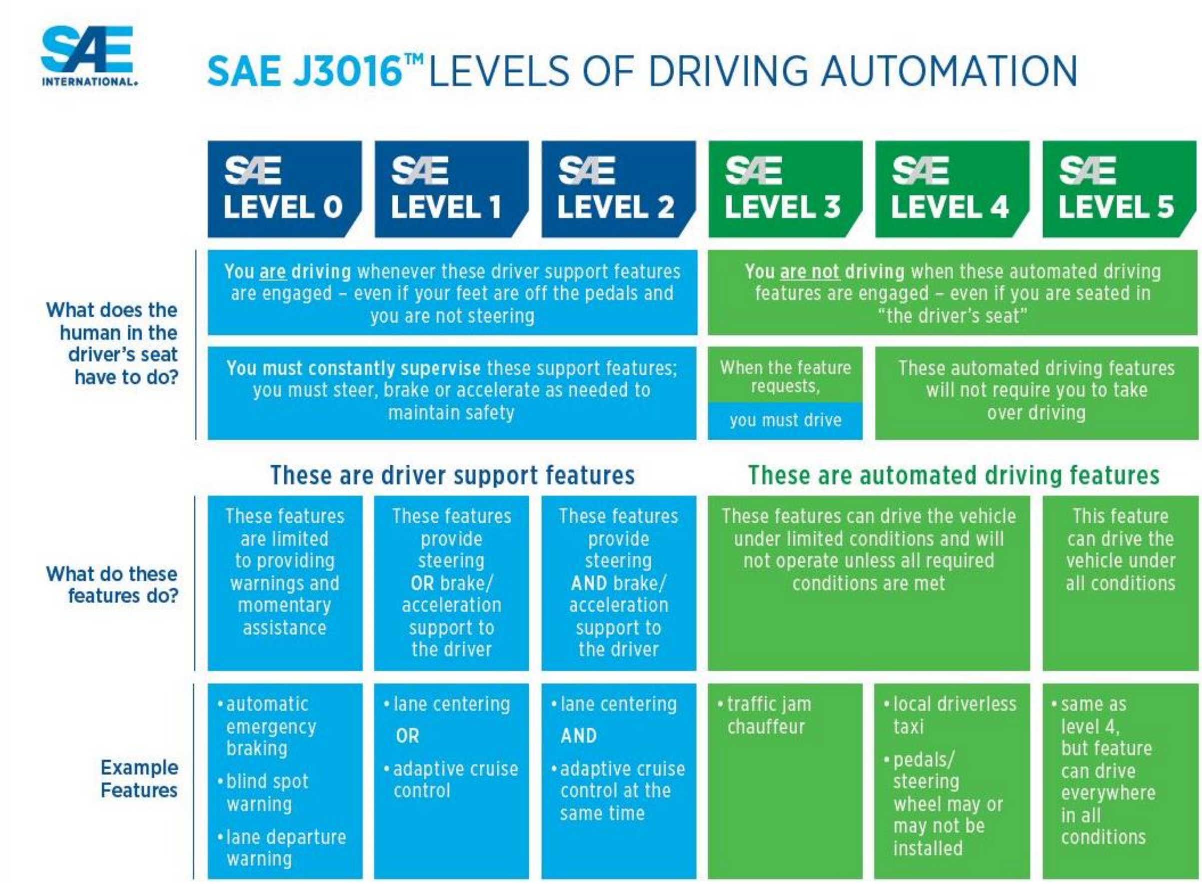

Figure 1: Levels of driving automation (SAE, 2018)

The highest levels of driving automation (Level 4 and Level 5) do not only relieve the driver from the driving tasks, but also enables the operation of additional new mobility services, such as ‘vehicle-on-demand’ (VoD) or ‘shared automated vehicles’ (SAV), which are similar to currently available carsharing or taxi services, but operate without a driver (Lenz and Fraedrich, 2016). Such services are called also ‘driverless taxi’. They can be used individually or trips can be shared with other users with similar itineraries; the benefit of sharing the ride for the users are lower cost, but include some waiting and/or detour times (Kröger and Kickhöfer, 2017). Moreover, privacy issues might be an acceptance barrier for sharing the ride with strangers. Shared mobility services can additionally facilitate multimodal trips when the SAVs are implemented as first or last mile solution in areas where public transport is deficient today (Yap et al., 2016, Mosquet et al., 2015, Ohnemus and Perl, 2016, Stark et al., 2019). The implementation and deployment of the different use cases or mobility services with automated vehicles will strongly depend on technical, legal and infrastructural conditions as well as on behavioural and societal aspects (Fraedrich et al., 2015).

The thesis focusses on privately-owned automated vehicles (PAVs) and shared automated vehicles (SAVs) - both introduced as door-to-door mobility options. The considered PAV and SAV concepts have both a level of automation which enables the vehicle to drive fully autonomously. For the SAV, individual use of a vehicle and the use in a ride-sharing arrangement are considered. Although first/last mile mobility services are also viable future usage scenario of automated vehicles, they are not addressed in the thesis. This is mainly because of the high complexity when introducing more than two new mobility concepts to study participants and additional aspects that have to be taken into account when including multimodal trips with AVs and public transport (such as cost structures, transfer time, vehicle concepts).

3 State of the art and knowledge on user preferences and value of travel time savings research for autonomous driving

In theoretical and empirical works on autonomous driving, the lower value of travel time savings compared to manual driving is postulated as one of the most important advantages of vehicle automation for the users and therefore an important factor in analysing changes in travel mode choice. However, depending on the study focus, the value of time is considered from different perspectives: among others (i) from the perspective of studying user acceptance of new technologies, (ii) travel demand modelling perspective, focussing on estimation of changes in the value of travel time savings, and (iii) from the perspective of theories about the positive utility of travel and the relationship between subjective well-being and travel (Kolarova et al., 2019a).

The analysis of changes in preferences and behaviour resulting from autonomous driving is a very interdisciplinary research field. Therefore, empirical works in this field can often not be categorized in only one of the mentioned types; there are always overlapping research questions. Looking at the issue from different perspectives, however, allows for a more holistic view on the topic and differentiates between the purposes of exploring the value of time. The user acceptance studies and also studies on the positive utility of travel attempt to understand user preferences and behaviour. Studies focussing on the approximation or estimation of the value of travel time savings aim mostly to quantify this value and to provide in this way an input for travel demand models. This allows the analysis of the effect of the introduction of new mobility options on a macro level (i.e. transport system level). All theories and scientific studies presented in this section focus on individual behaviour and the user perspective.

3.1 User acceptance: travel time use and comfort as relative advantages of autonomous driving

Studies which focus on the user acceptance of automated vehicles explore the factors which influence the willingness to use autonomous driving, including the opportunity to alternate time use and increased comfort (Fraedrich et al., 2016, Cyganski et al., 2015, Zmud et al., 2016b). These studies are often in line with user acceptance models, such as the Technology Acceptance Model, i.e. TAM, (Davis, 1985, Davis, 1989), the further development of the model to an Unified Theory of Acceptance and Use of Technology, i.e. UTAUT, (Venkatesh et al., 2003), or integrated user acceptance models, such as those proposed by Lucke (1995) or by Lüthje (2006). The models are based on psychological theories and theories on innovation which aim to describe and explain individual behaviour, for instance the Theory of Planned Behaviour from Ajzen (1991) or the Diffusion of Innovation Theory by Rogers (1995). Common determinants on the user acceptance of new technologies include (i) individual characteristics, such as socio-demographic factors and attitudes, (ii) attributes of the technology, such as perceived advantage, i.e. perceived usefulness, and ease of use, as well as (iii) context-specific factors. When interpreting the role of time use and time perception from the user acceptance perspective, researchers are interested in exploring the relative advantages of driving autonomously, including the feasibility of alternative travel time use and comfort, as determinants of the willingness to use the technology. Furthermore, some of the studies go a step further and look not only at the feasibility of activities while travelling in an AV as a perceived benefit, but also at which travel based activities are most desirable for potential users when riding autonomously. In other words, which activities that are potentially feasible while riding autonomously are from the users´ point of view the most beneficial?

User acceptance studies in the context of autonomous driving have a more explorative nature, focussing on understanding potential triggers and barriers of user acceptance and in some cases on quantifying the effects of certain variables on the willingness to use the technology. Such studies are an essential research step when exploring new mobility alternatives, not yet available in the market, and their perceived advantages and potential diffusion into the society. Theoretical approaches used in these studies are therefore more likely to come from research into innovations, consumer behaviour research, individual travel behaviour research, or a combined approach from a variety of research fields. The implications derived from the results will help to explore the changes in behaviour, once AVs become a desirable mode of travel. In the long run, acceptance studies can also support the anticipation of the take-up and market penetration of new mobility options (Woisetschläger, 2016).

In mostly theoretical discussions on the benefits of autonomous driving, one of the main postulated arguments for the technology, from the user perspective, is productive travel time use, i.e. the productivity gains resulting from the feasibility of doing something else in the car (Clements and Kockelman, 2017, Montgomery et al., 2018, Anderson et al., 2014). However, the results of empirical studies that look into factors which potentially influence travel time perception in an AV, suggest that users would not be eager to spend their travel time working or other productive ways. One study found a lower willingness to pay for saving travel time in an automated vehicle with an office interior than for a vehicle with an interior offering 'leisure facilities' (De Looff et al., 2018). At the same time, in user acceptance studies, being able to work while riding in an AV is only reported as an important benefit of vehicle automation by a small percentage (12%) of the respondents (Cyganski et al., 2015, Fraedrich et al., 2016). Furthermore, the results from explorative qualitative studies indicate that the idea of working in the automated car is viewed by some potential users as a rather negative aspect of vehicle automation. The arguments against the productive use of travel time in an AV mentioned in the same study, were concerns about trends towards a society increasingly oriented on efficiency and the blurring of lines between private, leisure, and work activities (Fraedrich and Lenz, 2016). These user concerns were also confirmed by a recent study conducted by Pudāne et al. (2019). Indeed, desirable activities performed in an AV are more likely to be those already performed while travelling (Cyganski et al., 2015, Fraedrich et al., 2016, Pudāne et al., 2019) and in particular, rather passive activities such as window gazing and relaxing (Cyganski et al., 2015, Fraedrich et al., 2016).

The activities which people would like to perform in an AV might depend on contextual and individual characteristics. For instance, Pudāne et al. (2019) proposed a categorization of on-board activities in an AV according to their priority level and novelty. High-priority activities, such as working or doing business, are often found to be desired by people who experience time pressure; current optional activities, such as phone checking or reading the news, are more desirable by people with a short travel time that does not allow for more substantial activities (Pudāne et al., 2019, Cyganski et al., 2015). Given the possibility of choosing the interior design of road vehicles, new optional activities, such as exercising or watching movies, are predominantly found to be desired by people currently having less time in their schedule for such activities (Pudāne et al., 2019). Besides that, trip purpose and also the direction of the trip (driving to work vs. driving home) influence desirable non-driving activities while riding in an AV. While preparing for work or business related engagements are preferred tasks during outbound trips, relaxing or sleeping/snoozing is more popular on return-to-home trips (Wadud and Huda, 2019).

Looking into how on-board activities affect the travel time evaluation in the car, there are also potentially negative effects of giving up the driving task and enabling other activities. The loss of driving pleasure and boredom were mentioned by potential users as a disadvantage of autonomous driving (Trommer et al., 2016, Fraedrich and Lenz, 2016, Pudāne et al., 2019). The driving pleasure can be seen from two sides: (i) as a desirable activity performed during travelling (a more instrumental view) and (ii) as having an intrinsic utility from car driving including self-development, enjoyment, feeling of control *(more about different motives for car use will be discussed in* *section 3.3* *which focuses on the positive elements of the utility of travel)*. Additionally, previous studies on time perception in currently available modes of transport found that subjective time perception on public transport differs from time perception in the car. Among other factors, this difference is related to mode-specific characteristics: the time is perceived to be rather shorter in a car, where the driver is actively involved in the driving task, compared to public transport due to the passive role of the passenger (Wächter, 2002, Heggie, 1976). This raises the question whether car driving can be seen as a desirable on-board activity and which elements of car driving make up its intrinsic utility (e.g. driving pleasure or enjoyment of driving). In particular, it seems worthwhile exploring which activities *en-route* compensate for, or outperform, the utility of driving, when there is a feasibility of new types of activities in an AV. This has to be also explored considering the potential role of the driver at the various automation levels and whether the AVs driving manoeuvres still have to be monitored similar to the autopilot functions in a plane. Along these lines, lack of trust in the technology in the early phase of the introduction of autonomous driving will potentially make watching the roadway and overseeing the system the most popular activities while riding in an AV; evidence for this was found for instance by Fraedrich et al. (2016) and Wadud and Huda (2019).

Considering further benefits of autonomous driving, results from empirical studies suggest that comfort and stress-free driving are among the most important aspects from the user perspective (Fraedrich et al., 2016, Pakusch et al., 2018b, Continental, 2015, Continental, 2018). These results are in line with the previously described insights that desirable activities while travelling in an AV are rather passive ones, including relaxing and window gazing.

In summary, user acceptance studies explore and analyse the factors which affect the evaluation of and willingness to use an AV, including alternative time use and increased comfort. Empirical evidence so far indicates that being productive in the car might not be among the most desirable ways to spend the time in an AV, but rather passive ones, such as relaxing, and activities already currently performed while travelling. Regarding intrinsic utility of riding autonomous, stress-relief, increased comfort and a more pleasant journey might prove as important aspects that influence the perception of time spent in an AV. Acceptance barrier on the other hand can result from perceived pressure for being productive while traveling, loss of driving pleasure and potential boredom resulting from the now passive role of the former car driver. Last but not least, the focus of the presented works is on the analyses of potential determinants of acceptance of AVs. Although many of these factors (e.g. time use opportunities or lower stress) are often discussed in relation to travel time perception in an AV, none of the existing quantitative studies measured their effects on the value of time for AV users.

This section only focuses on user acceptance determinants which are directly related to the value of time in an AV. Therefore, I have only focussed on the perceived benefits from riding autonomously in terms of using the travel time for other activities or enhanced comfort and stress-free driving when giving up the driving task. However, it should be mentioned that these are not the only determinants of user acceptance and that the evaluation and decision process for autonomous driving is more complex and will also potentially be influenced by other characteristics of the technology, the user, and the condition or context of use. The following factors have been found to have an influence on the desire to use an AV: (i) user characteristics, such as experience with advanced driver assistance systems or on the topic of autonomous driving and current travel behaviour, (ii) perceived technology characteristics, such as safety, efficiency or cost, and (iii) characteristics of the context, such as traffic conditions or geographical area (Becker and Axhausen, 2017, Gkartzonikas and Gkritza, 2019). While most of the factors are not directly related to the travel time evaluation in an AV, some of them might indirectly affect the value of time. For instance, trust in the technology, which depends, to a certain extent, on the experience with similar systems and technology awareness, can potentially influence the way people perceive the feasibility of activities while travelling or in general the willingness to give up the driving task. Furthermore, as proposed by Becker and Axhausen (2017), there can be an interaction between passion for driving and road and traffic conditions, e.g. enjoyment of driving might be inhibited/limited when stuck in traffic.

3.2 Value of travel time savings: potential differences between autonomous driving and currently available transport modes

In transport research, while the main research focus is the same (looking into determinants of mode choice, i.e. preference for an AV over other alternatives), the purpose of the analyses is slightly different. Travel time is considered to be a decisive determinant of mode choices and the utility (or rather the disutility) of travel time is quantified in empirical studies in order to predict (future) travel demand (Ortúzar and Willumsen, 2011, Knapp, 1998). The main purpose of the research is to quantify the effect of determinants of travel demand and to forecast the potential impact of changes in characteristics of transportation alternatives on the traffic system. The results of travel demand models support policy decision and transport planning. Similar to user acceptance surveys, the potential market share, i.e. market penetration of AVs, can be analysed with modelling methods. However, the diffusion of new mobility options is not the focus of the analyses, but rather additional input for forecasting the implications of travel behaviour changes.

The analysis of mode choices, as used in modelling approaches, is usually centred on estimating the value of travel time savings (VTTS) as a key element of cost-benefit analyses. VTTS is a concept which reflects the assumption in microeconomic theory, that people make transport decisions in the context of a constrained time budget. Time allocation theories that underlie this assumption have been known since the 1960s (Becker, 1965, Johnson, 1966, Oort, 1969, DeSerpa, 1971, Jara-Díaz, 2000). According to the theoretical framework, people choose whether they spend their time on one activity or another, and also how much they are willing to pay to save time spent on a particular activity (Hensher, 2011). Therefore, the subjective VTTS is the willingness to pay for marginal reduction of travel time, i.e. to reduce travel time by one unit (Jara-Díaz, 2000). For autonomous driving, it is reasonable to assume, that the willingness to pay for travel time savings changes compared to manual driving because the perception of the time spent in a vehicle change. It is noteworthy that the VTTS represents a trade-off between travel time and cost faced by an individual (Ortúzar and Willumsen, 2011). Although autonomous driving can also change cost for a trip in a vehicle (for instance because of the high cost of the technology for PAV or lower cost for SAV compared to taxis), these changes are highly uncertain and worth to be explored separately. This thesis focuses therefore only on the changes of the travel time value or perception resulting from vehicle automation.

In previous studies on VTTS, the values for currently available alternatives were estimated and their dependency on trip characteristics, such as trip purpose, trip length or perceived comfort level, was explored. The output of such studies, conducted usually to be representative for a particular country (Axhausen et al., 2014, Arup/ ITS Leeds/ Accent, 2015), is an important basis for transport infrastructure and policy planning. Generally speaking, VTTS are found to be higher for commuting trips than for leisure or shopping trips, driving under congestion has a higher value than in free-flowing traffic conditions, and VTTS for car passengers are found to be lower than for car drivers (Abrantes and Wardman, 2011, Shires and De Jong, 2009, Mackie et al., 2003). Putting these results in relation to AV suggests that autonomous driving might reduce VTTS since people will potentially travel as passengers. This may especially apply to certain trip types, such as commuting, or to certain traffic situations, such as heavy traffic, as it provides the opportunity for switching one's attention to other activities and reduces the negative effects of travelling by car *(see discussion in* *section 3.1* *on a conceptual level).*

Assessing VTTS for currently available modes of transport is also possible using the revealed preferences method (RP), but the quantification of the VTTS for new alternatives, such as autonomous driving, must rely on stated preference (SP) approaches or plausible assumptions. Both simulation studies (e.g. Gucwa, 2014, Childress et al., 2015, Kröger et al., 2016, Auld et al., 2017, Kockelman et al., 2017) and empirical works on mode choices in the presence towards AVs (e.g. Yap et al., 2016, Winter et al., 2017, Krueger et al., 2016, Steck et al., 2018, De Looff et al., 2018, Zhong et al., 2020) have provided early insights into the potential impact of vehicle automation on travel demand to date. In most of the studies, two concepts of AVs were considered (whether one of them or both simultaneously): privately-owned vehicles (PAVs) and shared automated vehicles (SAVs), i.e. vehicles on demand.

Simulation studies tested several scenarios about the impact of vehicle automation on VTTS and travel demand. Many of them assumed a reduction in VTTS for AV users of at least 25-50% of car drivers VTTS (Gucwa, 2014, Childress et al., 2015, Auld et al., 2017, Kockelman et al., 2017). There are also theoretical discussions on potential zero ‘value of time’ (e.g. Fosgerau, 2019), or in other words 100% reduction in VTTS compared to conventional car.

The first empirical studies that estimated VTTS in the context of autonomous driving focused on SAVs. For instance, a study conducted by Krueger et al. (2016) found that travel time savings is an important determinant of the mode choice decision for an SAV. Furthermore, the results of the study indicate that using an SAV alone and an SAV shared with strangers (i.e. an SAV with a dynamic ride-sharing, DRS) are perceived as two clearly distinct options. At the same time, an SP survey considering AV as an egress mode to the next train station found higher VTTS for this option (i.e. a more negative perception of the time spent in such vehicles) compared to driving manually, which the authors attributed to potentially psychological barriers to using automated vehicles (Yap et al., 2016). These results suggest that there is still a high level of uncertainty regarding the perception of on-demand services which are expected to be highly affected by the service characteristics, such as cost and travel time, but also sharing options or use/business cases (e.g. first/last mile solution). In the context of travel time perception in such services, privacy issues (in the case of sharing a ride in the vehicle with strangers) and trust in technology, might highly affect travel activities and the perceived level of comfort. Studies which focus on PAVs found initial empirical evidence for a reduction in the VTTS compared to manual driving for commuting (Steck et al., 2018) and for long distance trips (Kolarova and Steck, 2019) as well as for an AV with an office interior (De Looff et al., 2018, Correia et al., 2019). Most of the studies, apart from Steck et al. (2018) and a study conducted by Becker and Axhausen (2018), address only motorized modes of transport.

Overall, in spite of the increasing number of simulation and empirical studies on VTTS in the context of autonomous driving, no consensus been yet reached about the size and direction of the values. The majority of the studies suggest a reduction in VTTS for AV users compared to VTTS for car drivers, but there is a small but growing number of research papers that discuss the possibility of no reduction at all (Krueger et al., 2019) or even an increase in VTTS (Rashidi et al., 2020).

In summary, VTTS is an essential concept in the context of modelling travel demand. It is expected that autonomous driving will potentially change the VTTS for car drivers since it provides certain benefits to the users of the system. Anticipating the potential VTTS changes resulting from vehicle automation is, therefore, an important topic in transport research that focusses on travel demand impact of AVs. Despite the increasing number of works, there are still uncertainties about the size and direction of the changes in VTTS. Furthermore, while early empirical insights on VTTS changes are available, most of the studies focus mainly on specific use cases of autonomous driving and the characteristics of the trips that AVs are used for (e.g. first/last-mile, car- or ride-sharing, commuting trips, etc.). Moreover, in most cases, only motorized modes of transport have been considered and a baseline is missing, as the studies focus only on user preferences when future mobility options become available.

3.3 Positive utility of travel: potential change in travel activities and travel experiences due to autonomous driving

Although estimating, i.e. quantifying, the VTTS is a standard approach when addressing mode choices in transport research, explaining the observed differences in VTTS is addressed in considerably fewer theoretical and empirical works. At the same time, this aspect becomes increasingly important when it comes to analysing the impact of autonomous driving on time perception, since exploring the source of the changes themselves is essential for anticipating the potential effect of vehicle automation. Thus, exploring the mode choice decision process (i.e. how vehicle-specific characteristics, such as comfort or the opportunity to use the travel time for other activities, influence mode choices) can be seen as an overlapping area with user acceptance research. Consequently, the theoretical discussion and the empirical insights in this research area are similar to the aspects presented in section 3.1 but provide a more precise theoretical concept. They consider different elements of the utility of travel time and build a bridge to the approaches that address travel demand in transport research.

In transportation research, the demand for transport is traditionally considered as derived (Ortúzar and Willumsen, 2011). As described above, the travel is, according to the concept, only considered as a means to reach the destination and therefore an individual seeks to minimize travel time. Mokhtarian and Salomon (2001) postulate however, that travel is not always a derived demand, but can also be desired for its own sake, i.e. there can be also a positive utility for travel. The authors suggest that the nature of affinity for travel has three elements: (i) the activities conducted at the destination, (ii) activities that can be conducted while travelling, and (iii) the activity of travelling itself. The first element corresponds to the view of travel time as a derived demand and the other two consider the cases where travel time provides a certain utility to the person. In the context of AVs, it is reasonable to assume that the utility of the activity conducted at the destination will most likely remain the same, while the feasibility of conducting activities during the trip and the travel experiences will be affected by autonomous driving. These two elements were discussed in the context of the user acceptance of AVs; however, in research on the positive utility of travel there is an explicit focus on the relationship between these elements and the value of time. Along these lines, further relevant research, not only in the context of autonomous driving but in general, focussed on exploring the role of (travel-based) multitasking (Singleton, 2017, Singleton, 2018, Circella et al., 2012) and subjective well-being elements or travel experiences on the evaluation of travel time (Mokhtarian, 2018, Singleton, 2018, Singleton, 2017). Even though conducting activities while travelling and the travel experiences are strongly related to each other, theoretical and empirical works suggest considering them as separate aspects of travel time evaluation or travel satisfaction (Mokhtarian and Salomon, 2001, Singleton, 2017, Pudāne et al., 2019).

First, multitasking as the behaviour for doing multiple activities at the same time (or 'polychronicity' as the degree of preference for such behaviour) is explored by several researchers, also in the context of travel behaviour. Circella et al. (2012) conceptualize a general typology of multitasking behaviour along the dimensions of 'share of time' and 'share of resources' spent on each task, providing a detailed definition of this phenomenon. Special attention is placed on conducting other activities while travelling as a form of multitasking since travel is often viewed as (unproductive) transition time and hence invites other activities to be overlaid on it. According to the authors, travel can be either an active (e.g. driving) or passive (e.g. sitting in a vehicle as a passenger) activity depending on the resources required (Circella et al., 2012). In transport research, the role of multitasking on travel time evaluation has been mainly explored in the context of public transportation. The findings suggest that conducting activities while travelling indeed influence the travel time evaluation (Ettema et al., 2012, Frei et al., 2015). Studies on activities conducted while travelling in a car (e.g. listening to music) are rather scarce; the role of multitasking in this context was first considered in recent studies on potential activities while riding in an AV (Fraedrich et al., 2016, Wadud and Huda, 2019, Kyriakidis et al., 2015). A recent study conducted by Malokin et al. (2019) analyses for the first time the direct effect of activities conducted while commuting, on mode choices using revealed preference data. The authors derived implications for automated vehicle scenarios from the results. They suggested that in the long run, automated vehicle technology will potentially increase the feasibility of activities while travelling as well as improve mobility and accessibility which could become a threat for public transport and reinforce urban sprawl (Malokin et al., 2019, Mokhtarian, 2018). Another recent study conducted by Molin et al. (2020) addressed the impact of the ability to perform activities while travelling on the VTTS for public transport. The study provides an empirical evidence that the ability to conduct a preferred activity reduce the VTTS and that the values depend on trip purpose. A reduction in the value of time of around 30% was found for commuters and of almost 50% for leisure travellers who prefer to read during the trip (Molin et al., 2020). The authors suggest that similar research questions can be addressed also in the context of AVs using the methodological approach proposed in their paper.

Second, travel experiences or the intrinsic utility of travel is conceptualized and explored in several research works considering, among others, the affective evaluation of travelling and the relationship between subjective well-being and travel behaviour. An overview of relevant concepts related to travel experiences can be found in Singleton (2017). Research in this area suggests that besides instrumental factors, emotions or non-instrumental factors related to travelling also affect mode choices (Steg, 2005, Singleton, 2018, Singleton, 2017). Two complementary research areas provide theoretical and empirical insights on the role of non-instrumental aspects on travel time evaluation and mode choices: (i) research on different motives behind using a certain mode of transport, especially those that focus on car use motives (Steg, 2005, Steg et al., 2001) and (ii) works which focus on the subjective well-being and travel (Mokhtarian, 2019).

Research on car use motives suggests that using a car not only fulfils instrumental functions (e.g. flexibility, door-to-door mobility), but also has an important affective (e.g. enjoyment of driving) and symbolic (e.g. communication of status) function (Steg, 2005). The theoretical basis for this research is the theory of material possessions by Dittmar (1992), which suggests that material possessions, such as cars, also represent non-instrumental values. Steg (2005) found in her research that commuting related car use is more strongly related to affective and symbolic motives than to instrumental ones. Analysing the effect of underlying motives for car use on choosing an AV, can not only explain preferences for autonomous driving over manual driving, but can additionally provide insights into differences in the preferences for a privately-owned AV over a shared one. For instance, Riegler et al. (2016) used this differentiation of car use motives to analyse preferences for carsharing services and in particular to what extent shared vehicles can also fulfil non-instrumental car use motives.

Subjective well-being as a psychological concept encompasses hedonic (experience of happiness and pleasure) and eudemonic (experience of the meaning of life and personal growth) aspects and it is recognized to be linked to travel behaviour (De Vos et al., 2013, Mokhtarian, 2019). In the context of travelling and autonomous driving, the travel-related experiences (i.e. the hedonic aspect of subjective well-being) might play an important role. This is because an increase in convenience and comfort are among the most important advantages of AVs, from the user perspective, besides time utilization (Pakusch et al., 2018b). The role of travel experiences on the evaluation of travel time and travel time satisfaction as well as the role of individual and contextual characteristics is explored in previous works mainly focussing on commuting trips. Travel experiences are found to be important for mode choices and travel satisfaction in the context of both public transport (Jain and Lyons, 2008, Ettema et al., 2012) and, as mentioned above, car use (Steg, 2005, Ettema et al., 2013). For instance, commuting time is found to be, in certain cases, perceived as a 'gift', i.e. an important transition time between home and work, rather than a burden (Jain and Lyons, 2008). Also, long distance travel with young children is reported to be perceived as quality time with the family (Price and Matthews, 2013). Considering the eudemonic aspects of traveling by car, the enjoyment of driving itself, can be discussed as a part of people's opportunities for development; an aspect which is also mentioned in the official report of the German Ethics Commission for Automated and Connected Driving (BMVI, 2017b). It might have the opposite effect on the willingness to use an AV or the perception of travel time in an AV to hedonic aspects of autonomous driving, such as stress relief.

The two elements of the affinity for travel, activities while travelling and the utility of travelling itself (or by a certain mode of transport), can be linked, to a certain extent, to the empirical insights from the user acceptance studies on the potential benefits of autonomous driving presented in section 3.1. From the perspective of research on the positive utility of travel, the feasibility of activities while travelling and the improved travel experiences (e.g. increased comfort, stress-free driving) are elements of the travel time utility of autonomous driving. From the perspective of research on user acceptance they are determinants of the willingness to use an AV. In section 3.1, a strong focus was placed on the desirable activities, so this section will explore more deeply the link between well-being and travel as well as its implications for autonomous driving. Considering the relationship between travel and well-being, previous empirical studies have reported a higher perceived stress level for commuters travelling by car than travelling by any other mode of transport – even though mode-specific stressors were taken into account for all modes of transport, such as the walking time to public transport (Legrain et al., 2015). Along these lines, Singleton (2017) found that travel experiences (in terms of travel subjective well-being) are, beside the travel activities performed on-board, an important determinant of the travel time utility for commuting trips and that activities are rather performed to pass the time than being productive. Based on these insights and empirical evidence from the literature (mainly user acceptance studies in the context of AVs), Singleton (2018) suggests that, in the context of autonomous driving, elements of subjective well-being such as increased comfort and stress-relief while travelling will play a more important role than travel-based multitasking or productive time use. Overall however, the relationship between time perception in an AV and satisfaction with travel or the travel experiences has only been postulated theoretically (Singleton, 2018, Mokhtarian, 2018).

Moving further from travel time use to considering the allocation of a daily time budget for different activities, further model developments in the context of autonomous driving consider the potential re-scheduling of daily activity plans. For instance, Pudāne et al. (2019) have adopted a time-geography approach and time activities or time use perspectives for understanding future time allocation. Following the arguments also mentioned in the context of the positive utility of travel above, the authors stress the importance of separating satisfaction with travel and on-board activities, as both have different sources and will potentially affect travel time perception and rearrangements in daily activity patterns differently. In a related work, Pudāne et al. (2018) propose a modelling framework for capturing the effect of being able to perform on-board activities in an AV on time use and travel behaviour. The model considers not only the altered travel time utility, but also accounts for a possible transfer of activities in an AV, which in turn could change daily time use and travel patterns. The developed model is in line with time allocation theories and allows for the exploration of the effects of multitasking behaviour (such as potential daily activities rescheduling) which are overlooked in other studies. The potential re-scheduling of daily activities in the era of AVs is also explored in a study conducted by Das et al. (2017), where time-use survey data are utilized in order to analyse any potential changes in the time use of selected user groups of AVs. Although potential changes in daily time use patterns are not the focus of the analysis in this thesis, these are still an important part of the discussion on the broader or long-term impact of the availability of conducting other activities while travelling in an AV, on travel behaviour.

In summary, existing theoretical concepts which address the positive utility of travel, provide a conceptual base for explaining changes in time use and time perception in the context of vehicle automation and have a strong link to user acceptance research. Two elements of travel affinity are considered to change due to vehicle automation: (i) the feasibility of the activities while travelling and (ii) the travel experiences. Although there is a strong relationship between both, it is recommended to consider them as two distinct aspects. The literature so far suggests that the improvement of the travel experiences, i.e. affective elements of travelling, due to autonomous driving, will be more likely to reduce VTTS for an AV and therefore be an important determinant of the willingness to use an AV rather than a productive time use. However, this assumption is based on conceptual considerations and results from existing literature on currently available modes of transport or user acceptance studies in the context of AV, so there is a need for quantitative empirical works on the topic.

3.4 Research needs related to the value of travel time savings and user preferences for autonomous driving

The above overview on the state of the art and knowledge on user preferences and the VTTS for autonomous driving shows that different approaches have been used to address the topic and first insights into how vehicle automation might change the mode choice as well as the (potential) reasons for this. However, first, no consensus has been reached about the size and direction of VTTS changes for AV users compared to the VTTS for car drivers. Second, few empirical works have been published on the VTTS. Moreover, the existing studies focused strongly on specific use cases (e.g. commuting trips) or concepts of AVs (e.g. SAVs) as well as user preferences, once automated vehicles become available in the market. Third, the potential determinants of the willingness to use AVs are addressed in several (mainly) user acceptance studies. The effects of various factors (e.g. feasibility of activities during a trip in an AV, improved travel experiences and trust in the technology) on travel time perception or valuation is often discussed in the studies. However, it has not yet been measured or quantified empirically. Also in general in the transportation research field, the effect of individual characteristics, such as attitudes and perceptions is often studies in relation to mode choices (e.g. Golob, 2001, Johansson et al., 2006, Kamargianni and Polydoropoulou, 2013, Paulssen et al., 2014), but there is little research on the effect of such factors on the value of time (Abou-Zeid et al., 2010, Glerum et al., 2014, Thorhauge et al., 2019, Li and Kamargianni, 2020) and none of these studies is in the context of AVs.

Therefore, the topic should be further investigated by measuring, analysing and explaining the effect of autonomous driving on the VTTS to provide empirical insights that contribute to developing more differentiated scenarios concerning the impact of the technology on the travel demand.

Finally, the above overview suggests that combining the theoretical approaches described in this chapter in interdisciplinary research on how autonomous driving impacts time perception and mode choices is a promising research path, as many overlaps exist in the concepts; hence, they are partially compatible and complementary.

4 Focus of the thesis and addressed research questions

This thesis focuses on measuring and explaining the VTTS for autonomous driving. The first topic – the measurement of the VTTS for autonomous driving – is an important part of analysing the impact of vehicle automation on travel behaviour, as the estimated values can be used as an input for existing travel demand models. The second topic – explaining the potential VTTS changes – explores individual mode choice decision processes in more detail for new mobility options, such as AVs, and explores potential sources of heterogeneity in user preferences and the VTTS. Thus, the main contribution of the thesis is first to provide empirical insights into changes in user preferences due to vehicle automation. Second, it explains differences in user preferences depending on various factors and thus provides a basis for more differentiated scenarios concerning the impact of AVs.

Two different use cases of autonomous driving are addressed in the thesis: PAVs and SAVs. For SAVs, differences between preferences for individual usage of such vehicles and usage in a ride-sharing arrangement were analysed.

The following research questions guide the work within the thesis:

RQ1: How might autonomous driving change the VTTS for cars, and which (psychological) factors explain these changes? *(This relates to an explorative analysis of the VTTS for autonomous driving and their determinants.)*

RQ2: What is the effect of autonomous driving on the VTTS? *(This relates to the measurement of the VTTS for autonomous driving.)*

RQ3: How strong is the effect of selected factors, including the trip purpose and individual characteristics, especially psychological factors, on potential changes in the VTTS for autonomous driving? *(This relates to the analysis and quantification of the effect of selected factors on the VTTS for autonomous driving.)*

While RQ1 has a strong exploratory character, RQ2 and RQ3 aim to quantify the effects of autonomous driving on VTTS and of various (psychological) factors on the travel time valuation by the users. The three research questions build on each other: the potential changes in the VTTS and the determinants addressed in RQ1 are operationalised in RQ2 and RQ3. Moreover, sources of potential heterogeneity in user preferences and the VTTS found when addressing RQ2 are analysed when addressing RQ3. The research questions were thus addressed in three different, linked studies.

Note that when the first two studies of this thesis were conducted, empirical research on the topic was in its infancy, with few explorative qualitative or quantitative studies on the topic. In the last two to three years, the number of published studies on the VTTS for autonomous driving has increased. However, the insights derived from the empirical studies described in this thesis are an important input for existing models[1] for forecasting travel demand and useful additional sources for explaining changes in the value of time for autonomous driving.

[1] The data from one of the quantitative studies conducted in this thesis is utilized in several research projects of the Institute of Transport Research at the German Aerospace Center (DLR) for model-based simulations and scenarios related to the impact of the introduction of AVs.

5 Methodology

Both qualitative and quantitative methods have been applied in this thesis to measure, analyse and explain potential changes in the VTTS for autonomous driving compared to manual driving. In psychology or social science, qualitative and quantitative methods are often discussed as alternative approaches that follow different paradigms, have their strengths and weaknesses as research methods and are suitable for (slightly) different types of research questions (Todd et al., 2004, Lamnek, 2005). While quantitative research focuses on measuring a specific phenomenon, qualitative methods aim to understand it. Both approaches and the insights gained from them can therefore stand alone. However, an increasing number of researchers recognise that combining both methods is beneficial for several reasons (Todd et al., 2004, Brannen, 2017).

In this thesis, both types of research were combined for the following reasons: first, the two methods were used to explore different levels of the same phenomenon - why and how mode choices and the value of time might change (i.e. the underlying mechanisms) and how these changes manifest in the choices of individuals in terms of quantitative (measured) empirical evidence. Second, the qualitative study was used partly as a pilot study that supported the development of hypotheses and the questionnaire design used in the quantitative part of the thesis. Particularly, as the study also focused on psychological factors that affected mode choices and the value of time, the qualitative study explored which psychological constructs were most relevant to the quantitative part of the work and supported their operationalisation in psychometric scales.

5.1 Overview of the methods applied in the thesis

Table 2 overviews the methodology used to address this and the research focus on a single study level. All three studies in this thesis provide stand-alone insights on complementary aspects of the value of time for AV users. Thus, they provide a strong argument for combining qualitative and quantitative methods when analysing complex processes from a user perspective, especially for novel topics, such as autonomous driving.

Table 2: Overview of the studies with focus of the study and applied methods

Study Nr.	Focus of the study	Methods
Study 1	Exploration of potential determinants of the value of time for autonomous driving	• Focus group discussions with potential AV users (sample size: N=21) • Thematic qualitative test analysis using deductive-inductive category construction
Study 2	Measurement of value of travel time savings for autonomous driving	• Stated preference online survey (sample size: N=485) • Discrete choice model (Mixed Logit Model)
Study 3	Analysis of the effect of psychological factors on the value of travel time savings for autonomous driving	• Stated preference online survey including measurement of attitudes and perceptions (sample size: N=484) • Discrete choice model (Mixed Logit Model, Hybrid Choice Model)

The following sections provide a brief overview of the applied methodology approaches and how they build upon each other, while in each chapter dedicated to one of the three studies, the corresponding methodology is described in detail. In the parts that describe the quantitative study methodologies, I describe the theoretical modelling framework in detail: while all analyses follow the same theoretical framework and thus build upon each other, depending on the focus of the analyses, different extensions of the basic model were applied.

5.2 Explorative qualitative study on potential determinants of the value of time for autonomous driving users

Study 1 focuses on exploring the elements and determinants of the value of time for autonomous driving in comparison to manual driving. For this purpose, three (structured) focus group discussions with potential users of autonomous driving were conducted in Berlin, Germany.

Focus group discussions, as a qualitative research method for the empirical social sciences, are suitable for user acceptance analyses, such as exploring evaluation and perception patterns as well as decision-making processes for new (not yet available on the market) technology (Schulz et al., 2012). In contrast to individual interviews, opinions expressed in focus group discussions are assumed to represent typical argument patterns and attitudes among the participants that might be applied to broader population groups (Littig and Wallace, 1997). Overall, the focus group discussions rely on valuable group dynamics that positively influence engagement and readiness to share opinions on a certain topic (Schulz et al., 2012). For these reasons, the conducted focus group discussions represented a suitable technique to build hypotheses on potential changes in the value of time for autonomous driving compared to manual driving and their determinants or in general to explore potential preference changes once AVs become available in the market. Generally, the focus group discussion conducted in Study 1 included two parts: in the first part, the current travel behaviour of the participants was discussed and in the second the potential preferences and behaviour in the presence of AVs.

Two different concepts of autonomous driving were considered in this and all further studies – privately-owned as well as shared automated vehicles – although the focus group discussion did not contain a detailed description of the differences between the two use cases. An AV was defined as a vehicle that can drive autonomously, where the system can take over control of the vehicle so that the vehicle user is not required to focus on the traffic, steer, or brake, allowing them to use the travel time for other activities. Based on this description, different pictures of AV concepts were provided to the study participants, who were asked to choose and reflect on the one that best represented a desirable concept of autonomous driving for their daily life.

The data was analysed using thematic qualitative text analysis according to a procedure proposed in the literature using a deductive-inductive category construction (the applied methodology follows an approach described in Kuckartz, 2016). The text was categorised based on literature hypotheses and simultaneously enhanced with new information that appeared during the discussion. The analyses focused on the determinants and elements of the positive utility of travel, comparing insights on the (dis)utility of manual driving (discussed in the first parts of the focus group sessions) and the (dis)utility of autonomous driving (discussed in the second parts of the sessions). Hence, the study explored both the potential benefits of autonomous driving, which were the main focus of studies on AVs from a user perspective, and the utility of manual driving, which may hinder positive assessment of the new option.

A detailed description of the approach and the insights derived from the analyses are presented in Chapter 6.

5.3 Stated preferences study for measurements of the value of travel time savings in the context of autonomous driving

Study 2 focuses on measuring the VTTS for AVs. For this purpose, two stated choice experiments were performed. The first captured user preferences for currently available modes of transport, and the second additionally captured those towards AVs that will potentially be available in the future. Thus, the study followed a similar approach to that used in the first explorative study, where the first part of the focus group discussion focused on the current mode choices and experiences, while the second part was dedicated to the evaluation and potential preference for and use of autonomous driving. The data were analysed using discrete choice models.

In this second study, again, two autonomous driving concepts were considered and presented to the study participants: a privately-owned vehicle and a shared one. The general introduction to an AV was the same as that used in the first study. Additionally, rather than pictures, two videos were presented to the respondents showing how such vehicles (a privately-owned AV and a shared AV) can be used on one (daily) trip. The storyboards of the videos as well as sample scenes of the video can be found in Annex II. The descriptions of the presented short stories in the videos are summarized also in Chapter 7 which is dedicated to Study 2.

A combination of stated choice (SC) surveys and discrete choice models for analysing the data from the surveys is the most commonly used method for estimating the value of time in transportation research (Ortúzar and Willumsen, 2011). Therefore, this approach is suitable for estimating potential changes in the VTTS for autonomous driving for two reasons. First, it allows estimated values to be compared with existing ones and second, the model estimations can be used as an input for existing travel demand models.

It is noteworthy that stated choice (SC) survey is, besides the contingent valuation and conjoint analysis, one of the most common stated preference (SP) methods. In transport research, the term 'SP' has been used when referring to either conjoint analysis or stated choice survey without a formal distinction (Ortúzar and Willumsen, 2011, Ortúzar and Garrido, 1994). Hence, in the thesis, 'SP' and 'SC' are used as synonyms.

SC surveys and discrete choice models were used in both quantitative studies conducted within the thesis. Although the method is also described in the corresponding scientific papers included in this thesis, it is important to present here the general theoretical and methodological framework and to emphasise the differences and commonalities between the two quantitative studies. This explains how the single parts of the thesis complement each other to provide a basis for a discussion on the implications of the results for travel demand modelling.

In SC surveys, the respondents are confronted with several hypothetical situations, in which they must choose between a set of alternatives with certain characteristics (Ortúzar and Willumsen, 2011). The attribute levels or values vary between the different choice situations, enabling the importance or weight for each attribute of the choice of a certain alternative to be estimated using statistical models. In this case, the choice metric is consistent with the discrete choice models that are used for such analysis. In transport research and this thesis, the SC experiments were mode choice experiments where respondents chose between different modes of transportation with certain attributes, including travel time and trip cost. To reduce the degree of artificiality of the choice situations, that is, to gain empirical insights into choices that people would make in reality, the analyst could create a decision context and alternatives that were as close as possible to the real situation of the respondents. This could be achieved, for instance, by asking the respondent to choose a mode of transport for a trip they currently make and providing alternatives with attribute levels that were close or the same as for their current mode of transport (Ortúzar and Willumsen, 2011).

In Study 2, two SC experiments were incorporated into the survey questionnaire. One focused on currently available modes of transport (walking, bike, public transport, and a conventional car), that is, on current user preferences. The second included, rather than a conventional car, an automated vehicle able to drive autonomously or manually (depending on user preference) and a shared automated vehicle. The attributes of the alternatives included travel time and trip cost (for the motorised transport modes), access or egress time (for the public transport), waiting time (for public transport, PAV and SAV) and an attribute indicating whether the shared automated vehicle was used individually or whether the ride was shared with other users. All respondents faced eight decision situations per SC experiment. The choices and corresponding attribute values for the alternatives as well as selected socio-demographic characteristics of the respondents are the data basis for estimating the discrete choice models.

The most commonly used theoretical paradigm for generating discrete choice models – also base for the quantitative studies in this thesis – is the random utility theory (Thurstone, 1927, McFadden, 1973, Ortúzar and Willumsen, 2011). It postulates that individuals who belong to a given homogeneous population Q, has information about all alternatives in a certain choice set A = (A_1,.., A_j,..., A_N) which they face and act rationally choosing the option which maximizes their net personal utility subject to all kinds of constraints, such as for instance budgetary (time and money) constraints. Consequentially, the individual q will choose the maximum-utility alternative, i.e. the alternative A_j among the choice set A (q) if, and only if $U_{jq} \geq U_{iq}$, $\forall A_i \in A(q)$ (Ortúzar and Willumsen, 2011).

As the modeller does not have the information about all aspects/elements considered by the individual during the decision process (and the choice-maker does not possess complete perfect information about the alternatives), the modeller assumes that the utility U_{jq} is a random variable composed by two elements: (i) a representative part V_{jq} which is a function of measured and known characteristics X_{jq} ($V_{jq} = \sum_k \theta_{kj} X_{kjq}$) and (ii) a random component ε_{jq} which accounts for all decision-relevant aspects which are not explicitly known (and ignored) by the modeller. Assuming additive linearity, the expected utility can be expressed as follows:

$$U_{jq} = V_{jq} + \varepsilon_{jq} \tag{1}$$

Since the utility is treated as a random variable, it is not possible to establish which alternative will be chosen, but can only compute the probability for individual q choosing A_j which can be expressed as:

$$P_{jq} = Prob(U_{jq} \geq U_{iq}, \forall A_i \in A(q)) \tag{2}$$

Assuming that the residuals are random variables with a certain distribution, i.e. certain density function $f(\varepsilon) = f(\varepsilon_1, \ldots, \varepsilon_N)$, P_{jq} can be written as:

$$P_{jq} = \int_{R_N} f(\varepsilon) d\varepsilon \tag{3}$$

Different discrete choice models can be generated depending on the assumptions that are met regarding the distribution of ε (Train, 2009, Ortúzar and Willumsen, 2011).

The simplest and most commonly used discrete choice model is the multinomial logit (MNL) model (Domencich and McFadden, 1975). This model is generated assuming independent and identically distributed (IID) Extreme Value Type 1 error terms. In this case, the probability of choosing alternative i is:

$$P_{iq} = \frac{e^{\lambda V_{iq}}}{\sum_j e^{\lambda V_{jq}}} \tag{4}$$

, where the parameter λ is usually normalized to one in order to cope with identification issues (Walker, 2002).

The MNL model, however, has certain limitations which the highly flexible mixed logit (ML) model can cope with (Boyd and Mellman, 1980, Cardell and Dunbar, 1980, Train, 2009). In particular, the ML model allows for '*random taste variation, unrestricted substitution patterns, and correlation in unobserved factors over time*' (Train, 2009). In Study 2, using an ML allows for considering preference heterogeneity among the respondents, i.e. taste variation, and the correlation across choices of one person in the sample (representing the fact that one person faces eight decision situations in each SC experiment). The probabilities in the ML can be expressed as an integral of standard MNL probabilities L_{iq} over the density of a set of parameters β (Train, 2009):

$$P_{iq} = \int L_{iq}(\beta) f(\beta) d\beta \tag{5}$$

As we observe more than one response by a person in the study (one respondent faces eight decision situations), conditional on β the probability that the person q makes this sequence of choices is the product of the logit probabilities of each of his/her choices t (Train, 2009):

$$L_{iq} = \prod_{t=1}^{T} \left[\frac{e^{\beta X_{iqt}}}{\sum e^{\beta X_{jqt}}} \right] \quad (6)$$

The modelling procedure in Study 2 includes two analysis steps. In the first step, two distinct ML models were estimated - one with the data from the first SC experiment (i.e. the data on current user preferences) and another with the data from the second SC experiment (i.e. the data on user preferences related to alternatives available in the future, including AVs). In the second step, a joint model based on the data from both experiments was estimated using a similar technique as used for estimating revealed (RP) and stated preference (SP) data simultaneously (Cherchi and Ortúzar, 2011, Ortúzar and Willumsen, 2011). This technique allows comparing parameters for the alternative´ attributes from both experiments (i.e. user preferences related to currently available and future available alternatives) directly and therefore, analysing potential mode choice preference changes due to the availability of AVs in the choice set. Finally, the VTTS for all modes of transport, including the AV concepts, is established (in euro per hour) using the estimated time and cost parameters:

$$VTTS = \frac{\partial U_i / \partial TT_i}{\partial U_i / \partial TC_j} = \frac{\beta_{Time,i}}{\beta_{Cost,j}} \quad (7)$$

The detailed description of the study design, set up and the modelling procedure as well as the insights from the study are presented in Chapter 7.

5.4 Stated preference study for analysing the effect of psychological factors on the value of travel time savings for of autonomous driving

The focus of Study 3 is the analysis and quantification of the effect of selected psychological factors on VTTS in the context of autonomous driving. Particular, the effect of (i) expected travel experiences in an AV besides activities conducted during travelling in an AV and (ii) trust in the AV technology were measured. Study 3 builds upon the Study 1 and Study 2 in two ways: first, it uses the same SC experiment as used in Study 2 (however, only the one that includes future available modes of transport) to measure VTTS. Also, it uses the same videos to present the concepts of a PAV and an SAV to the respondents, but with some improvements in the presentation of the SAV use cases (see Annex II). Second, it tests hypotheses about the effect of selected psychological factors on the value of time for AVs found in the explorative study (Study 1). In other words, in contrast to Study 2 which quantifies the differences in the travel time valuation depending on whether people would like to ride autonomously or drive manually, Study 3 focusses on analysing the reasons behind these differences.

In Study 3, the addressed psychological constructs trust in an AV and travel experiences were operationalized using psychometric scales. Psychometric scales have been developed to measure psychological construct, such as attitudes and perceptions. The scales are usually a collection of items or short statements which aim to reveal the level of an underlying theoretical construct or variable (DeVellis, 2016). A widely used technique, also applied in this study, is the Likert scale (Likert, 1932) where the items are presented as statements following by a responds options indicating the degree to which the respondent agree with the statement (DeVellis, 2016). The simplest original scale proposed by Likert (1932) is a five point scale. The author compared it with a seven-point scale and found benefits for using the simpler one, including almost identical results as with the seven-point scale. In some studies, also six-point scale is used (avoiding the middle or undecided value) which has the benefit of finding the trend expression of a particulate construct clearer. In Study 3, the most commonly used five-point scale was applied to measure trust in an AV. Anticipated travel experiences were measured instead using a semantic differential (description of this technique of measurement can be find in Osgood et al., 1957). Developing new scales in terms of items which measure a certain psychological factor is a challengeable task. Thus, it is recommendable to use already existing and tested scales to measures well know constructs in order to ensure the quality of the instruments (i.e. instruments that meet quality criteria, such as reliability and validity). Consequentially, in Study 3, both psychological constructs were operationalized relying on existing scales from the literature.

In Study 2, only directly measurable determinants of mode choices were considered, such as alternatives´ characteristics (including travel time, cost) or individual characteristics (including possession of a driving license, public transport pass). Thus, an ML model is a suitable method to analyse the effect of these factors on the individual choice. Psychological constructs, such as anticipated travel experiences and trust in the AV, on the other hand, cannot be directly observed or quantified. Therefore, an expended discrete choice framework is needed to address them when modelling mode choice with these variables as determinants.

The hybrid choice model (HCM), or also called integrated discrete choice latent variable (ICLV) model, enhances the basic Random Utility Model (RUM) framework and allows to (i) include explicitly latent (not directly observable) psychological constructs in the model, (ii) to consider heterogeneity and (iii) to model latent segmentation of the population (Ben-Akiva et al., 2002, Walker and Ben-Akiva, 2002). Figure 2 shows the generalized framework of the HCM with selected extensions of the basic discrete choice framework. The vertical axis of the figure represents the structure which was used also in Study 2: (selected) observable explanatory variables influence the decision process and lead to the stated choices of one of the alternatives in the experiment. The extensions of this model include (i) incorporating latent psychological variables as explanatory variables (latent variables) and (ii) considering latent segmentation (latent classes). In Study 3, the first mentioned extension was used to quantify the effect of the selected psychological factors on the user preferences for AVs.

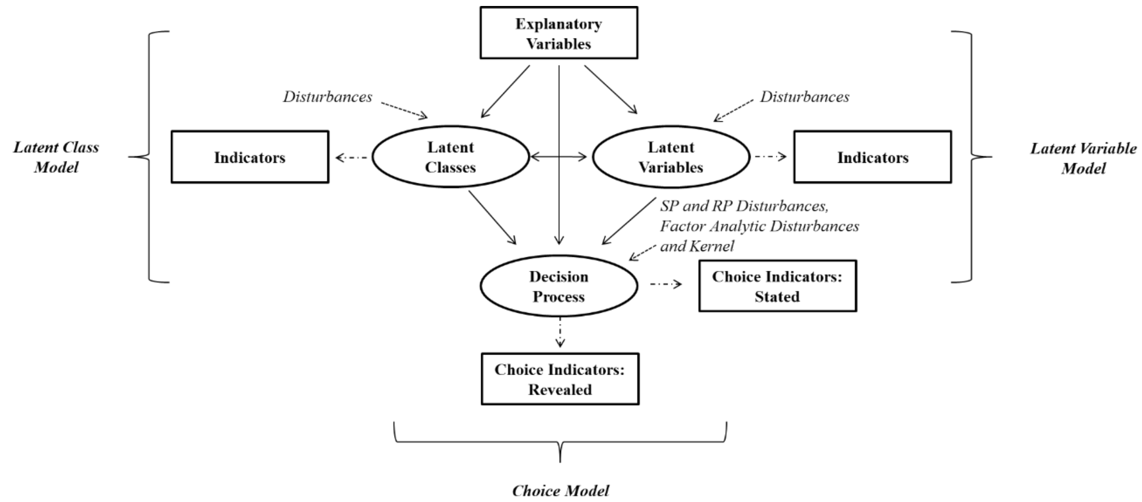

Figure 2: Hybrid Choice Model (follows Walker and Ben-Akiva, 2002)

By adding latent variables as explanatory variables to the model, the measurable part V_{iq} of the utility function described in equation 2 becomes:

$$V_{iq} = \sum_k \theta_{ik} X_{ikq} + \sum_l \tau_{il} \eta_{ilq} \quad (8)$$

, where η_{liq} are latent variables, X_{ikq} are objective attributes, θ_{ik} and τ_{il} are parameters to be estimated; the index i refers to an alternative, q to an individual, l to a latent variable, k to an objective attribute (Ortúzar and Willumsen, 2011).

Latent variables (LVs) cannot be directly measured as other variables, such as time, cost or age, but information about them can be inferred from observable (measurable) indicators using a Multiple Indicator Multiple Cause (MIMIC) model (Bollen, 1989). These indicators can be the answers on questions in a survey that capture attitudes or perceptions (or items from a psychometric scale), such as those used to operationalize the selected psychological factors in Study 3.

In the MIMIC model, the latent variables η_{liq} are explained, on the one hand, by observed explanatory variables s_{riq} (e.g., characteristic of the individual or of the alternative; r) through structural equations (Equation 9). On the other hand, η_{liq} explains the indicators I_{ipq} through measurement equations (Equation 10) (Ortúzar and Willumsen, 2011, Bahamonde Birke, 2016).

$$\eta_{ilq} = \sum_r \alpha_{ilr} s_{iqr} + \nu_{ilq} \tag{9}$$

$$I_{ipq} = \sum_l \gamma_{ilp} \eta_{ilq} + \zeta_{ipq} \tag{10}$$

The α_{ilr} and γ_{ilp} are parameters to be estimated (the index *r* refers to an explanatory variable and *p* to an indicator); ν_{ilq} and ζ_{ipq} are error terms following any distribution (ν_{ilq} is usually assumed to be Normal with mean zero and a given covariance matrix; the distribution of ζ_{ipq} depends on the assumptions regarding the indicators). Both equations are considered in the modelling process jointly as η_{ilq} is unknown (Ortúzar and Willumsen, 2011).

The joint likelihood function for the HCM can be expressed as follows:

$$L = \int_\eta P(I \mid X, \eta; \alpha, \gamma, \varsigma, \upsilon) \cdot P(y \mid X, \eta; \alpha, b, \varepsilon, \nu) \cdot f(\eta \mid X, \eta^*; \alpha, \nu) d\eta \tag{11}$$

The above presented description of the HCM overviews the general characteristics of this type of choice model. In this thesis, however, an extended model specification was used. The aim of Study 3 was to analyse the impact of several LVs on the value of time. Therefore, parameters for the interaction between the LVs and travel time were estimated instead of parameters for the direct effect of LVs on the stated mode choice. The detailed description of the model specification can be found in Chapter 8.

Lastly, although the latent class (LC) model was not used in the thesis, it is worth to be described briefly together with its potential application in the context of autonomous driving. The LC model captures - as the mixed logit and the latent variable model – taste heterogeneity, but assumes that the population can be divided into discrete (unobservable) segments of decision makers (Walker and Ben-Akiva, 2002). These segments differ in their preferences or perceptions and exhibit therefore different choice behaviour. For instance, if we are interested in the travel time evaluation differences, we can estimate time parameters assuming to be class-specific. A detailed description of the theoretical differences between the ML model and the LC model can be found in Greene and Hensher (2003) and Hess (2014). In the basic version of the LC, the class allocation probabilities are assumed to be constant across individuals, but they can be also linked to characteristics of the individuals (Kamakura and Russell, 1989, Gupta and Chintagunta, 1994, Hess, 2014). In the latter case, two models have to be estimated – a class-specific model and additionally a class membership model that defines the probability belonging to a class depending on individual characteristics (including for instance latent variables; see examples in Walker and Ben-Akiva, 2002, Hess et al., 2013). In the case of user preferences for autonomous driving, we can define different segments depending on, for instance, attitudes towards AVs or level of trust in the technology. This allows on the one hand, similarly to the latent variable model, for considering the effect of psychological factors on user preferences and VTTS (only in a different manner). On the other hand, similarly to the mixed logit model, it allows for considering taste heterogeneity in the population, but in this case considering the differences between pre-defined latent classes. Such model was not applied in the thesis due to its complex structure when considering the effect of more than one latent variable on VTTS.

Chapter 8 of this thesis is dedicated to the detailed description of the study set up and the modelling procedure as well as the insights from Study 3 regarding the effect of the selected psychological factors on mode choice and VTTS.

6 Exploration of potential determinants of the value of time for autonomous driving

'It used to be said that a man's home is his castle, in deference to the fact that at home one feels more secure and in control than anywhere else. But increasingly in our culture it could be said that a man's – and especially a woman's – car is the place where freedom, security, and control are most deeply experienced.'

Mihaly Csikszentmihalyi, 1996
'Creativity: flow and the psychology of discovery and invention', New York: Harper Collins.

How will autonomous driving change the meaning of the car and the perception of time spent in a vehicle in the future?

In the introduction to the thesis, I briefly summarised the main arguments from the literature discussions regarding the effects of autonomous driving on mode choice preferences and the value of time. Vehicle automation is expected to enable other activities to be undertaken while riding more comfortably, which will potentially increase the attractiveness of using a car. However, the above quote highlights that in our society and culture, the car has a meaning, function and personal value that transcend its technical features, driving skill requirements and its role as a mode of transport. Specifically, driving or using a car also represents a certain utility for the users. Focusing only on the disadvantages of the driving task, which can be removed using an AV system that manages them, might therefore be insufficient to explain the potential changes in user perception and evaluation of an AV. Returning to the above quote, one might ask, for instance, how the experiences of freedom and control change when we can ride autonomously, as relinquishing control of the vehicle to the system is the main purpose of autonomous driving. Moreover, do the benefits of being able to perform other activities and having less driving-related stress outperform the value that users place on driving a car or the enjoyment that some experience when driving?

The following paper, **'Exploring the elements and determinants of the value of time for manual driving and autonomous driving using a qualitative approach',** addresses the potential changes that vehicle automation might impose on mode choices and travel time evaluation by comparing manual driving today with autonomous driving in the future from a user perspective. For this purpose, an explorative qualitative study was conducted.

The results of the study provide deeper insights into the evaluation and decision processes of potential users regarding autonomous driving and suggest that certain characteristics of manual driving today might partially counterbalance the potential benefits of vehicle automation. The value of time for an AV from a user perspective is currently strongly related to the value of time for a conventional car. Moreover, the analyses show that context- and individual-related characteristics shape this effect. These results, together with those obtained from an extensive literature review, provide a conceptual basis for measuring and analysing the changes in the VTTS for autonomous driving observed in the studies described in this thesis.

Exploring the elements and determinants of the value of time for manual driving and autonomous driving using a qualitative approach

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Abstract

Autonomous driving (AD) is expected to change significantly individual travel behavior. Main postulated reason behind is an increase in comfort and feasibility of on-board activities which will potentially change the way people perceive time spent in a vehicle and consequentially their mode preferences. Understanding how value of time (VoT) might change and what determines the changes can be crucial when assessing the impact of vehicle automation. Recent studies address potential changes that the automation might have on VoT based on analyses of time use and perception in current modes of transport or focusing only on the utility of driving autonomously. However, there is a lack of research addressing both – the utility of car driving compared with the utility of riding autonomously from user perspective. To address this research question, focus group discussions with car driver were conducted. The data was analyzed using a thematic qualitative text analysis. The results suggest that the utility of car driving today, including aspects of driving pleasure, various (passive) activities performed in the car and also the driving as an activity itself will counterbalance to a certain extent the effect of the benefits of AD, such as improved travel experiences and feasibility of activities. Moreover, context-related and individual characteristics shape these effects. This paper summarizes the main study results, including potential short and long term travel behavior changes resulting from the availability of AD. Lastly, implications from the qualitative research for quantitative studies on value of travel time savings for autonomous vehicles are discussed.

Keywords: autonomous driving, car driving, value of time, positive utility of travel, travel behavior, focus group discussions, qualitative approach

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6.1 Introduction

The rapid technological advancement in the recent two decades has led to ever increasing automation in all areas of daily life, including transportation. Autonomous driving might soon become reality due to the advanced automation functions of road vehicles and digitalization trends which change not only the technical characteristics of cars, but also enables new use and business cases, such as vehicles on demand. From the technical perspective, vehicle automation is classified in five levels ranging from no automation (level 0), through low or partly automation (level 1 and 2), conditional automation (level 3) and high (level 4) to full automation, i.e., driverless vehicles (level 5) (SAE, 2018). The highest level of automation enables additionally new mobility services, so-called “shared automated vehicles” (SAV), which will potentially be similar to current carsharing or taxi services, but operating without a driver (Lenz and Fraedrich, 2016).

Understanding preferences in the context of autonomous driving gains an increasing attention in the literature as potential modal shifts toward individual motorized transport and change in travel behavior patterns can result in an increase of vehicle kilometers travelled and related transport issues (Bahamonde Birke et al., 2018, Trommer et al., 2016, Childress et al., 2015). Two reasons are mainly discussed to be behind these changes - a postulated change in the value of time and access to individual mobility of new user groups. For the value of time, it is expected that vehicle automation will allow people to take their hand of the steering wheel and potentially shift their attention to other activities while travelling in a more comfortable way and consequentially make using a car more attractive (Trommer et al., 2016, Anderson et al., 2014). Regarding this aspect, the research goes in two directions – (i) estimating the changes in value of time and (ii) analyzing the reasons behind potential changes, in particular analyzing the elements of the positive utility of autonomous driving (a comprehensive literature review can be found in Kolarova et al., 2019).

The concept of value of time (VoT) or the value of travel time savings (VTTS) is one of the most often used concept in transportation - it reflects the assumption in microeconomic theory that people make transport decisions in the context of constrained time budgets. Consequentially, they have to choose whether they spend their time on one activity or another, and also how much they are willing to pay to save time spent on a particular activity (Hensher, 2011), in this context for saving travel time (Jara-Diaz, 2000). In the context of autonomous driving, it is reasonable to assume a potential reduction in the VTTS due to the improved travel quality and time use. Empirical studies on VTTS in the context of autonomous driving found indeed a reduction of VTTS for autonomous driving, however, they differ between automated vehicle (AV) concepts (e.g. privately-owned vehicle compared to car sharing; Steck et al., 2018), trip types (lower for commuting and long distance trips, but not for short trips; Steck et al., 2018, Kolarova and Steck, 2019, Yap et al., 2016), and vehicle design offering different opportunities for time use (office interior found to be lower than in a leisure one Correia et al., 2019). Moreover, significant heterogeneity in the value of time among potential users can be shown (Steck et al., 2018). These findings indicate that certain vehicle, context, and individual characteristics might play an important role in the evaluation of AV benefits.

Theoretical approaches which focus on explaining value of time differences suggest that different elements of the positive utility of travel shape the value of time (Mokhtarian and Salomon, 2001). According to this approach, the three elements are (i) the activities conducted at the destination, (ii) the activities that can be conducted while travelling, and (iii) the activity of traveling itself. In the context of autonomous driving, it is reasonable to assume that the utility at the destination will remain the same, while the possibility of conducting activities during the trip and the travel experiences will be affected by autonomous driving. A question arise which activities will be most desirable when driving autonomously and the weight of both aspects – travel experiences and travel activities. First studies on this topic consider the changes due to automation on a conceptual level and/or based on the relation between elements of the positive utility of travel and mode choices by existing modes of transport (e.g. Singleton, 2018, Mokhtarian, 2018). Explorative studies in the context of autonomous driving complement the conceptual works with first insights on potential time use and evaluation of AVs from user perspective (e.g. Cyganski et al., 2015, Fraedrich, 2017, Pudāne et al., 2019). A common result from these works is a suggested separation of travel experiences or the intrinsic utility of riding autonomously from the feasibility of on-board activities as well as suggested higher benefit from passive and relaxing activities in an AV than productive one. However, in general it is still a need for further research on the travel time implications of autonomous driving using both qualitative and quantitative methods to contribute understanding the complex mode choice decisions in the context of autonomous driving (Singleton, 2018, Mokhtarian, 2018, Milakis et al., 2017). One aspect barely discussed is the fact, that while autonomous driving provides certain benefits compared to manual driving, still, car driving today have also certain utility which will potentially counterbalance or diminish the benefit of driving autonomously (an aspect raised on a conceptual level Singleton, 2018, Kolarova et al., 2019).

In summary, recent studies on positive utility of time in an AV address potential changes conceptually on the basis of analysis of time perception in current modes of transport, or focus (almost) exclusively on the utility of driving autonomously. Thus, to our best knowledge, there is a lack of research addressing and comparing both – the utility of car driving and the utility of driving autonomously at once from user perspective.

The focus of this study is therefore to analyze the potential changes in the evaluation of travel time due to automation by comparing time spent in a conventional car today with anticipated time in an AV – both from a user perspective. It aims further to explore the elements of the time value and its determinants. In order to this, we choose a qualitative approach allowing to look deeper and more explorative into the complex decision-making process of potential users of the new technology. Last but not least, the study aims to derive implication for further (quantitative) research on the topic and to contribute with empirical insights to the current discussions in the literature on potential changes in time evaluation due to automation. For this purpose, this paper includes also a discussion on the implications of the insights from the qualitative research for quantitative studies on VTTS.

6.2 Methods

To address the research questions, a qualitative approach was chosen in form of focus group discussions. Three focus group discussions were conducted in Berlin, Germany. Each group consisted of 7 participants, adding up to 21 participants in total. Since the focus of the study was to compare manual driving today with riding autonomously, the sample consisted, with one exception, of car drivers. Note that in this case car drivers do not mean that the participants use only the car - many reported also using public transport or a bicycle, but their travel patterns were characterized by high vehicle kilometers travelled. All study participants were recruited using a professional service provider. Each person received an incentive of 45€ to participate in the study. Three different segments were selected due their differences in mobility-related needs – (i) urban area residents, (ii) suburban or rural area residents, and (iii) mobility constrained people (elderly and physically disabled people). Table 3 gives an overview of the characteristics of the participants presented in an aggregated level by group.

Table 3: Overview of the study sample

Group (nr. of participants)	**Residential location**	**Age**	**Gender**	**Average vehicle kilometres per day**	**Physical disabilities**
Group 1 (n=7)	all urban*	Min-Max: 27-54 Mean: 37 Median: 33	n=3 women n=4 men	Min-Max: 45-80 Mean: 53 Median: 45	all no
Group 2 (n=7)	n=3 suburban** n=4 rural	Min-Max: 22-50 Mean: 40 Median: 42	n=3 women n=4 men	Min-Max: 45-200 Mean: 76 Median: 60	n=1 yes n=6 no
Group 3 (n=7)	n=2 urban * n=3 suburban** n=2 rural area	Min-Max: 53-70 Mean: 63 Median: 62	n=3 women n=4 men	Min-Max: 30-100 Mean: 68 Median: 60	all yes

* urban= inside the “city ring” of Berlin
** suburban = outside of the “city ring” of Berlin, suburban area of Berlin

The focus group discussions were semi-structured. A common script with standardized guiding questions, session structure, and presentation of the concept of automated driving were used in order to enable better comparison of the results. Each session took about 2 hours.

The sessions were structured as follows: In the introduction part the participants had to report the mode used to reach the venue and about their usual mode use. The first part was dedicated to the (everyday) mobility of the participants and their car use experiences, including free association about car and car driving as well as detailed discussion on typical driving situations. The second part of the session was dedicated to the evaluation and potential use of automated vehicle (AV) introduced as follows: "*In general self-driving cars are (road) vehicles in which the car driver don´t need to pay attention to the traffic or to concentrate on driving and van let the car drive by itself. That means for instance, that the driver can do something else while travelling*". As next, the participants were first asked to note free associations about autonomous driving. After brief discussion, each participant received 13 pictures representing automated driving and had to choose the one which in his/her perspective best represents how he/she would use an automated vehicle. The pictures were chosen to represent different concepts of automated vehicles, trip purposes, activities performed during the trip, and vehicle sizes. Finally, a guided discussion about desirable use of autonomous driving, reasons behind, potential on-board activities, and potential changes in the (daily) mobility was performed.

All focus group discussions were video-recorded and fully (word to word) transcribed. A *thematic qualitative text analysis* was performed based on the transcripts using the software MAXQDA and following a procedure as proposed by Kuckartz (2016). A *deductive-inductive category construction* was used, i.e., the categories were formulated using own hypotheses and existing literature, but at the same time new categories were derived from unexpected elements/aspects in the data. The initial coding system followed the guiding questions. The final consolidated coding system has a strong focus on aspects which are relevant for the analyses of differences between car driving today and autonomous driving from today´s perspective and important determinants of travel time evaluation. The main findings are presented in the following section and illustrated using quotes from the discussions. The main paragraphs in the results section follow the consolidated topic categories.

6.3 Results

Before looking into the elements and determinants of the travel time perception in a conventional car and autonomous vehicle, we briefly discuss the overall utilities that a car and an AV have today for car users as they seem to shape not only the way these alternatives are perceived, but also influence strongly the travel time evaluation, i.e., the perceived quality of travel in both alternatives.

Car use and the (dis)utility of manual driving vs. autonomous vehicles and the utility of riding autonomously

The car (and car use) today – providing pleasure and flexibility, a commodity, a private space, "a partner", but also stressful and expensive

The car has a meaning for its users which goes beyond its purely instrumental function as a mean of transport, including certain affective and symbolic functions which can be even stronger motives for its use than instrumental one (Steg, 2005). In the focus groups, mostly instrumental and affective functions of the car came up in the discussion (both almost equally frequent), while symbolic or social-expressive meaning of the car as a prestige object or status symbol were rarely mentioned.

In its *instrumental function*, the car was mostly described as a commodity with main function as a convenient alternative for door-to-door mobility and as a mean for carrying stuff or people. In this sense it has been described as "practical", "useful", "necessary", "convenient", but also "expensive" and "slow" (e.g., in the city traffic). Total travel time, cost, (lack of) access to other modes of transport and accessibility of destinations, need to carrying things, comfort as well as traffic and parking situation at the destination were therefore pointed out as main instrumental motives for choosing (or not choosing) a car over other modes of transport.

In its *affective function,* the car not only enables personal mobility, but also "inspires personal mobility" (as described by one of the participants) and provides a feeling of independency, freedom and pleasure. Affective motives for car use are closely related to the evaluation of travel time in the car and will be explored in detail in the next results section.

On a decision-making level, car users seem to have different decision rules and also strategies to maintain their car choice - ranging from highly rational choices (e.g., fastest, cheapest alternative) to strong car affinity and habits.

> *"I came today with the public transport – I have a good public transport connection from my place to the venue. Otherwise I use bicycle, car at the weekend, everything – depending on the situation. Due to my partner I get to know also carsharing, so I have also a carsharing membership." (Andreas, man, 54 years old, Group 1)*

> *"I came today by car. I checked where the venue is and thought first "Finding parking spot will be hard"; also my colleagues told me "You are crazy, take the public transport!", but no – I drive a car. And I found also immediately a parking spot. It took me more than an hour to get here because of the traffic ... I drive a car since I turned 18 and the public transport is for me a nightmare. ... I am a car driver; there is no other option for me." (Birgit, woman, 46 years old, Group 2)*

Besides as a "commodity", the car is described by some study participants as an important *(living) space* – "a living room", "an office", a cozy place, a protected private space. The car as a *space* seems to have again an instrumental and an affective aspect – it can be a space for transporting goods and items, to store things needed in the everyday life, but also is associated with spending quality time with family and friends, and is a place when one feel protected from the outside, an own comfort zone.

> *"My car is a kind of living room – cozy, comfortable, music, which is impossible in the public transport. ... And what is very important for me – I can take my dog with me." (Petra, woman, 50 years old, Group 2)*

A side aspect which arise during one of the discussions was also *the relationship to the own car* – three of the participants describe their own car as "a partner/a friend" and reported to sometimes talk to it.

The autonomous vehicle (and use of AVs) from today´s perspective – a hybrid between a car and public transport, comfortable and stress relieving, time gaining, but also not trustworthy, increasing technology dependency

While there are various associations related to the car and car use today including positive and negative aspects of it, the concept of automated driving seems to be rather ambiguous in the mind of potential users – associated with skeptic and fears on the one hand and improvements and new opportunities for time use on the other. As a mode of transportation, many of the participants classified AVs between a car and a public transport. It is seen as serving some of the main functions of the car today in terms of door-to-door mobility and transportation options, but taking also the enjoinment of travel. Along these lines, potential differences are anticipated in relation to travel time aspects, but also in potential (higher) purchasing cost. As a technology, different positive (e.g., efficiency) as well as negative aspects (e.g., risk of malfunction, data privacy concerns, and liability) are attached to the meaning of an AV. A main topic discussed across all discussion in relation to this is the aspect of *trust* in the reliability of the technology.

> *"And there is a high risk that the technology has a malfunction. When I trust the technology and the computer or the system of my car has a malfunction while I think I can make a call, drink a beer or put my feet up, then it can crash somewhere." (Juergen, man, 62 years old, Group 3, hearing-impared)*

> *"It is related mainly to trust – in the technology, in the OEM ... Because at the end you put your life in their hands." (Daniel, man, 22 years old, Group 2)*

Table 4 summarizes the main discussed aspects related to the car (and car use) today compared to the autonomous vehicle (and use of AVs) from today´s perspective.

Table 4: Comparison between car (and car use) today vs. autonomous vehicle (and use of AVs) from today´s perspective

The car (and car use) today	**The autonomous vehicle (and use of AVs) from today´s perspective (effect evaluation)**
Instrumental reasons for use / non-use - door-to-door mobility - mean for carrying stuff or people - travel time - cost	*Instrumental reasons for use / non-use* - *remains the same* - *remains the same* - *remains the same (exception: access/ egress time; potential traffic efficiency increase)* - cost (-) - new travel time use opportunities (+) - efficiency (+) - data privacy concerns (-)
Affective reasons for use / non-use - feeling of independency, freedom - driving pleasure	*Affective reasons for use / non-use* - feeling of independency, freedom (-) - (takes away) driving pleasure (-) - skepticism, (lack of) trust in the technology (-) - anxiety, unfamiliarity (-)
Additional meaning / aspects - important (living) space	*Additional meaning / aspects* - *unclear effect* - concept between car and public transport (+/-)

Elements of the value of travel in a conventional car compared to an automated vehicle

Car driving today – driving pleasure vs. stress

As recognized in the literature (Mokhtarian and Salomon, 2001, Singleton, 2018), while travel experience and activities during travelling are closely related to each other, it is useful to consider them as two distinct elements of the positive utility of travel. Consequentially, we analyzed the utility of car driving and riding autonomously along these two categories.

The travel experience in a conventional car is related to the enjoyment/pleasure of driving, but also to stress in demanding driving situations. The analyses of the discussions reveal different elements of driving pleasure: enjoyment and excitement of acceleration and movement, feeling of being in control of the car/ situation/ speed/ route, but also travelling in a relaxing, comfortable way and having time for oneself.

> *"Radio on, music on ... The feeling in a car is different. I don´t stress myself when I drive; for me it is like walking – it has something meditative for me." (Mirko, man, 31 years old, Group 1)*

> *"I am a technology fan. So, for me a driving pleasure is when you know the car well and can handle it well. You have then the power over this machine, can accelerate and brake as you want to." (Yannick, man, 27 years old, Group 1)*

> *"I drive at the weekend just very relaxed, visit nice lakes, just by myself. For me it is a pure luxury, I can call a friend while driving, turn on a nice music. It is a luxury for me." (Birgit, woman, 46 years old, Group 2)*

„For me, driving to work and from work home is always a kind of relaxation. Even though the driving itself require concentration, this is the time that I have for myself." (Peter, man, 39 years old, Group 2)

In a broader since, car driving is considered by participants as providing a feeling of freedom and it is discussed as a mean of self-expression. Negative experience related to car driving is associated with stress in heavy traffic as well as other demanding driving situations, such as searching for a parking spot. These aspects were mention often by participants who live in the city and often avoid using the car because of that. On the other hand, participants who have high affinity for car use seem to develop strategies to cope with the stress in congestion.

"I belong to the people who would take 40 km detour on an 80 km trip if needed – the most important thing is that I am moving forward [instead of being stuck in traffic]." (Jacquelin, woman, 42 years old, Group 2)

Currently feasible passive activities while travelling are reported to be also important part of travelling by car and to contribute making car driving less-stressful or more productive. In fact, a range of activities is reported to be performed in the car today including listening to music or radio, making phone calls, eating and drinking, interacting with other passengers, or even learning a foreign language. Even though mainly passive activities are feasible due to the need to drive, people attach a certain value to them.

"*It can be stressful in a heavy traffic, but it is comfortable in the car. I listen to the music in the car, so it is acceptable.*" *(Mirko, man, 31 years old, Group 1)*

„I cannot afford being underway 4-5 hours without doing anything ... And I am not someone who drives with the phone in the hand – in my car, my smartphone is connected with the radio, the radio turns down and I can take up the call using a button on the steering wheel." (Jacquelin, woman, 42 years old, Group 2)

The last quote illustrates also the role of infotainment systems for enabling a range of activities in the car today, which add an important aspect to the discussion of potential new activities feasible in an AV.

Riding autonomously from today´s perspective – more pleasurable or more productive time use, stress-relief vs. loss of control and boredom

The evaluation of the time spent riding autonomously is highly affected by the evaluation of the time in a conventional car (or in other currently available modes of transportation). Loss of driving pleasure, giving up the control over the driving situation, and becoming dependent on the technology are main concerns related to the usage of an AV. While control and dependency on the technology are often mention in the context of trust in the technology, loss of driving pleasure is associated with loss of a specific enjoyment and excitement during travelling. Additionally, giving up the driving task as an activity raises concerns by some participants that travelling will become boring.

"The enjoyment of driving goes away. But the comfort remains, as a passenger then." (Yannick, man, 27 years old, Group 1)

"And then we will say like the children - "Are we there yet?"" (Mirko, man, 31 years old, Group 1)

Beside the mentioned concerns, many of the participants see also benefits from the autonomous driving, such as an improved travel experiences in terms of less stress and increased comfort (given they trust in the reliability of the technology). Also, improvement in the travel experiences seems to have a higher value for potential users than the feasibility of activities. This is reflected in the desirability level of different activities while travelling in an AV – passive or entertaining activities (such as listening to music, relaxing) are mentioned more often than productive one. Consequentially, the time spent in an

AV is anticipated to be relaxing and stress-relieving compared to travelling in a car today (mentioned as an important advantage of autonomous driving by 9 out of the 21 study participants).

> *"There is the aspect of being able to relax. Not looking at the road and paying attention to the traffic, it has something of travelling by train. The difference is the door-to-door connection." (Christiane, woman, 46 years old, Group 1)*

> *"And the advantage that I see is – when you trust the car – that you travel in a more relaxing way." (Oliver, man, 47 years old, Group 2)*

> *"I can imagine it being really relaxing, similar as in the public transport, but you are completely for yourself – you can adjust the sit according to your wishes, turn the music on; you can also sleep." (Daniel, man, 22 years old, Group 2)*

At the same time, only 4 out of the 21 respondents stated that they would use the time in an AV for working. All four associate it with tele-working in the car; main reason behind is potential saved time at the office; two of these participants have a flexible working time as both are self-employed.

> *"I see as a big advantage not having to drive the car and the possibility of accomplishing tasks which I otherwise have to do at home or at the office. So, I would turn my car into a small mobile office ... I would really try to do some work – everything for that I don´t have to be at the working place – organizational stuff and office work." (Manuel, man, 36 years old, Group 2)*

> *"Home-office is nowadays available and it is very attractive. ... Instead of 8 hours I can spent 6 hours at the office and the rest 2 hours of working time in the car." (Mirko, man, 31 years old, Group 1)*

Other participants also discussed the advantage of working in the car, but for people with business trip purposes and stated not for themselves. Moreover, there were also skeptical voices regarding the idea of working in the car:

> *"I don´t want to start working when I sit in such vehicle. No way! I have the whole day a computer in front of me at the work and I don´t need it also in the car, and at home neither." (Oliver, man, 47 years old, Group 2)*

> *"It will end up in people working even more ... And at the end we will have no free time at all." (Birgit, woman, 46 years old, Group 2)*

Motion sickness is often discussed in the literature as important limitation for performing a range of potential activities in the vehicle. In our group discussions, however, the topic was barely touched as only one of the participants stated to experience a motion sickness in the car and thus not seeing having an advantage for herself from the vehicle automation. Table 5 summarizes the discussed elements of the utility of manual driving compared to autonomous driving.

Table 5: Comparison between elements of utility of manual driving vs. autonomous driving

Elements	**Manual driving**	**Autonomous driving (effect evaluation)**
Utility of time at destination	*remains the same*	
Travel experiences	Driving pleasure – control Driving pleasure – feeling Driving pleasure – freedom Driving-related stress	Loss of control, feeling of dependency (-) Loss of excitement/feeling of controlled movement (-) Loss of freedom (-) Stress relief (+)

Travel activities	Driving – an active task Passive activities – listening to music, enjoying landscape Feasible productive activities – e.g. making phone calls	Riding – a passive task (potential boredom when not replaced with other active tasks) (- /+) Passive activities intensity – listening to music, enjoying landscape (+) Preferred activities in an AV – passive one, relax, productive only when saving working time at the office

Determinants of travel time utility in a conventional car vs. automated vehicle

Context-related characteristics, such as trip purpose or traffic situation, as well as user characteristics, such as mobility-related needs and attitudes, affect strongly both mode choices and the evaluation of the travel time. We focused the analyses on the last-mentioned aspect. Table 6 gives an overview of the main results regarding the explored determinants of travel time utility.

Table 6: Overview of determinants of travel time evaluation

Category	**Determinants**
Context - external factors or travel-related stressors - individual situation	 - traffic situation; parking situation at destination; mixed traffic of car drivers, cyclists, and pedestrians; road constructions - trip purpose, time schedule, travelling alone or with significant other
Individual characteristics - socio-economic characteristics - attitudes	 - gender *(different definition of "driving pleasure")*, age *(weak effect)* - trust *(influenced by individual experience),* desire for control over the driving situation

Context

> *"When the roads are empty, I don´t know ... I drive on Saturday to horse-riding outside Berlin, then I am more relaxed, listen to my favorite music, sing loud and then driving a car is totally different – without any stress. Whether I arrive 10 Minutes earlier or later, it doesn´t matter. And this is different on the way to work – then is horrible, this congestion." (Petra, woman, 50 years old, Group 2)*

The quote illustrates the role of two context-related aspects which affect both travel experience when driving a car today and which were mentioned often in the discussion – external factors, such as the traffic situation and individual situation, e.g., trip purpose and time pressure. Besides these aspects, also the following one were found to impact travel time evaluation in a car today during the discussions: (i) external factors or travel-related stressors – parking situation at destination; mixed traffic of car drivers, cyclists, and pedestrians; road constructions, (ii) individual situation - trip purpose, time schedule, travelling alone or with significant other.

Asked about the usage of an AV and desirable activities, many participants struggled to express a strong preference for one particular main benefit or disadvantage of autonomous driving – *"it depends on the situation".* Additionally, the role of the vehicle equipment and the potential role of the driver (i.e., level of automation) were mentioned as an important aspect.

> *"[Both are considerable – entertainment activities or work] it depends – for instance when I go on holiday, then I can imagine watching movie or so. But I can imagine preparing for my lecture when I drive to the university too ... So, both, depending on the situation. If there is an internet access, then one can do actually everything – working as well as watching movies." (Daniel, man, 22 years old, Group 2)*

"I know that some machines are not allowed to work without a supervision, so such a vehicle probably also not. One should always be ready to overtake. So, you still have to pay attention and cannot do something else which means that the time that you potentially gain with automation is lost again." (Yannick, man, 27 years old, Group 1)

Considering concrete usage scenarios, two applications of autonomous driving were often mentioned – on commuting trips (mainly because of potentially less stress in heavy traffic) and on long distance trips (also because of the relaxing aspect or because of opportunity to have intensive and quality time with the family).

"On the way to work would be nice (to have it), because then I would arrive much calmer/more relaxed at work." (Jörg, man, 70 years old, Group 3, severely-disabled by 80%)

"For longer trips would be nice so you can relax if you have eight hours drive, for instance to Munich; this is something that I can imagine very well." (Christiane, woman, 46 years old, Group 1)

Besides the usage context itself, also the drivers′ interpretation of the context and preferences seems to influence time evaluation and perception. For instance, even though stress and frustration were expressed in relation to commuting trips, being able to remain in control over the vehicle and the route was main barriers to consider riding autonomously on such trips. Here again, trust and experience with the technology mainly influence the evaluation of the AV.

Individual characteristics

Given the small sample, findings on the effect of socio-economic characteristics on time evaluation and car use motives cannot be generalized. However, the analyses of the discussions reveal some potential trends about the effect of individual characteristics.

Regarding *gender*, no notable differences can be identified regarding type of car use motives (instrumental vs. affective) between women and men. However, some differences can be found in the definition of *enjoyment of driving* – while women referred to aspects, such as feeling of freedom, sitting comfortably, enjoying road trips at the weekend - "it is a kind of luxury", men stress often the interaction with the car, excitement of speed, and the feeling of being in control/having power over the "machine". While again, these findings cannot be generalized, they indicate potentially differences in technology affinity between women and men. Considering potential time use, on the other hand, suggest that not the gender, but rather the individual situation and daily tasks influence desirability of activities. For instance, two of the persons reporting to be willing to work in the car – one woman and one man – both self-employed and with high vehicle kilometers travelled today, reported similar time use-related patterns and needs as well as preferences toward an AV. Along these lines, working time flexibility and type of occupation affect time pressure on commuting trips, commuting hours as well as feasibility of working-related activities during the trip.

Interestingly, there was no notable effect of *age* on the evaluation of car driving or automated driving. At the same time, notable differences were found depending on the *residential location* of respondents mainly shaped by availability of alternatives, accessibility of destinations and traffic situation between urban areas and less dense areas. Also, people who live in the city reported lower car dependency and attachment to the car, openness and exposure to new mobility options, such as car sharing, and were more likely to anticipate benefits of riding autonomously.

Two of the most important influencing factors on both the overall evaluation of AV and of time spent riding autonomously discussed in all focus groups were the trust in the technology and the desire for having the control over the driving situation. Trust in turn is highly dependent on *individual experience* of the participants with vehicle technologies, such as advanced assistance systems (ADAS) or navigation system, and the topic of automated driving.

"I´ve tested a Tesla once – it is already well equipped with different features. It holds the distance to the car in front, so you don´t need to accelerate and brake. ... It is indeed more relaxed when you drive in a convoy/platoon." (Gerd, man, 68 years old, Group 3, hearing-impared)

"For me, automatically parking is part of it. I tried it once with colleagues of mine for first time. It was great, but I cannot imagine using it. ... It worked, but I still didn´t trust it, although it proved me the opposite. When I drive, I will still feel the urge to park by myself." (Kathleen, woman, 30 years old, Group 1)

Potential short- and long-term changes in travel behavior

Potential mode choice changes were indicated several times during the discussion. First, some of the common free associations of the focus group participants related to autonomous driving were about the nature of automated vehicles which in their view represent a hybrid between a car and public transport, i.e., combine advantages of both. Second, in the discussion on potential use of an autonomous driving, an AV was associated with carsharing and taxi concepts, although there were also participants who referred to it as their potential private vehicle. As a combination between a private vehicle and public transport, most often mentioned application of an AV was replacing train or a flight on long distance trips *(see also section "Riding autonomously from today´s perspective")*.

"[the selected picture of an AV] illustrates for me what we all really want – we want to travel like in a train. ... It would mean we can travel on long distances in a comfortable way." (Hartmut, man, 60 years old, Group 3, paraplegic)

On the other hand, while some of the participants anticipate the advantage of an AV over public transport related to privacy and individual route, other express concerns about potential high cost for an AV and some even don´t see any benefits of riding autonomously in a car:

"When someone wants to do something else (work or other stuff), then he should take the train and don´t need a car... If I wanted to ride autonomously, then I would take the bus." (Petra, woman, 50 years old, Group 2)

Regarding car ownership and shared used of AVs, main aspects mentioned were related again to the potential higher purchase cost of an AV and the quality of sharing services. Asked about the condition under which they would get rid of their car, participants who would consider the change stated that constant availability of a vehicle is a prerequisite.

"The alternative should be always available ... This means that I don´t have to wait hours until a car becomes available. When I want to go, then I can go immediately. ... I can also walk 100 m if needed, but it should be available immediately." (Jacquelin, woman, 42 years old, Group 2)

Potential long-term changes, such as making more and/or longer trips or changing residential location, were barely considerable from the participants´ perspective. Although some could imagine moving to a house outside the city, the mentioned reasons behind were not directly related to the availability of autonomous driving. Regarding re-arrangements of daily activities, some participants express potential saving of working hours at the office *(see also section "Riding autonomously from today´s perspective")*, other imagine that they can sleep longer and do their morning routine in the vehicle on the way to work.

6.4 Discussion and conclusions

This study focusses on exploring the potential changes in the evaluation of travel time, resulting from availability of autonomous driving, by comparing time spent in a conventional car today with anticipated time in an AV. For this purpose, focus group discussions with car drivers were conducted.

First, the results of the analyses suggest that the utility of car use today includes different aspects of driving pleasure, various (passive) activities performed in the car and also the driving as an activity itself which counterbalance to some extent the benefits of autonomous driving in terms of improved travel quality and feasibility of activities. While these aspects are discussed in recent literature on the conceptual level or based on analyses of current car use (Singleton, 2018), this study provides a deeper look into the single elements of car use today and the potential car use in the future using qualitative research data. Regarding the role of travel experience and feasibility of travel activities in an AV on the evaluation of travel time, the results align with previous studies (e.g. Cyganski et al., 2015, Pudāne et al., 2019) suggesting that affective aspects, such as stress-relief and rather passive activities are perceived as benefits of automation rather than productive time use. Exception here can be specific user segments as we found high importance attached to this benefit of an AV by people currently using the car for work-related purposes and occupation allowing them tele-working in the car.

Second, the study explored the determinants of travel time evaluation in both conventional car and an AV. The results suggest that both context-related characteristics and individual characteristics play a role when considering driving autonomously. In particular, most attractive applications of autonomous driving were found to be long distance and commuting trips. Moreover, personal needs, attitudes and experience shape the evaluation of autonomous driving rather than socio-economic characteristics. These findings suggest among others that autonomous vehicles (or services) should be developed in a way serving different purposes.

While quantitative approaches are useful for estimating the impact of various factors on mode choices, i.e., the willingness to use new mobility options, as well as modelling travel demand after introduction of new mobility concepts, qualitative approaches allow due to their explorative nature understanding the complexity of mode choice decisions processes. Hence, combining both can provide a comprehensive overview of travel behavior changes resulting from the introduction of new options, such as the automated driving.

Along these lines, the results of this study confirm the importance of considering psychological factors in the analyses of the impact of autonomous driving, including trust in the technology, driving pleasure as well as subjective evaluation of travel experience and desirable on-board activities. In the next step, quantitative studies can be conducted focusing on the estimation their direct and indirect effects on mode choices and travel time evaluation. Considering a discrete choice model framework – a common modelling framework for analyzing mode choice decisions and quantifying VTTS – this can be done in several ways. In the following, we will elaborate of three different potential ways to do this.

First, methods for incorporating latent variables into (discrete) choice models, i.e. using so called integrated choice and latent variable (ICLV) or hybrid choice model can be used (Ashok et al., 2002, Ben-Akiva et al., 2002). The insights provided by the explorative qualitative study allow developing hypotheses on which psychological factors are relevant and how they might affect mode choices, which can be tested using discrete choice models with latent variables. For instance, while some latent constructs, such as trust in the technology or some instrumental motives for car use can directly influence the decision for choosing a car or an AV, other aspects, such as driving pleasure or travel time use are rather related to the value of travel time and affect therefore indirectly the choice of an alternative (i.e., as part of the travel time utility). In this case, it can be reasonable to consider interaction effects between these aspects and the travel time when analyzing mode choice decisions. However, also this approach can be not straightforward when aiming to understand the impact of travel activities and travel-experience factors on the value of time. In the literature that explores VTTS and positive utility of travel, it is recognized that quantifying the impact of the elements of the positive utility of travel on the value of time (found to be in this study essential for understanding willingness to use an AV) is a challengeable task, but also a very important aspect to consider when aiming to understand different time use evaluation (Hess et al., 2005).

Second, more advanced discrete choice models which allow considering heterogeneity in the sample regarding the perception of the alternatives and/or regarding specifically travel time perception are the mixed logit (ML) model and the latent class (LC) model. While the ML allows capturing the distribution of the time parameter across individual instead of one fixed parameter (as estimated in the multinomial logit, MNL), the LC assume a discrete number of classes which accounts for the preference heterogeneity (see for instance Hensher and Greene, 2003). In other words, in both models we can consider the fact that different individuals evaluate travel time differently with the difference that in the first case we can capture the distribution of the different values and in the second case we can estimate different (fixed) parameters for different *groups* of people. The insights from explorative qualitative research, such as the study presented in this paper, can be used to define such different groups or user segments and to estimate different time parameters for each group revealing source of heterogeneity in the time perception and estimating different VTTS for different segments. A suitable approach for this can be applying a latent variable latent class (LVLC) model (an example of the application of such model can be find in (Hess et al., 2013). For instance, classes can be defined depending on underlying motives for car use of individuals, on different preferences for time use and/perception of travel time, or on attitudes, such as technology affinity. This can allow estimating travel demand impact scenarios of AV for different segments and/or providing basis for segment-tailored technology development and marketing strategies.

Third, in a recent qualitative study conducted by (Pudāne et al., 2019) the authors derived implications for future travel behavior models (including time-use models) from the results of focus groups discussions with commuters in Netherland. The researchers explored the effect of the feasibility of activities in an AV on mode choices and time use in a vehicle, but also on daily activity patterns, i.e. potential re-arrangements of activity schedules. Although this topic was barely addressed in the focus group discussions that we have conducted in Berlin, this is an important research avenue to follow in future studies which aim to explain and modelling the impact of autonomous driving on travel behavior and time use.

In summary, this qualitative study provides insights on how current car use shapes the expectation of potential users regarding automated driving. However, further research is needed to for creating a holistic concept on the complex relationship between different elements of the utility of travel time – considering also different concepts of autonomous driving in terms of level of automation and shared vehicle services. Moreover, while first direction of potential user segmentations can be derived from the findings, a larger scale research is needed in order to quantify potential user groups and their benefits of autonomous driving. Last but not least, qualitative research can be combined with quantitative studies. For instance, quantitative studies based on insights from qualitative explorative research allow quantifying the direct and indirect effects of psychological and other factors on mode choices and VTTS as well as to analyze future travel demand scenarios.

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7 Measurement of the value of travel time savings for autonomous driving

'Autonomous driving can reduce drivers' stress and tedium, and increase their productivity. They can be mobile offices and bedrooms … allowing passengers to rest or work while travelling. This reduces travel time unit costs (cost per hour).'

Todd Litman, 2017
'Autonomous Vehicle Implementation Predictions', Victoria, Canada: Victoria Transport Policy Institute.

How might autonomous driving change the VTTS for a car, and what is the effect of the context of use?

The above quote reflects the assumption that dominates the discussion in the transportation field, that vehicle automation will reduce the VTTS for a car. The results of the study presented in the previous chapter support this statement. However, they suggest that, first, the utility of manual driving today must be considered and, second, that both the context of the usage and individual characteristics will shape this effect. Despite the high relevance of the topic for future transport planning, when the study presented in this chapter was conducted, few quantitative empirical studies addressing the topic had been published. Moreover, all of them focused on the potential future situation when AVs will be available as an alternative and did not directly consider the preferences of potential users of AVs for currently available modes of transport.

The following paper, '**Assessing the effect of autonomous driving on value of travel time savings: a comparison between current and future preferences**', aims to contribute to closing this research gap by providing quantitative empirical insights into changes in the VTTS due to vehicle automation. A stated choice experiment was conducted with a sample chosen to represent the German population aged between 18 and 69. The data were analysed using advanced discrete choice modelling. The study built on the first study in two ways: first, it again compared current user preferences for a manually driven car with user preferences for two concepts of automated vehicles. Second, as the results of the explorative qualitative study suggest a strong effect of the usage context of the effect of vehicle automation on the VTTS, different trip purposes were considered in the study (commuting, shopping and leisure trips).

The results of the study confirm a reduction in the VTTS for autonomous driving compared to manual driving, however, only for commuting trips. Furthermore, the study quantifies this effect, providing an empirical data basis for existing travel demand models. Moreover, the study found significant heterogeneity in the travel time valuation for riding autonomously. Finally, differences between user preferences for PAVs and SAVs were observed, suggesting that people perceive an SAV as a less attractive option. Based on the findings, policy implications are discussed.

Overall, the following study provides quantitative empirical evidence for VTTS reduction due to vehicle automation. Simultaneously, significant heterogeneity in user preferences was found. Based on the background of these insights, the second quantitative study presented in Chapter 8 analyses sources of preference heterogeneity by considering the effect of individual characteristics, including attitudes and perceptions.

Assessing the effect of autonomous driving on value of travel time savings: a comparison between current and future preferences

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Abstract

Due to digitalization trends and rapid technological development, cars are becoming more technologically advanced with an on-going trend towards fully automated vehicles. Understanding possible changes in user preferences and the impact on mobility of autonomous driving is of great importance for policy and transport planning authorities in light of urbanization trends, demographic change, and environmental challenges. Despite the relevance of the topic, there are limited empirical insights on user preferences, once autonomous driving becomes available. To close this gap and analyze the potential changes in the value of travel time savings (VTTS) resulting from the availability of autonomous driving, an online survey using revealed and stated preference methods was conducted. In the survey user preferences toward currently available and future available modes of transportation were assessed using two discrete choice experiments. VTTS calculations are based on an estimated joint mixed logit model. The results of the study show an average VTTS reduction of 41% for autonomous driving compared to driving a conventional car, however, only for commuting trips. For leisure or shopping trips, no significant changes in the VTTS were found. Considering shared autonomous vehicles (SAV), the results indicate that using SAV is perceived as a less attractive option than using a privately-owned autonomous vehicle. Translating the results into policy implications, a potential conflict between individual benefits of autonomous driving and societal goals is identified. Finally, policy recommendations are discussed.

Keywords: autonomous vehicles, shared autonomous vehicles, value of travel time savings, discrete choice experiment, mixed logit

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7.1 Introduction

In recent decades, the trends towards digitalisation and rapid developments in technology have led to ever-increasing automation in all areas of daily life. As a result, road vehicles, too, are becoming more technologically advanced in their automation and connectivity and there is a continuing trend towards fully autonomous vehicles (Fagnant and Kockelman, 2015). In terms of automated driving functions, vehicles can be classified into five levels – ranging from driver assistance and partial automation (level 1 and 2), through conditional automation (level 3) and high automation (level 4) to full automation (level 5), in other words potentially driverless (SAE, 2019). The highest level of automation (level 5) can enable new mobility services (Lenz and Fraedrich, 2016), such as shared autonomous vehicles (SAVs). These vehicles are not privately-owned by a single person, but provided by a company. They can be then used on demand - either as individual autonomous car-sharing services, similar to current taxi services, or as an autonomous ride-sharing service, where people with destinations near each other can share the ride, having the advantage of lower cost per kilometre travel, although with somewhat higher waiting times than those associated with autonomous car-sharing services (Kröger and Kickhöfer, 2017). Both kinds of services could complement traditional public transport (e.g. solving the first/last-mile problem), or even, where it is deficient today, act as a substitute (Yap et al., 2016, Mosquet et al., 2015, Ohnemus and Perl, 2016). From a user perspective, these services could allow true door-to-door trips for individuals not having access to a car today (Burns et al., 2013).

There are high expectations placed on autonomous driving, amongst which are: a higher level of safety on the roads; reduced congestion; provision of individual mobility to people currently not allowed or not able to drive; and enabling people who use a car to undertake other activities, while also travelling in a more comfortable way (Trommer et al., 2016, Anderson et al., 2014, Litman, 2014). At the same time, as travel time can be spent in a more pleasurable or more productive way, using a car might become more attractive. Moreover, considering a use case where autonomous vehicles (AVs) make up part of a car-sharing fleet, the use of individual mobility options might become attractive for an even broader group of users who cannot – or do not wish to – own a private vehicle. Consequently, if using a motor vehicle becomes more attractive and, additionally, available to a broader user group, the result will be more vehicles on the road and more vehicle-kilometres travelled (Trommer et al., 2016, Gucwa, 2014, Childress et al., 2015, Harper et al., 2016). Thus, despite the potential benefits of autonomous driving, there is also a risk of causing additional traffic and hence adding to, rather than resolving, transport-related challenges.

In summary, it is expected that autonomous driving may significantly change travel behaviour and mode choice, potentially transforming our understanding of mobility in a way that is hard to predict at this point. At the same time, understanding user preferences, once autonomous driving is available, becomes increasingly relevant in the light of urbanisation trends, demographic change, and environmental challenges. Even though vehicles with level 5 automation will potentially enter the market no sooner than 2027 (ERTRAC, 2015, Dokic et al., 2015, PwC, 2015) and it might take decades for the technology to reach a substantial penetration rate (Trommer et al., 2016, Nieuwenhuijsen et al., 2018, Litman, 2018), anticipating its future impact on mobility is crucial for developing a desirable transition pathway of the technology. Along these lines, offering early insights into the potential impact of automation on user preferences is of great importance for policy and transport planning authorities. Those insights are crucial to design strategies and in evaluating future possible scenarios, in order to integrate AVs into transport systems in a way that allows for their full potential to unfold, while preventing, or at least mitigating, potential negative developments.

The examination of mode choice preferences in theoretical and empirical studies in transport usually centres around estimating the value of travel-time savings (VTTS). The concept of VTTS reflects the reality, derived from microeconomic theory, that people take transport decisions in the context of a constrained time budget – this constraint determines how people choose whether they spend their time on one activity or on another, and how much they would pay to avoid having to spend time on a particular activity (Hensher, 2011). The subjective VTTS is therefore defined as the willingness to pay for one unit of travel time saving (Jara-Diaz, 2000). In the context of autonomous driving, it is reasonable to assume that the perception of time spent in a vehicle might change (from present-day values) in a positive way – that is, the VTTS for autonomous driving might decrease (i.e. the disutility of travel time become less negative). This is because people can spend their time in a more pleasurable or productive way; and, moreover, the stress level in tiresome traffic situations, such as congestion or monotonous routine commuting trips, might reduce when riding autonomously (Becker and Axhausen, 2017). There thus arises the question, when considering the impact of these changes on travel behaviour and mode choice: what variation in the VTTS can be expected, once autonomous driving is available? Furthermore, estimating the VTTS for new mobility options, such as SAVs, becomes ever more relevant when forecasting mode choice decisions.

There is a large body of theoretical and empirical literature dedicated to the estimation of the VTTS for the currently available modes of transport as national studies on mode choices and the role of VTTS (Axhausen et al., 2014, Arup/ ITS Leeds/ Accent, 2015) are an important base for transport infrastructure and policy planning. Results from previous studies on VTTS show that the values differ between modes of transport, according to trip purposes, and depending on the trip distance; they are also affected by specific characteristics of the route, such as the level of congestion or the need to change mode or vehicle *en route* (Abrantes and Wardman, 2011, Shires and De Jong, 2009). For instance, the VTTS for commuting trips is found to be higher than that for leisure or shopping trips, and driving in congestion is associated with a higher VTTS than driving in a free-flowing traffic (Abrantes and Wardman, 2011). Also, car passengers are found to have a lower VTTS than car drivers (Mackie et al., 2003). Therefore, when considering how automation might affect VTTSs, we can expect that there will be a reduction in the VTTS since users travel as passengers in a way that is similar to using taxis or taking public transport (although in fact AVs will exhibit substantial advantages over these alternatives, in terms of privacy afforded and the range of activities that can be performed *en route*, especially if the internal configuration of the vehicle can be personalised). However, empirical data is required to validate this assumption, and to find out how riding autonomously in a privately-owned car differs from riding in an SAV.

While the VTTS for current existing modes of transport can be estimated by relying upon revealed or stated preference (SP) methods, seeking to establish the VTTS for novel (as yet unavailable) mobility options, such as autonomous driving, is possible only using SP approaches or plausible assumptions. While relying on plausible assumptions and sensitivity analysis on the basis of simulation models might provide significant insight into the possible impacts of automation, empirical research is still required in order to address the users' perspective and to validate/provide data input for travel behavioural models upon which the simulation tools are based. Along these lines, there are early simulation studies which report that a reduction in the VTTS through automation might potentially lead to an increase in travel demand and in car mode share (Gucwa, 2014, Childress et al., 2015, Kröger et al., 2016, Wadud et al., 2016, Correia and van Arem, 2016), but they simply rely upon assumption to quantify the extent to which the VTTS will be affected by automation. While the technique of SP suffers from shortcomings when used to address new, for the respondents unfamiliar, alternatives, it still can help gaining empirical insights about potential user preferences regarding autonomous driving. Acknowledging the limitations of SP, using them and interpreting their results with care, can be a suitable tool to consider the user perspective on the new technology.

Early empirical works have addressed the VTTS for autonomous driving by relying on the SP approach (Yap et al., 2016, Winter et al., 2017, Krueger et al., 2016, Steck et al., 2018, De Looff et al., 2018). The focus of most of them is user preferences regarding different types of SAV, owing to the higher level of uncertainty about the impact of these new mobility options compared to privately-owned AVs. The results broadly indicate differences between early and late adopters of these services (Winter et al., 2017), as well as showing that using an SAV alone and sharing the journey are perceived as two distinct mobility options (Krueger et al., 2016). These differences might be partly related to psychological barriers associated with sharing a ride with strangers as such acceptance issues were found in early studies on carpooling service (e.g. Correia and Viegas, 2011). Considering a privately-owned AV, there is early empirical evidence for a reduction of the VTTS for commuting trips (Steck et al., 2018) and for an AV with an office interior compared to a an AV with a leisure one (De Looff et al., 2018, Correia et al., 2019). The results from the latter study confirm also a theoretical reduction in VTTS for work vehicle derived by the authors from the existing microeconomics theory on perceived VTTS (see Correia et al., 2019). Simultaneously, a rather higher VTTS was found for the use of AVs as a first/last-mile solution, suggesting concerns in attitude towards and perception of the technology (Yap et al., 2016). However, these studies focus mainly on specific use cases of autonomous driving and the characteristics of the trips that AVs are used for (first/last-mile, car- or ride-sharing, commuting, etc.). Moreover, in most cases only motorised modes of transport have been considered, and a baseline can only be a comparison with existing values from the literature, as the studies focus only on user preferences when future mobility options are available. An exception here is the study from Correia et al. (2019), where the same experiment was conducted with a different sample presenting a chauffeur-driven vehicle instead of an AV. At the same time, we suggest that assessing preferences regarding currently available modes of transport of the same sample can be a more accurate base line. This is because changes in the preferences can be directly addressed avoiding additional error sources, such as differences in the samples or in the methodology used.

The aim of this study is to contribute to the field by closing these research gaps by providing empirical evidence on how autonomous driving might change the VTTS and choice of mode. The study addresses both privately-owned AVs and SAVs. Moreover, while the SP approach provides powerful insights into the aforementioned new use cases, the lack of familiarity of the population with these options might affect the accuracy of their responses. Therefore, we have focused our analysis on higher-level features, such as that of the VTTS. Along these lines, and in order to have a better depiction of the situation regarding available choices, we contrast current preferences (also based on SP, but considering currently available mobility options) with potential choices when AVs become available. The results of the study can potentially constitute an important building block in the planning of future strategic policy steps for the implementation of autonomous driving into existing transport systems.

7.2 Study design and data set

To address the value of travel-time savings (VTTS) for autonomous driving, an online survey was conducted in 2017. The respondents were contacted by a professional service provider using an online panel, and the sample, consisting of 511 respondents, was drawn to represent the age and gender distribution in the German population of the age group between 18 and 69 years old. After removing incomplete/implausible records, and non-trading, lexicographic and inconsistent response patterns, as well as response of an implausible duration, the final sample consisted of 485 individual records of adequate quality for inclusion. To assess the VTTS for autonomous driving, a combination of revealed and stated preference (SP) methods was applied following a pivot design, i.e. a discrete-choice experiment with the attributes of the alternatives pivoted around a given value, as proposed by Hensher and Greene (2003). Additionally, the survey includes questions on individual travel patterns, socioeconomic data, and willingness to use and pay for autonomous driving functions.

In the revealed preference part of the survey, the respondents were asked to report details of their regular commuting, leisure or shopping trips. The reported trips were used as reference trips for creating individual decision situations in the SP part of the survey by reducing or increasing the trip time and cost of each alternative around a computed base level. The base level for the mode of transport which is currently used by the respondents was computed using the reported trip duration. The individual base levels for all other alternatives were estimated using the reported trip length and additional data from the literature (see notes in Table 7). The SP part consisted of two discrete-choice experiments. In the first choice experiment, the respondents had to choose between currently available modes of transport for their reported trip, including walk, bicycle, privately-owned car and public transport. The second discrete-choice experiment additionally included mobility options available in the future: two autonomous driving concepts to replace a privately-owned conventional car – a privately-owned vehicle with automation capability, and a shared autonomous vehicle (SAV), i.e. an autonomous vehicle (AV) that can be used on demand. As the SAV combines characteristics of taxi and car-sharing concepts, we named this mobility option ‘driverless taxi’ in the survey and in the video used for introducing the concept in order to provide a ready understanding of its characteristics to the participants. This was done because we assumed that a significant part of the general population is not familiar with on-demand or shared vehicle services (both as a term and as a service) and that a taxi service is the one closest to the concept that we looked at. In this paper we will, however, refer to this alternative using the term ‘SAV’.

The two autonomous driving concepts were presented to the participant by means of two short animated videos before the second choice experiment. Acknowledging that the responses regarding autonomous driving are highly affected by the way the concept is presented, we used the videos instead of only providing text description, presented how a trip with an AV might looks like instead of showing only information about such vehicles, and described the usage of AVs in as neutral a way as possible avoiding evaluative adjectives. An autonomous vehicle was described as *"a road vehicle which can perform the driving task, i.e. can brake, steer and accelerate by itself. The driver doesn´t have to pay attention to the traffic or to take care of the driving task and can use the travel time for other activities (such as reading, watching movies, surfing in internet).*" In the videos, the main character, Mrs Schmidt, uses her privately-owned AV or an SAV to reach her destination. Both vehicles are shown picking her up from her location and dropping her off at a given destination. Hence, there is no access and egress time, but she need to wait for the vehicle. In the privately-owned AV, Mrs. Schmidt could choose whether she wants to drive manually or ride autonomously. This description of the vehicle's capabilities allows us to avoid confronting the respondents with two different vehicle types in the choice sets (a conventional vehicle and an AV), as this would make the choice situation more complicated and would require an early purchase decision about an AV. Consequentially, if a respondent chooses to use an AV for the trip, then he/she could decide whether riding autonomously or driving manually (i.e. using the AV as a conventional car). An additional question after the choice experiments addresses the preferences of each of the respondents regarding riding autonomously or driving manually. We used this question in model estimation to distinguish between the perceptions of the time spent in an AV riding autonomously and in an AV driving manually (i.e. using an AV as a conventional car). Confronting respondents with a privately-owned car able to drive autonomously allows for assessing willingness to use the function and its impact on the time evaluation instead of assessing car purchase, which is a more complex decision process. Simultaneously, given that the first choice experiment included a conventional car in the choice-set, this experiment is used as a control groups and allows validating the results on preferences toward use of a privately-owned car. In contrast to the privately-owned car (i.e. the privatelyowned AV), the SAV was presented as a vehicle which has no steering wheel or brakes, and so could not be driven manually. A ride with an SAV could additionally be shared with other passengers who have similar origin and destination with the advantage of lower cost for the service users. This, however, was only described in a short text and was not shown in the video as it was only an additionally considered aspect and not the main scope of the study.

Each of the two discrete-choice experiments consisted of eight choice situations. The attributes, along with the attribute levels used in the experiments are summarised in Table 7. Since we aimed to assess the individual trade-offs between time and cost, we considered the travel, access/egress and waiting times as well as the cost of the different alternatives. In order to confront the respondents with realistic alternatives, we used a pivot design based on the reported trip length and duration combined with additional information on the average speeds and costs of each transport mode in Germany to create the characteristics of the alternatives. The range of reduction and increase around the computed values follow the variation used in the national survey on VTTS for Germany conducted by Axhausen et al. (2014). The SAV had an additional attribute showing whether the respondent will use the vehicle alone, or will have to share the vehicle with other passengers. When sharing a ride, the cost per kilometre was reduced proportionally. In this way, the concept of comparing car-sharing with ride-sharing could be approached without introducing an additional mobility option into the choice set.

Table 7: Attributes and their levels

Mode of transport	**Walk**	**Bike**	**Public transport**
Attribute: Attribute levels	Time: −30% | −10% | +20% of the reported trip time (Speed: 4.9 km/h)	Time: −30% | −10% | +20% of the reported trip time (Speed: 15 km/h)	In-vehicle time: −30% | −10% | +20% of the reported trip time (Speed: 18–51 km/h*)
			Access/egress time: 2 | 5 | 10 min
			Waiting time: 2 | 5 | 10 min
			Costs: −30% | −10% | +20% of estimated cost for the trip (1.5 - 6 Euro*)
Mode of transport	**Conventional car** *(only in the first experiment)*	**Autonomous vehicle** *(only in the second choice experiment)*	**Shared autonomous vehicle** *(only in the second choice experiment)*
Attribute: Attribute levels	In-vehicle time: −30% | −10% | +20% of the reported trip time (Speed: 26–68 km/h*)	In-vehicle time: −30% | −10% | +20% of the reported trip time (Speed: 26–68 km/h*)	In-vehicle time: −30% | −10% | +20% of the reported trip time (Speed: 26–68 km/h*)
	Access/egress time: 2 | 5 | 10 min		
		Waiting time: 2 | 5 | 10 min	Waiting time: 2 | 5 | 10 min
			Ride-sharing: no | yes
	Costs: −30% | −10% | +20% of estimated cost for the trip (0.20 Euro/min*)	Costs: −30% | −10% | +20% of estimated cost for the trip (0.20 Euro/min*)	Costs: −30% | −10% | +20% of estimated cost for the trip (0.20 Euro/min*)

*distance-dependent estimation

Note: Average speeds per mode of transport were computed using the German National Household Travel Survey, MiD (DLR and infas, 2010); the costs per kilometre for the privately-owned car were drawn from ADAC (2017) – only fuel and maintenance costs were included; the price for using a shared autonomous vehicle followed results from current analysis (Kröger and Kickhöfer, 2017); distance-dependent costs for public transport were drawn from existing rates for Germany starting from 1.5 Euro; season, year or student pass/tickets for public transport were not considered

In order to enhance the data quality of the experiments by maximising the information obtained from each choice situation, a Bayesian efficient design was created using the software Ngene (ChoiceMetrics, 2012). The priors, i.e. the parameters for the estimation of the efficient design, were drawn from model estimations using the data collected in a pre-test with 30 participants prior to the field test. Despite the small sample size of the pre-test, the relevant priors were significant and also of the expected range and sign. Following suggestions from the literature, a statistically more efficient design can be generated even when limited information about the parameters is given (Bliemer and Rose, 2005). Moreover, we optimised the design for different trip lengths in order to consider the effect of trip distance on mode choice.Table 8 provides an overview of the characteristics of the reference trips reported in the revealed preference part of the survey and a comparison of the study sample with the German National household travel survey, Mobilität in Deutschland or MiD 2008 (DLR and infas, 2010). The reference trips refer, as mentioned above, to regular trips made by the participant used as a reference for creating individual decision situations in the SP. The descriptive analysis shows that commuting trips are on average longer than shopping and leisure trips. A comparison of the modal split between trip purposes shows that the privately-owned car is the preferred mode of transport across all trip purposes. Leisure and shopping trips are characterised by a higher share of trips made by foot, which can be attributed to the short distances involved. After the privately-owned car, public transport is the second most popular mode of transport for commuting trips. When comparing these values with the average characteristics of trips in the German National household travel survey MiD 2008 (DLR and infas, 2010), similar tendencies can be observed in both trip distance statistics and the modal split. Only commuting trips are on average longer in the study sample than in MiD 2008; also, some active modes of transport (bicycle for shopping trips, and walk for leisure trips) are underrepresented and public transport (for commuting and leisure trips) overrepresented in the study sample when compared to MiD 2008.

Table 8: Overview of the characteristics of the reported reference trips compared to the German National household travel survey MiD 2008 (DLR and infas, 2010)

Trip purpose:	**commuting**		**leisure**		**shopping**	
	Study sample (n=172)	*MiD 2008*	Study sample (n=142)	*MiD 2008*	Study sample (n=171)	*MiD 2008*
Trip distance statistics [km]						
1st quartile	5	*3*	3	*1*	1	*1*
Median	15	*9*	6	*4*	3	*2*
Mean (std. dev.)	18 (17)	*14 (16)*	11 (15)	*9 (13)*	5 (7)	*5 (8)*
3rd quartile	25	19	12	*10*	6	*5*
Mode of transport [%] *						
Walk	9	*8*	20	*32*	31	*26*
Bicycle	8	*11*	12	*10*	4	*11*
Public transport	23	*14*	13	*6*	4	*3*
Privately-owned car	61	*67*	55	*51*	61	*61*

**Note: (%) refers to the modal share, within the trip purpose, of this mode*

Further descriptive analysis was carried out of the distribution of socioeconomic characteristics within the study sample, and then compared to the characteristics of the German population as a whole. The study sample was recruited to be representative by age and gender for Germany. A comparison of the share of individuals belonging to different income classes shows that solely persons with high income were underrepresented in the study sample – this was probably due to the method of sample recruitment, which involved a small payment of 2 Euro as an incentive to take part in the survey.

7.3 Theoretical and modelling framework

The most common approach to address discrete choices in transportation is based on the random utility theory, which postulates that an individual, n, assigns a specific utility to every available alternative, i, and chooses the one that maximises his/her net personal utility (McFadden, 1973, Ortúzar and Willumsen, 2011). As the modeller does not have information about all elements considered by each individual, the net utility $U_{n,i}$ of the alternative i for the individual n is represented through a measurable deterministic part and a random, i.e. stochastic, component. The deterministic part is a vector of the explanatory variables including the attributes of the alternatives, as well as the socioeconomic characteristics of the individuals. The stochastic component, represented through the error term $\varepsilon_{n,i}$, accounts for all relevant attributes ignored by the modeller. Assuming an additive linearity, the expected utility of the alternative i can therefore be expressed as follows:

$$U_{n,i} = \beta X_{n,i} + \varepsilon_{n,i} \quad (1)$$

, where β is a vector of parameters to be estimated. The assumptions regarding the error term $\varepsilon_{n,i}$, would lead to different model specifications. The most common assumption is that the random residuals are independent and identically distributed (iid) following a Gumbel (also called Extreme Value Type I, or EV1) distribution, which leads to the Multinomial Logit (MNL) model (McFadden, 1973, Ortúzar and Willumsen, 2011). Hence, the MNL does not allow for any consideration of heterogeneity among the respondents, nor can it capture the pseudo-panel nature of the discrete-choice data (i.e. more than one response per respondent). In order to cope with these restrictions inherent in the MNL, it is possible to rely upon a Mixed Logit (ML; Boyd and Mellman, 1980, Cardell and Dunbar, 1980, Train, 2009) specification, which allows relaxing the assumptions that the model parameters are the same for all individuals in the sample, and likewise the assumption that there is no correlation across observations from the same respondent (Hensher and Greene, 2003, Revelt and Train, 1998). The utility function of an ML with pseudo-panel data extends equation (1) to the following formulation:

$$U_{n,i,t} = bX_{n,i,t} + \eta_n X_{n,i,t} + \varepsilon_{n,i,t} \quad (2)$$

In equation (2), the coefficient vector β from equation (1) is represented as $\beta_n = b + \eta_n$, where b is the population mean and the η_n is a random term following a distribution to be established by the analysis with zero mean and a standard deviation to be estimated. Estimating b as a random parameter allows for analysis of different evaluations of $X_{n,i,t}$ across the respondents. The t represents the choice situations with which a single respondent n is confronted. Therefore, $b + \eta_n$ is assumed not to vary across t taking into account that the evaluation of the attributes of the alternatives remains the same across all observations associated with the same respondent. Consequently, in the ML the probability of choosing the alternative i is a weighted mean of the MNL probabilities at a specific η, weighted over the distribution of η. In the following formulation, the choice probability $L_{n,i}$ represents the MNL probabilities for a given value of η:

$$P_{n,i} = \int L_{n,i}(\beta) f(\beta|\eta)\, d\beta \quad (3)$$

Considering that one individual faces t choice situations, the probability of observing a set of individual choices can be expressed as follows:

$$L_{n,i}(\beta) = \prod_{t=1}^{T} \left(\frac{e^{\beta X_{n,i,t}}}{\sum_{j=1}^{J} e^{\beta X_{n,j,t}}} \right) \quad (4)$$

All model estimations were performed using the software PythonBiogeme (Bierlaire, 2003). An iterative procedure was used to obtain the final model. As we are dealing with two separated experiments with common alternatives and variables, it is reasonable to consider that the valuation of attributes by the same individuals across the different experiments will be similar. Therefore, common parameters are considered, acknowledging possible scale differences, using a similar technique akin to the technique used to model with RP and SP data simultaneously (Train, 2009, Ortúzar and Willumsen, 2011). In a first step, two distinct models were estimated – a model based on the data from the discrete-choice experiment on user preferences regarding currently available modes of transport, and a second model based on the data for alternatives available in the future. Common variables were used in both models in order to enable a comparison between the results. One exception to this was variables available in only one of the two choice experiments, for example access/egress time for conventional car in the first one, and the attributes of the SAV in the second one. In the next step of the analysis, a joint model based on the data from both choice experiments was estimated. To account for differences between the effects of unobserved factors in the two experiments, as well as for the different number of options, separate alternative-specific constants are estimated for current and future choices. The utility functions for the experiment on future preferences are scaled by a constant parameter μ, which accounts for differences in the variability of the error terms.

In early estimations, the effect of the trip purpose on travel-time perception was tested by estimating coefficients for the interaction between in-vehicle time and the trip purpose, but no significant differences between different trip types were found for most of the alternatives. Statistically significant differences were only found between time perception when driving on commuting trips compared to driving on leisure/shopping trips suggesting a more negative perception of the time spent driving to/from work. These results can be related to trip characteristics, such as length, routine character, high risk for heavy traffic and time pressure on working days which make driving a tedious task when commuting. As the focus of the study was exploring the changes in time valuation resulting from automation and potential differences between the different trip purposes are important indicators for factors affecting these changes, the interaction between trip purpose, driving manually compared to riding autonomously, and in-vehicle time was included in the final model estimation. The effect of age and gender was also tested in early model estimations. However, as none of these variables showed any significant effect on potential user preferences regarding autonomous driving, they have been excluded from the final models. In contrast to this, a possession of a driving license and/or public transport pass had both a significant effect on mode choices and thus, they were included in the final model. Furthermore, an interaction between cost and the income class a person belongs to was included in the model in order to examine potential differences in perception of cost depending on income.

To indicate respondents' preferences regarding riding autonomously, as opposed to driving manually in a privately-owned AV, two dichotomous variables were computed on the basis of an additional question in the survey which asked for these preferences on a five-point Likert-scale. The respondents could choose on a scale between "riding only autonomously" to "driving only manually". The dichotomous variable for autonomous driving was computed using the responses on the scale related to the choice for riding "only autonomously" or "most of the time autonomously". Consequentially, the variable which indicates preference for driving manually refers to the choices of driving "partly autonomously/partly manually", "most of the time manually", and "only manually". Two coefficients – for the interaction between in-vehicle time valuation, and the preference towards driving autonomously compared to driving manually – were estimated. Using a similar procedure, two different coefficients for the perception of in-vehicle time in an SAV - one for the situation when a person uses the vehicle alone, and one for when he/she has to share the ride – were estimated. Whether a ride with an SAV is a shared one or the person is travelling alone was one of the attributes that describe this alternative itself in the choice experiment (Table 7). The attributes of the alternatives, the trip types and the socioeconomic factors which were included in the final model are presented in Table 9.

Table 9: List of variables included in the final model

Variable	**Description**
$TIME_i$	*in-vehicle time for mode i (minutes)*
$COST_i$	*travel cost of mode i (€)*
AET_i	*access/egress time for mode i (minutes)*
WT_i	*waiting time for mode i (minutes)*
RIDE-SHARING	*dummy variable for sharing the ride in the SAV with other persons [corresponds to the level/value of the attribute "ride-sharing" in the choice experiment where 0 = travelling alone, 1 = ride-sharing/the ride is shared with other passengers; "ride-sharing" was one of the attributes that describe the alternative SAV]*
MANUALLY	*dummy variable indicating preference for driving the privately-owned AV manually [computed using the answers on the question "Imagine that you have your own automated vehicle that you can use for the reported trip. Would you use this vehicle in an autonomous or in manual mode?"; value '1' of this dummy variable corresponds to the following original scale values: "partly autonomously/partly manually", "most of the time manually", "only manually"]*
AUTONOMOUSLY	*dummy variable indicating preference for driving the privately-owned AV autonomously [computed using the answers on the question used also to compute the dummy variable 'Manually'; value '1' of this dummy variable corresponds to the following original scale values: "only autonomously", "most of the time autonomously"]*
COMMUTING	*dummy variable for commuting trips*
LEISURE/SHOPPING	*dummy variable for leisure or shopping trips*
DL	*dummy variable indicating possession of driving licence*
PT PASS	*dummy variable indicating possession of public transport pass*
$INCOME_j$	*dummy variable indicating which income class a respondent belongs to (low: up to €1,500/month, middle: €1,500 – €3,000/month, high: more than €3,000/month)*

The joint mixed logit model was estimated using an iterative procedure to explore relevant random effects. This allowed considering the pseudo-panel nature of the data, i.e. to account for the correlation among the preferences associated with the same respondent (Walker et al., 2007). The coefficients for in-vehicle time as well as for access/egress and waiting time were included as random parameters in the model in order to examine potential heterogeneity in preferences across respondents. Only time elements for which a significant heterogeneity in the preferences was found were considered as random parameters in the final model. This includes random parameters for the following time elements: *en-route* time for walking and cycling; in-vehicle time for public transport, for an SAV as ride-sharing, and for autonomous driving on commuting trips; access/egress time for conventional car and for public transport (however, only in the future scenario), and waiting time for AV/SAV.

The distribution of the random parameters was simulated using 8,000 MLHS (Modified Latin Hypercube Sampling) draws (Hess et al., 2006); the large number of draws was decided on to reflect the high number of dimensions over which the likelihood function must be integrated. Initially, a normal distribution was assumed for all random parameters including the random components for the pseudo-panel (i.e. agent) effect. From behaviour perspective, however, the normal distribution might not be the most appropriate one when estimating time parameters in the context of mode choices. Alternatives to the normal distribution coping with some of its shortcomings, including the fact that its unbounded and symmetrical nature might cause a significant proportion of the distribution to exhibit wrong signs, are the lognormal and the triangular distribution (Hess et al., 2005). Therefore, these two distributions were tested for the random time coefficients in the further model estimations, while the random components related to the pseudo-panel effect were assumed to follow a normal distribution in all estimated models. Insignificant variance parameters were found using the lognormal distribution instead of the normal one which suggests less adequate fit to the study data. Assuming triangular distribution, on the other hand, provided better results than a normal or log-normal distribution (both in terms of model adjustment and plausibility of the estimated parameters, i.e. percentage of the population exhibiting the expected sign for the time parameters). The comparison of the models was performed in two steps. First, a comparison on the basis of the Akaike information criterion (AIC) favours the model assuming triangularly distributed random parameters. Second, we used the cumulative distribution functions for the selected distribution types and the model data to calculate the amount of values that exhibit a non-intuitive (positive) sign for the time parameters. The results show a smaller amount of time parameter values over zero in the model assuming triangularly distributed random parameters compared to the other models. Thus, in the final model, a triangular distribution for the random time coefficients is used.

Symmetrical triangular distributions were simulated in Biogeme as the sum of two independently and uniformly distributed random variables (U_1 and U_2) ranging between -1 and 1. Consequently, the triangular distribution is given by $ß + \sigma * 0.5 * (U_1 + U_2)$, where ß represents the mean and σ the semi-range of the distribution. After estimating the parameters ß and σ, we have calculated the standard deviation for each random parameter for which a symmetrical triangular distribution was assumed using the following formulation: $\eta = \sqrt{6}(\sigma * 2)/12$.

7.4 Results and discussion

7.4.1. Estimated model coefficients

The results of the final separate models are summarised in Table 10. The table gives an overview of the estimated model coefficients (ß), the estimated (or calculated) standard deviations (η) of the random coefficients, and the model fit of the model. Overall, the estimated model parameters show plausible signs and values.

Table 10: Results of the two distinct mixed logit model estimation

	Current preferences				**Future preferences**			
Coefficient	**Est. value ß**	**Est./ calc. value η**	**t-value ß**	**t-value η**	**Est. value ß**	**Est./ calc. value η**	**t-value ß**	**t-value η**
ASC$_{\text{CAR}}$	0		*fixed*		-		-	
η_{CAR}		*3.6*		*(11.64)*		-		-
ASC$_{\text{AV}}$	-		-		0		*fixed*	
η_{AV}		-		-		*-2.32*		*(-8.53)*
ASC$_{\text{WALK}}$	6.7		*(6.03)*		10.7		*(7.69)*	
η_{WALK}		*1.42*		*(2.08)*		*2.73*		*(4.57)*
ASC$_{\text{BICYCLE}}$	-2.76		*(-4.67)*		-1.56		*(-2.81)*	
$\eta_{BICYCLE}$		*3.1*		*(7.02)*		*4.62*		*(9.15)*
ASC$_{\text{PT}}$	-0.74		*(-0.84)*		-3.11		*(-2.37)*	
η_{PT}		*1.02*		*(2.73)*		*4.13*		*(8.74)*
ASC$_{\text{SAV}}$	-		-		-1.00		*(-3.15)*	
η_{SAV}		-		-		*1.31*		*(3.74)*
ß$_{\text{TIME WALK}}$	-0.344		*(-11.0)*		-0.433		*(-10.5)*	
$\eta_{TIME\ WALK\ (triangular\ dist.)}$		*0.140*		*(10.03)*		*-0.184*		*(-10.1)*
ß$_{\text{TIME BICYCLE}}$	-0.234		*(-8.02)*		-0.273		*(-9.15)*	
$\eta_{TIME\ BICYCLE\ (triangular\ dist.)}$		*0.106*		*(4.84)*		*0.124*		*(8.05)*
ß$_{\text{TIME PT}}$	-0.065		*(-5.99)*		-0.046		*(-3.21)*	
$\eta_{TIME\ PT\ (triangular\ dist.)}$		*0.005*		*(0.23)*		*0.045*		*(4.68)*
ß$_{\text{TIME CAR commuting}}$	-0.106		*(-6.13)*		-		-	
ß$_{\text{TIME CAR leisure/shopping}}$	-0.063		*(-3.15)*		-		-	
ß$_{\text{TIME AV MANUALLY commuting}}$	-		-		-0.092		*(-6.05)*	
ß$_{\text{TIME AV MANUALLY leisure/shopping}}$	-		-		-0.052		*(-2.78)*	
ß$_{\text{TIME AV AUTONOMOUSLY commuting}}$	-		-		-0.059		*(-2.75)*	
η $_{\text{TIME AV AUTONOMOUSLY commuting (triangular dist.)}}$	-		-			*0.053*		*(1.69)*
ß$_{\text{TIME AV AUTONOMOUSLY leisure/shopping}}$	-		-		-0.060		*(-2.63)*	
ß$_{\text{TIME SAV used individually}}$	-		-		-0.093		*(-5.48)*	
ß$_{\text{TIME SAV ride-sharing}}$	-		-		-0.098		*(-5.80)*	
η $_{\text{TIME SAV ride-sharing (triangular dist.)}}$	-	-		-		*-0.033*		*(-1.65)*
ß$_{\text{WAITING TIME PT}}$	-0.082		*(-2.57)*		-0.09		*(-3.7)*	
ß$_{\text{WAITING TIME AV \& SAV}}$	-		-		-0.109		*(-6.94)*	
η $_{\text{WAITING TIME AV \& SAV (triangular dist.)}}$		-				*-0.118*		*(5.42)*
ß$_{\text{ACCESS/EGRESS TIME PT}}$	-0.153		*(-3.12)*		-0.26		*(-0.77)*	
η $_{\text{ACCESS/EGRESS TIME PT (triangular dist.)}}$		*0.136*		*(2.09)*		-		
ß$_{\text{ACCESS/EGRESS TIME CAR}}$	-0.141		*(-5.44)*		-		-	
η $_{\text{ACCESS/EGRESS TIME CAR; (triangular dist.)}}$		*0.118*		*(2.83)*		-		
ß$_{\text{COST LOW INCOME}}$	-1.08		*(−5.89)*		−1.19		*(−8.41)*	
ß$_{\text{COST MIDDLE INCOME}}$	−0.70		*(−5.97)*		−0.949		*(−8.61)*	
ß$_{\text{COST HIGH INCOME}}$	−0.523		*(−4.77)*		−0.585		*(−6.82)*	
ß$_{\text{RIDE-SHARING}}$	-		-		0.0999		*(0.42)*	
ß$_{\text{PT PASS on WALK}}$	3.88		*(5.34)*		-		-	
ß$_{\text{PT PASS on BICYCLE}}$	4.56		*(6.23)*		1.81		*(2.94)*	
ß$_{\text{PT PASS on PT}}$	5.35		*(8.53)*		3.1		*(4.68)*	
ß$_{\text{DRIVING LICENCE on WALK}}$	-2.95		*(−2.88)*		-4.66		*(−3.8)*	
ß$_{\text{DRIVING LICENCE on PT}}$	-3.68		*(−4.65)*		-1.92		*(−1.58)*	
Model fit								
Log-likelihood (0)	- 5378.82				- 6244.62			
Log-likelihood (final)	- 1897.952				- 2689.44			
ρ^2	0.647				0.569			
Estimated Parameters	28				35			
Observations	3880				3880			

To justify the estimation of the joint model, the relationship between the common parameters (time elements parameters for common modes of transport and cost parameters) in the two distinct models was examined. The comparison shows that they exhibit similar tendencies and are highly correlated with each other (see Figure 3). In general terms, the magnitude of the estimated parameters is slightly larger in the future preferences models, which is indicative for a smaller variance, but the differences are minimal. Therefore, it seems plausible to estimate a joint model considering common parameters across the experiments.

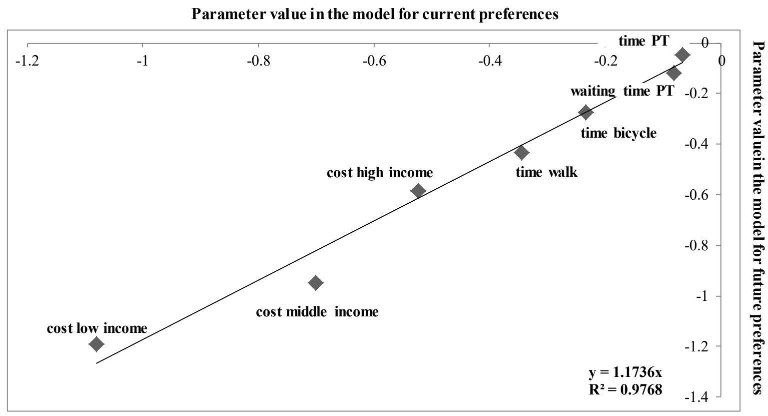

Figure 3: Relationship between the common parameters in the model on current preferences and the model on future preferences

Table 11 summarizes the results from the estimated joint model. The table presents again the estimated model coefficients, including the estimated deviations of the random coefficients as well as the scaling parameter μ. Additionally, it is indicated when the parameters are related only to current or only to future conditions (i.e. are estimated only using the data from the first or only from the second choice experiment). The results show that the models estimated separately for the current and future choice situation do not statistically outperform the joint model considering common parameters in both choice situations ($\chi^2(9) = 4.782$, $p > 0.05$). However, considering the joint model allows for a direct comparison of the changes in marginal utilities associated with the introduction of AVs.

Overall, all estimated coefficients for the time and cost attributes have a significant effect on the mode choice. The alternative-specific time coefficients were compared with each other using a t-test for generic parameters in order to analyse whether there are statistically significant differences between the coefficients. The following formulation was used for the estimations: $(ß_1 - ß_2) / \sqrt{(s_1^2 + s_2^2 - 2 * s_{12}^2)}$, where $ß_1$ and $ß_2$ are the estimated parameters which are compared with each other, s_1^2 and s_2^2 are their variances, and s_{12}^2 is their covariance. The comparisons and the calculated t-values are reported in the following part.

The results of the estimations and the comparison of the estimated coefficients for current and future preferences (which can be directly compared given the estimation approach) show that, for commuting trips, riding autonomously ($ß_{\text{time AV autonomously commuting}} = -0.0621$) is perceived less negatively than driving a conventional car nowadays ($ß_{\text{time car commuting}} = -0.105$; $t = 1.65$, $p < 0.05$ considering a one-tailed t-test as the direction of the effect is known *a priori*). Along these lines, the results also suggest that people perceive time spent in a conventional car ($ß_{\text{time car commuting}} = -0.105$) and in an AV which is used as a conventional one (i.e. is driven manually; $ß_{\text{time AV manually commuting}} = -0.0966$) similarly ($t = -0.37$, $p > 0.05$). Differences between riding AVs autonomously and manually are nearly significant ($t = 1.59$, □=6% one-tailed test) and point in the same direction. Furthermore, the results show that when driving manually (current and future preferences), leisure trips are perceived less negatively than communing trips ($ß_{\text{time car leisure/shopping}} = -0.0649$ and $ß_{\text{time car commuting}} = -0.105$, $t = 1.84$, $p < 0.05$; $ß_{\text{time AV manually leisure/shopping}} = -0.0539$ and $ß_{\text{time AV manually commuting}} = -0.0966$, $t = 2.23$, $p < 0.05$). This difference, however, vanishes when driving autonomously. In general, the perception of time spent on leisure trips is perceived similarly, disregarding whether the vehicles are driven manually or autonomously. Moreover, there is a significant heterogeneity across the respondents in the perception of in-vehicle time riding autonomously on commuting and thus, the reported difference refers to the average value of the sample. A comparison of autonomous driving with using other modes of transport shows that riding autonomously in a privately-owned vehicle ($ß_{time\ AV\ autonomously\ commuting}$ = -0.0621) is perceived similarly to spending in-vehicle time on public transport ($ß_{time\ PT}$ = -0.0577; t = - 0.21, p > 0.05). At the same time, riding in an SAV ($ß_{time\ SAV\ ride\text{-}sharing}$ = -0.11) is found to be less attractive than using either privately-owned AV riding autonomously ($ß_{time\ AV\ autonomously\ commuting}$ = -0.0621; t = 2.12, p < 0.05) or public transport ($ß_{time\ PT}$ = -0.0577; t = - 2.92, p < 0.05). Furthermore, when considering the in-vehicle time in an SAV, no significant differences were found between using the shared vehicle alone ($ß_{time\ SAV\ used\ individually}$ = -0.103) and sharing the ride with strangers ($ß_{time\ SAV\ ride\text{-}sharing}$ = - 0.11; t = -0.45, p > 0.05). A similar tendency is evident in that the coefficient for a shared ride ($ß_{ride\text{-}sharing}$ = 0.118) is likewise not significant. Simultaneously, there is a significant heterogeneity in the sample regarding perception of in-vehicle time when sharing the ride, but no differences across the respondents for the perception of time spent riding in an SAV alone.

Table 11: Results of the joint mixed logit model estimation

Coefficient	**Est. value ß**	**Est./ calc. value η**	**t-value ß**	**t-value η**
ASC $_{CAR;\ current}$	0		*fixed*	
η $_{CAR;\ current}$		*3.26*		*(10.65)*
ASC $_{AV;\ future}$	0		*fixed*	
η $_{AV;\ future}$		*2.39*		*(8.83)*
ASC $_{WALK;\ current}$	6.58		*(5.73)*	
η $_{WALK;\ current}$		*-1.23*		*(-2.16)*
ASC $_{WALK;\ future}$	10.2		*(8.08)*	
η $_{WALK;\ future}$		*2.77*		*(5.44)*
ASC $_{BICYCLE;\ current}$	-2.83		*(-5.56)*	
η $_{BICYCLE;\ current}$		*3.01*		*(7.61)*
ASC $_{BICYCLE;\ future}$	-1.47		*(-2.75)*	
η $_{BICYCLE;\ future}$		*-4.58*		*(-10.69)*
ASC $_{PT;\ current}$	-1.03		*(-1.13)*	
η $_{PT;\ current}$		*-1.44*		*(-2.36)*
ASC $_{PT;\ future}$	-3.23		*(-2.11)*	
η $_{PT;\ future}$		*-4.41*		*(-8.28)*
ASC $_{SAV;\ future}$	-0.927		*(-2.83)*	
η $_{SAV;\ future}$		*-1.15*		*(-2.53)*
ß $_{TIME\ WALK}$	-0.366		*(-12.54)*	
η $_{TIME\ WALK;\ (triangular\ dist.)}$		*0.152*		*(12.2)*
ß $_{TIME\ BICYCLE}$	-0.233		*(-11.69)*	
η $_{TIME\ BICYCLE;\ (triangular\ dist.)}$		*0.100*		*(10.41)*
ß $_{TIME\ PT}$	-0.0577		*(-5.83)*	
η $_{TIME\ PT;\ (triangular\ dist.)}$		*0.039*		*(3.85)*
ß $_{TIME\ CAR\ commuting;\ current}$	-0.105		*(−5.96)*	
ß $_{TIME\ CAR\ leisure/shopping,\ current}$	−0.0649		*(−3.32)*	
ß $_{TIME\ AV\ MANUALLY\ commuting;\ future}$	-0.0966		*(-6.33)*	
ß $_{TIME\ AV\ MANUALLY\ leisure/shopping;\ future}$	-0.0539		*(-2.94)*	
ß $_{TIME\ AV\ AUTONOMOUSLY\ commuting;\ future}$	-0.0621		*(-2.98)*	
η $_{TIME\ AV\ AUTONOMOUSLY\ commuting;\ future;\ (triangular\ dist.)}$		*0.063*		*(2.55)*
ß $_{TIME\ AV\ AUTONOMOUSLY\ leisure/shopping;\ future}$	-0.0643		*(-2.60)*	
ß $_{TIME\ SAV\ used\ individually;\ future}$	-0.103		*(-5.98)*	
ß $_{TIME\ SAV\ ride\text{-}sharing;\ future}$	-0.11		*(-6.45)*	
η $_{TIME\ SAV\ ride\text{-}sharing;\ future;\ (triangular\ dist.)}$		*0.039*		*(2.37)*
ß $_{WAITING\ TIME\ PT}$	-0.088		*(-3.8)*	
ß $_{WAITING\ TIME\ AV\ \&\ SAV}$	-0.112		*(-7.06)*	
η $_{WAITING\ TIME\ AV\ \&\ SAV;\ future;\ (triangular\ dist.)}$		*0.298*		*(5.59)*

ß ACCESS/EGRESS TIME PT; current	-0.151		*(-3.12)*	
η ACCESS/EGRESS TIME PT; current; (triangular dist.)		*0.120*		*(1.66)*
ß ACCESS/EGRESS TIME PT; future	-0.031		*(-0.87)*	
ß ACCESS/EGRESS TIME CAR; current	-0.142		*(-5.4)*	
η ACCESS/EGRESS TIME CAR; current; (triangular dist.)		*0.140*		*(3.03)*
ß COST LOW INCOME	−0.991		*(−8.56)*	
ß COST MIDDLE INCOME	−0.806		*(−9.25)*	
ß COST HIGH INCOME	−0.561		*(−7.89)*	
μ (SCALING PARAMETER; applied on the data set for future preferences)	1.15		*(0.102)*	
ß RIDE-SHARING; future	0.118		*(0.49)*	
ß PT PASS on WALK; current	4.26		*(5.98)*	
ß PT PASS on BICYCLE; current	4.72		*(7.27)*	
ß PT PASS on BICYCLE; future	1.99		*(3.07)*	
ß PT PASS on PT; current	5.44		*(8.58)*	
ß PT PASS on PT; future	3.02		*(4.74)*	
ß DRIVING LICENCE on WALK; current	-2.77		*(−2.5)*	
ß DRIVING LICENCE on WALK; future	-4.28		*(−3.55)*	
ß DRIVING LICENCE on PT; current	-3.62		*(−4.48)*	
ß DRIVING LICENCE on PT; future	-1.92		*(−1.35)*	
Model Fit				
Log-likelihood (0)	-11623.44			
Log-likelihood (final)	- 4589.783			
ρ2	0.605			
Estimated Parameters	54			
Observations	7760			

Coefficients for access/egress and waiting times were estimated as mode-specific parameters instead of generic ones. This was in order to allow a comparison between a privately-owned conventional car and an AV which differ in these aspects. The conventional car is presented as having an access/egress time, while the AV has a waiting time instead (as it picks up its passenger and drops them off at their destination). Overall, access/egress time and waiting time for public transport and for conventional car are perceived more negatively than the in-vehicle time. An exception is the estimated coefficient for access/egress time for public transport under future conditions (i.e. when AVs are available) which is not statistically significantly different from zero. As there was no difference between the perceptions of waiting time for a privately-owned vehicle and for SAV in the early model estimations, the waiting time parameter was considered for both alternatives. The results indicate that waiting time for both autonomous driving concepts is perceived as slightly more negative than in-vehicle time, and that there is a significant heterogeneity in the perception of waiting time for AV/SAV across the respondents.

The cost coefficients were estimated depending on the income class to which the respondents belonged. The results show, unsurprisingly, that individuals with a high income perceive cost less negatively than individuals with middle or low incomes, and that those with a middle income perceive cost less negatively than those with a low income. The perception of cost as influenced by trip purpose was tested in early model estimations, but no significant differences were found between the trip purposes.

The characteristics of individual mobility, such as possession of a driving licence or a public transport pass, are also strongly related to mode choice preferences. Having a driving licence decreases the probability of choosing any modes of transport other than the car or an AV, with the exception of choosing a bicycle. Further, the probability of choosing AV or SAV is similarly affected by driving licence possession. Possession of a public transport pass, on the other hand, increases the probability of choosing any mode of transport other than the car or an AV – except that the probability of travelling by SAV is unaffected, remaining the same as the probability of travelling by AV. Overall, the effect of individual mobility characteristics seems not to change significantly when AVs become available.

7.4.2. VTTS and policy implications

Finally, we calculated the VTTS (in euros per hour) for each mode of transport, for each income class, using the following function:

$$VTTS = \frac{\partial U_i / \partial TT_i}{\partial U_i / \partial TC_j} = \frac{\beta_{Time,i}}{\beta_{Cost,j}} \qquad (5)$$

The VTTS presented in Table 6 were calculated based on the results of the final estimated joint mixed logit model. We calculated the VTTS for each mode of transport in Euros per hour separately for each income class. The VTTS calculations for the random time coefficients are based on the mean values of the random distribution, i.e. the estimated ß-time parameters. As the cost parameters used for calculating the VTTS within a single income class are fixed, the results from the comparison of statistical differences between the ß-time parameters reported in section 7.4.1. apply also for the VTTS reported in Table 12.

Table 12: Estimated value of travel-time savings for different modes of transport and income classes [in €/h]

Mode of transport	**Income class**		
	Low income	**Middle income**	**High income**
Walk	22.2	27.3	39.1
Bicycle	14.1	17.3	24.9
Public transport	3.5	4.3	6.2
Conventional car*; commuting trips*	6.4	7.8	11.2
Conventional car; *leisure/shopping trips*	3.9	4.8	6.9
Autonomous vehicle (manually driven); *commuting trips*	5.8	7.2	10.3
Autonomous vehicle (manually driven); *leisure/shopping trips*	3.3	4.0	5.8
Autonomous vehicle (riding autonomously); *commuting trips*	3.8	4.6	6.6
Autonomous vehicle (riding autonomously); *leisure/shopping trips*	3.9	4.8	6.9
Shared autonomous vehicle (used individually)	6.2	7.7	11.0
Shared autonomous vehicle (ride-sharing)	6.7	8.2	11.8

As indicated above, there are differences in the perception of costs, depending on income class to which a person belongs. Thus, we have estimated the VTTS for each income class by using the cost-coefficients corresponding to the particular income category. Consequentially, the estimated values for people with higher household income are higher than of those belonging to middle- or low-income classes, but the proportional differences between the mode-specific values remain the same across the income classes. The values for public transport and for conventional car are in the same range as existing values derived from a representative study on the values of travel time savings for Germany (Axhausen et al., 2014). This indicates that the results of the model estimations performed in the study presented in this paper are plausible.

For commuting trips only, using riding autonomously leads to an average reduction in the VTTS by 41% compared to driving a conventional car nowadays and it is perceived similar as time spent in public transport. However, owing to the additional access/egress and waiting time involved in travelling by public transport, it can be assumed that using an AV for commuting trips is more attractive than using public transport. These results are in line with the results of a previous study on using AVs for commuting trips conducted in Germany (Steck et al., 2018). No significant effect was found regarding autonomous driving for leisure or shopping trips. This may be related to the fact that the VTTS for leisure and shopping trips are, in general, lower than the values for commuting trips. Also, as discussed above, due to the specific characteristics of commuting trips, commuters might be more likely to benefit from using travel time for other activities, and, in addition, automation can lower the stress caused by being stuck in traffic (see also Trommer et al., 2016). Moreover, the type of activities which individuals would like to perform in an AV can affect the travel time perception. For instance, as mentioned above, Correia et al. (2019) found differences in the VTTS for an AV with working compared to an AV with leisure interior. These results were in line with the authors´ theoretical assumption derived from the microeconomics theory that a work AV would have lower VTTS than a leisure one (Correia et al., 2019). Although the authors considered the different types of activities only for commuting trips, the trip purpose might also affect the desirable activities. In our study, desirable activities were not explicitly captured, but differences in time perception depending on trip purpose can be first indications for reasons behind potential preference changes. Hence, given the insights from recent studies and our results, the relationship between travel activities or other benefits from using an AV and trip characteristics (such as trip purpose) have to be further explored in a following works.

The SAV seems to be perceived as a less attractive option than using a privately-owned AV, but considering the additional access/egress and waiting time for public transport, it can be, from a user perspective, a viable alternative to it. Further, no differences were found in the in-vehicle time across the various trip purposes, neither was any difference seen when comparing use of the SAV alone with sharing the ride with strangers. This last result suggests that the respondents perceived both options similarly – but this could be because the concept is, at this point in time, too abstract for most respondents to grasp adequately. Gaining insights into preferences regarding SAVs is important for future planning, since the SAV might be a viable mobility option supporting more efficient car use and contributing to a reduction in vehicle ownership. Since the results of this study are only partly in line with the results of previous studies, especially regarding ride-sharing, further research in this field is needed. Also, the willingness to use SAVs as a complementary instead of competitive option to public transport in areas where the public transport services are deficient today (e.g. periphery or rural areas) has to be explored in further works owing to the fact that public transport is in general more efficient in terms of number of passengers carried.

Turning to policy and transport planning implications, the study findings provide empirical arguments to support the case that, unless there is some form of policy intervention, the reduction of the VTTS of a privately-owned car, especially for commuting trips, can lessen or eliminate some of the potential benefits of autonomous driving. As also discussed in previous studies, the reduction in the VTTS (and thus of the generalised cost of travel) can lead to an increase of the attractiveness of travelling in general, and a shift from non-motorised to motorised modes of transport, as well as increasing the tendency to travel longer distances, by bringing about a change in choice of destination (Bahamonde Birke et al., 2018, Wadud et al., 2016, Gruel and Stanford, 2016). This carries the potential of causing a substantial increase in travelled vehicle-kilometres, along with an overproportional increase in the negative externalities of transportation (as the relationship between the negative effects of polluting emissions and congestion is not linear) that may end up diminishing the social welfare.

Along these lines, the fact that VTTS by means of autonomous driving would be reduced to the level of public transport, may also result in demand shift from public to private transportation putting the transit system under financial pressure. Therefore, when formulating policy measures, including pricing policy, designed to facilitate sustainable transport, the potential conflict between, on the one hand, improving the quality of individual mobility, and, on the other hand, challenges related to the transport system that arise from a reduced VTTS, has to be considered. Since improvements in traffic efficiency and road capacity arising from automation can be achieved only when the share of AVs on the street increases (Hartmann et al., 2017, Calvert et al., 2017) and especially if connectivity between the AVs (and infrastructure) is given (Milakis et al., 2017), policy measures are needed to ensure an efficient use of the technology from the point of its implementation into the transport system onwards. One possible strategy could be incentivising multimodality by facilitating the use of AVs, especially SAVs, as a solution to the first/last-mile problem, and thereby improving the quality of public transport as a viable and reliable door-to-door mobility option (Scheltes and de Almeida Correia, 2017). Such measures, however, would have to tackle the large negative incentives against transferring (represented through the waiting time coefficients in our model) that may prevent individuals to use AVs in that way and encourage riding AVs from origin to destination instead.

Other viable policy measures, especially in urban areas, might include ones intended to facilitate the use of SAV, especially as a ride-sharing service. However, the results of our study suggest that this mobility alternative might be less preferable to users than a privately-owned AV, which challenges the vision that AVs are mostly going to be used as shared vehicles. Hence, the potential for such measures – for example supporting the use of SAV by reducing prices, or permitting only SAVs in urban centres – needs to be explored in future studies concentrating on this topic, as substantial incentives may be required, while prohibition may face strong public opposition. Here again, the potential of using SAVs as a part of an integrated transport system, and as an alternative to the privately-owned vehicles instead to public transport, has to be in focus of these analyses.

All in one, the results of the study support the hypothesis that AVs will facilitate individual motorized mobility. Consequentially, in the absence of measures to impose additional restrictions on car usage or force users to internalise the externalities of their behaviour by means of pricing, such as tolling systems, there is a high risk of undesired shifts from non-motorized transportations modes and increases in travel demand (Bahamonde Birke et al., 2018, Gruel and Stanford, 2016).

7.5 Conclusions

The aim of the study was to estimate potential changes in the value of travel-time savings (VTTS) when autonomous driving becomes available. For this purpose, user preferences regarding currently available modes of transport and user preferences regarding modes of transport available in the future were compared using two discrete-choice experiments. The VTTSs for two concepts of autonomous driving – privately-owned autonomous vehicle (AV) and a shared autonomous vehicle (SAV) – were calculated on the basis of the results of a joint mixed logit model.

First, the results suggest a VTTS reduction of 41% for commuting trips for autonomous driving as compared to driving a conventional car nowadays. However, no changes in the VTTS were found for leisure or shopping trips, suggesting that a general VTTS reduction resulting from availability of autonomous driving cannot be confirmed by the study results. Second, in-vehicle time in an SAV is found to be perceived more negatively than using either a privately-owned AV (riding autonomously) or public transport. However, here too, a consideration of the access/egress and waiting time besides the in-vehicle time associated with public transport suggests the potential for the SAV as a service that is an alternative – or complementary – to public transport. Third, policy implications that can be drawn from the results of the study suggest that there is a potential conflict between user benefits of autonomous driving and societal goals. This is related to the fact that a reduction of the VTTS for autonomous driving on commuting trips will potentially lead to an increase in vehicle-kilometres travelled. Similarly, as the reduction of VTTS mostly affects private transportation, it can also cause a shift in the demand from public transportation and non-motorized alternatives to privately-owned vehicles. Both phenomena may pose a challenge to transport planners, as increases in the demand for private transportation at the expense of the demand for more efficient alternatives can cause an increase in the negative externalities of transportation and, hence, welfare losses.

Because the technology is not yet available in the market, any assessment of the impact of automation using stated preference methods has its limitations and it is highly dependent on the chosen study design, especially on the way new alternatives are presented. A privately-owned AV can be presented to respondents in different ways, including presenting a fully automated vehicle in the same choice set with a conventional one or adding the function of automation as an attribute of the alternative “car”. We have chosen to present a car able to drive autonomously or manually upon request in order to avoid an implicit purchasing decision for a type of car which might potentially influence the choices of respondents. It is therefore important to interpret the results of the study from the background of the chosen design. Acknowledging the challenges related to stated preference methods in general, we have focused the analysis on higher-level constructs such as that of the VTTS. Furthermore, using a reference trip and addressing first the user preferences regarding current modes of transport (including a privately-owned conventional car) allows considering individual knowledge and perceptions as a baseline and this improves the accuracy of the estimation of changes in VTTS. The approach used in this study provides a better understanding of user preference changes, as considering only future preferences would not capture the baseline, that is to say mode choice preferences under current conditions. Moreover, capturing both current mode choice preferences and future preferences considering new mobility options provides more accurate input for travel demand models, which are an important tool for analysing the possible impact of automation on travel behaviour.

Last but not least, further empirical work on the effects of the way in which autonomous driving, and especially of SAVs, are introduced to the respondents is required. Using visual materials such as videos, as done in this study, might be better than providing only text description, but their limitations have to be considered when interpreting the results. Experience-centered methods, such as field tests or using virtual reality can be explored in future works on potential user preferences even though the higher cost of those methods might be a limitation.

In summary, this study has provided valuable empirical insights into potential changes in the VTTS for autonomous driving. Further empirical research could explore the factors affecting the reduction of the VTTS for autonomous driving in more detail, including characteristics related to context, such as geographical factors, as well as current congestion levels or other restrictions on comfort levels. Furthermore, exploring attitudinal and perceptual variables could provide valuable insights into the mode choice decision-making process, once the technology becomes available in the market. These can additionally contribute to the development of efficient measures for implementing and promoting the technology in a way which considers users' needs and their mobility requirements. Along these lines, exploring the willingness to perform different activities while riding autonomously (e.g. working, reading) or to relax during the trip can contribute to evaluating the potential impact of autonomous driving on travel quality, economical welfare and well-being. Finally, the use of SAVs and their impact on vehicle ownership and mobility behaviour in general is an important avenue of research on which future studies should focus. Because this study focused on mode choice, vehicle purchase decisions were not considered. As discussed above, policy and transport planning authorities face new challenges resulting from the implementation of vehicle automation. Empirical evidence, as provided in this paper, is thus of great importance when considering and discussing both the opportunities, and also the risks, associated with implementing this technology.

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8 Analysis of the effects of psychological factors on the value of travel time savings for autonomous driving

'… AVs' VoT [value of time] impact might be more modest than anticipated and derive from a different source. … Although AV riders will likely have greater activity participation during travel, many in-vehicle activities today may be more about coping with commuting burdens than productively using travel time. Instead, VoT reductions may be more likely to arise from a different 'positive utility' – subjective well-being improvements through reduced stresses of driving or the ability to relax and mentally transition. Given the high uncertainty, further empirical research on the experiential, time use, and VoT impacts of AVs is needed.'

Patrick A. Singleton, 2018
'Discussing the 'positive utilities' of autonomous vehicles: Will travellers really use their time productively?', Transport reviews 39(1): 50-65.

To what extent do psychological factors, i.e. attitudes and perceptions, influence the VTTS for autonomous driving?

In the previous quantitative study, we found that autonomous driving led to a reduction in the VTTS for a car, but only on commuting trips. Moreover, consistent with the vast literature on 'traditional' transport modes, the study also found significant heterogeneity in the sensitivity to travel time in AVs. Understanding the sources of this preference heterogeneity would enable the development of more differentiated scenarios concerning how vehicle automation will affect travel time valuation and mode choices. The above quote represents the view of one of an increasing number of researchers who question the general assumption that autonomous driving will reduce the VTTS and suggest investigating potential influencing factors more deeply to understand the mechanism behind potential behavioural changes. Consistent with this, the findings of the explorative qualitative study (Study 1) described in this thesis suggest that the attitudes and perceptions of potential users influence how they perceive the travel time spent in an AV. Despite the literature discussion and the insights from the qualitative analyses, the effect of psychological factors on the VTTS for AVs has not been yet quantified. Also in general in the transportation research field, while the effect of these factors on mode choices is addressed in several studies, their impact on VTTS is considered only in few research works.

The following paper, '**Analysing the impact of psychological factors on mode choice preferences and value of travel time savings for autonomous driving**', focuses on quantifying the effect of selected individual characteristics on the VTTS with a specific focus on attitudes and perceptions. Similarly to the previous quantitative study, it uses the SP approach and discrete choice model (in this case, a hybrid choice model).

The results of the study suggest that perceived travel experiences in an AV as well as trust in the technology positively affect the valuation of travel time spent riding autonomously. Moreover, VTTS for different user segments depending on their socio-demographics and attitudes were calculated. Policy and practice implications are derived from the results of the study.

The study contributes to the overall discussion on how vehicle automation will influence the VTTS by providing empirical evidence about the important role of psychological factors when analysing the travel time sensitivity of various potential user segments of AVs.

Impact of trust and travel experiences on the value of travel time savings for autonomous driving

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Abstract

Autonomous driving is expected to strongly influence the value of travel time savings (VTTS) which is crucial for the assessment of the impact of automated vehicles (AVs). However, no consensus has been reached yet about the size and direction of the effect of AVs on VTTS. This high uncertainty around the VTTS is most likely due to high heterogeneity in preferences for travel time. Our hypothesis is that a key role in the heterogeneity of the VTTS for AVs is played by psychological factors. We focus in particular on Travel Experiences (besides individual preference for activities conducted during travelling) and Trust in travel time preferences for AVs. For this purpose, an online survey with a stated choice experiment and psychometric scales was conducted. Besides currently available transport modes, also a privately-owned AV (PAV) and a shared AV (SAV) were included in the choice sets. The data was analysed using a hybrid choice model. T-test and confidence intervals of the estimated VTTS are computed to assess if the VTTS are statistically significant and statistically different among user groups. Results confirm that both psychological factors have significant positive effect on VTTS for AVs. Gender, age, level of education and experience with similar systems were found to affect the VTTS directly and indirectly through their impact on the individual attitudes. Our results show that the average VTTS for SAV is lower than for PAV, but they show also that this the difference is not statistically significant. Differences are found instead among some user segments, in particular in terms of trust to technology and anticipated travel experiences. For example, men are found to trust the technology more than women and also to have potentially higher technology affinity. However, our results show that they also perceive higher marginal disutility for travel time. Lastly, implications for policy and technology deployment strategies are discussed based on the findings.

Keywords: automated vehicles, autonomous driving, value of travel time savings, willingness to pay, positive utility of travel, hybrid choice model, attitudes

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8.1 Introduction

Autonomous driving is expected to strongly affect the preferences for time spent in a vehicle and consequentially, also the value of travel time savings (VTTS), i.e. the willingness to pay for marginal reduction in travel time. As VTTS is a key element of transport cost-benefit analysis, anticipating travel time preferences for travelling in an autonomous vehicle (AV) is crucial for the assessment of the impact of this new technology.

The impact of autonomous driving in the preferences for travel time has been extensively discussed in the recent literature, but no consensus has been yet reached about the size and direction of this impact. The majority of the studies (e.g. Gucwa, 2014, Anderson et al., 2014, Childress et al., 2015, Kröger et al., 2016, Wadud et al., 2016) has assumed (in few cases found empirically (Becker and Axhausen, 2018, Correia et al., 2019, Kolarova et al., 2019b, Kolarova and Steck, 2019)) a significant reduction in VTTS for AV users, i.e. that time is perceived less negative when riding autonomously in a vehicle compared to driving manually. However, there is a small but growing number of researchers suggesting that this reduction will be more modest than expected (Singleton, 2018, Pudāne et al., 2019) or that there will be no reduction (Krueger et al., 2019) or even an increase in VTTS (Rashidi et al., 2020). The high uncertainties regarding size and direction of the VTTS is reflected also in an overview of researchers´ opinions provided by Singleton (2018): for instance, he cites the work of Willumsen and Kohli (2016), who report that the VTTS impacts of AVs ranged from 50% reduction to 50% increase.

This high uncertainty around the VTTS is most likely due to high heterogeneity in preferences for travel time. However, contrary to the vast literature on 'traditional' transport modes, few empirical studies have studied heterogeneity in the preference for travel time on AVs. These studies do not relate VTTS differences to individual characteristics but mostly to the vehicle concept (privately-owned AV, shared AV, or first/last mile mobility solution; Steck et al., 2018, Krueger et al., 2016, Yap et al., 2016, Alonso-González et al., 2020, Moore et al., 2020), trip purpose and/or trip length (Kolarova et al., 2019b, Ashkrof et al., 2019), vehicle equipment (office vs. leisure interior; Correia et al., 2019, De Looff et al., 2018), or spatial characteristics (suburban, urban and rural areas; Zhong et al., 2020).

Both, attitudes and perceptions of potential users have been found to play a crucial role in the user evaluation of riding autonomously (see literature reviews by Becker and Axhausen, 2017, Gkartzonikas and Gkritza, 2019). These include travel experiences (Singleton, 2018, Pudāne et al., 2019), trust in the technology (Ashkrof et al., 2019, Molnar et al., 2018, Yap et al., 2016, Zhang et al., 2019), technology awareness (e.g. Silberg et al., 2013, Schoettle and Sivak, 2014), consumer innovativeness (e.g. Silberg et al., 2013, Haboucha et al., 2017, Schoettle and Sivak, 2014), safety concerns (e.g. Jardim et al., 2013, Yap et al., 2016, Howard and Dai, 2014), environmental concerns (e.g. Jardim et al., 2013, Brown et al., 2014, Haboucha et al., 2017, Bansal et al., 2016), perceived opportunity for productivity or time use and lower stress (e.g. Zmud et al., 2016a, Shabanpour et al., 2018), passion for driving or driving related sensation-seeking (e.g. Silberg et al., 2013, Ipsos MORI, 2014), and data privacy concerns (e.g. Zmud et al., 2016a, Silberg et al., 2013). Although some factors (e.g. lower stress or trust in the technology) have been discussed in relation to travel perception, these empirical studies focus only on the effect of the psychological constructs on the willingness to use AVs; they do not discuss and even less measure to what extent attitudinal factors can explain uncertainty around the VTTS for AV users.

In addition, in general in the transportation field, while the impact of psychological variables on mode choices is addressed in various empirical works (e.g. Golob, 2001, Johansson et al., 2006, Kamargianni and Polydoropoulou, 2013, Paulssen et al., 2014), there is only little empirical research on the impact of psychological factors on the value of time. A study conducted by Abou-Zeid et al. (2010) quantifies, according to the authors, for the first time the effect of attitudes on the value of time distribution. The authors looked at cost sensitivity of travellers depending on their attitude toward car use. Similar approach for analysing variation in the willingness to pay related to attitudinal factors was applied in forecasting the demand of electric vehicle (Glerum et al., 2014) or the impact of congestion price in the departure time (Thorhauge et al., 2019). Studies addressing travel time sensitivity to psychological factors are, on the other hand, scarce. Bahamonde-Birke et al. (2017) measured the effect of attitudes and perceptions on travel time preferences in a study on interurban public transport, whereas Li and

Kamargianni (2020) measured the impact of three attitudinal factors on travel time sensitivity in a recently published research work on preferences for bike- and car-sharing services.

Given the wide range of potential factors that can affect users' preferences for AVs, understanding the sources of variation in travel time preferences for AVs is crucial for developing more realistic and differentiated scenarios about the impact of autonomous driving on mode choices and travel demand. This study aims to contribute to the above literature by discussing the impact of Travel experiences (besides individual preference for activities conducted during travelling) and Trust in travel time preferences for AVs and providing empirical evidence about the extent to which these factors, and the socio-economic characteristics that explain them, affect heterogeneity around the VTTS for AVs. T-test and confidence intervals of the estimated VTTS are computed to assess if the VTTS are statistically significant and statistically different among user groups. At the best of our knowledge, none of the studies on AVs discussed the statistical significance of the VTTS. Other psychological factors mentioned above were found to be related to the intention to use AVs, but these are not directly related to travel time perceptions and are consequentially also not in focus of this study. Passion for driving or driving related sensation-seeking was also found to affect negatively VTTS for AVs, but we did not consider this factor in our study because it is part of the travel experiences in a car and because it is related to the positive utility of manual driving rather than to autonomous driving. Finally, it is worth noting that we focus on travel experiences, besides individual preference for activities conducted during travelling. Research found that people travelling in an AV are more likely to relax than to work (Cyganski et al., 2015, Fraedrich et al., 2016, Roeckle et al., 2018). The role of trust in travel time perception in an AV is a requirement to consider performing activities in such vehicles.

The paper is organised as follows: in section 8.2 we discuss the role of travel experiences and trust in the VTTS; in section 8.3 we describe the methodology used to collect the data (section 8.3.1), to estimate the demand model (section 8.3.2) and to compute the VTTS (section 8.3.3). In section 8.4 we present and discuss the results of the models´ estimated, while in section 8.5 we discuss the VTTS computed for different user groups and the implications for the development of the AV technology. Finally, in section 8.6 we summarise the conclusions derived from this study as well as future research.

8.2 Impact of travel experiences and trust in an AV on the preferences for autonomous driving

In the following, we give a brief overview of the state of the art and knowledge on potential determinants and elements of the value of time for AVs, focusing on the two selected psychological factors for this study.

8.2.1. Travel experiences and activities conducted during travelling

One theoretical justification of the changes in travel time preferences due to vehicle automation can be derived from conceptual and empirical works on the positive utility of travel. It is an extension to the assumption that travel is a derived demand and is theoretically postulated by . These authors suggest that travel can also be desired for its own sake, i.e. travel time can have a positive utility for an individual. Thus, they conceptualize three elements of the utility of travel: (i) activities conducted at the destination, (ii) activities that can be conducted while travelling, and (iii) the activity of travelling itself. The first element won´t change due to vehicle automation, whereas the feasibility of new activities during travelling potentially will. Also, theoretical works on the positive utility of travel in the context of AVs suggest that potential improvement of the travel experiences or the travel-related subjective well-being, in terms of stress relief or increased comfort level, will play an important role in travel time valuation (Mokhtarian, 2018, Singleton, 2018). Although these two elements are strongly interrelated with each other, theoretical and empirical works suggest that it is useful to consider them as separate elements of the travel utility (Mokhtarian and Salomon, 2001, Singleton, 2017) as they have different determinants and implications for travel demand (Pudāne et al., 2019).

Previous studies for currently available modes of transport found that commute well-being (e.g. Smith, 2017, Ettema et al., 2013) as well as conducting activities while travelling (e.g. Molin et al., 2020, Malokin et al., 2019) influence mode choices and VTTS. However, there are contradictory empirical findings, some suggesting lower VTTS for AVs with an office interior than for a conventional vehicle or an AV with a leisure one (Correia et al., 2019). These authors stress that the results are not intuitive and in line with the expectation of several experts and recommend further research on the role of leisure activities on travel time perception in an AV. In a follow-up comment published by Pudāne and Correia (2020), a potential explanation of the findings is provided linking the feasibility of on-board activities with out-of-vehicle time use. Again, the authors suggest further research in this field, among others, accounting for various types of work and leisure activities. Along these lines, context-related characteristics can shape the utility of giving up the driving task (see also Kolarova et al., 2019a). For example, performing different activities while travelling can become relevant on longer trips as some of them might require certain minimal time (e.g. reading, watching movie, etc.). Also Malokin et al. (2019) analysed the effect of activities during travelling on mode choices and looked at potential AV scenarios. The authors found that the propensity to engage in productive activities influence the VTTS.

The role of both feasibility of activities performed while travelling and improvement of travel experiences together, is discussed so far in theoretical works (Mokhtarian, 2018, Singleton, 2018) or in explorative qualitative studies (Pudāne et al., 2019, Kolarova, 2020). These studies suggest that VTTS for AVs might change mainly because of advantages related to reduced stress of driving and ability to relax during the trips rather than of being able to use the travel time in a productive way, which is often postulated in the literature as an important benefit of vehicle automation (Singleton, 2018).

In line with this discussion, the results of a study conducted by Cyganski et al. (2015) on the desirable activities performed during travelling in an AV, suggest that, in contrast to the theoretically assumed productivity benefits of vehicle automation (Clements and Kockelman, 2017, Montgomery et al., 2018, Anderson et al., 2014), working is among the least preferred activities in an AV. Indeed, desirable activities performed in an AV are more likely to be those also currently performed while travelling (Cyganski et al., 2015, Fraedrich et al., 2016, Pudāne et al., 2019) and in particular rather passive activities, such as enjoying the trip and the landscape and/or relaxing (Cyganski et al., 2015, Fraedrich et al., 2016, Roeckle et al., 2018). This supports our choice to focus on the travel experiences in terms of travel quality rather than on how the time inside the car is used. So far, this discussion lacks quantitative empirical evidence especially for the impact of travel experiences on travel time valuation of AV users.

All in one, improvement of travel experiences in terms of reduced stress when riding autonomously is discussed to play even more important role for travel time valuation in an AV than using travel time for other (productive) activities (Singleton, 2018).

8.2.2. Trust in the automated technology

Among the several psychological factors discussed in the AV literature, trust in the technology is (one of) the most relevant psychological determinants of the willingness to ride autonomously (e.g. Zmud et al., 2016a, Molnar et al., 2018, Ashkrof et al., 2019). Furthermore, trust has been proven to play in general a key role in the adoption of new technologies (e.g. Gefen et al., 2003, Pavlou, 2003).

Research in the context of AVs has focused on the effect of trust on the willingness to use an AV. Across different types of studies, trust in AVs is found to influence: user acceptance in terms of intention to use an AV (e.g. Choi and Ji, 2015, Kaur and Rampersad, 2018), mode choice preferences for AVs (e.g. Yap et al., 2016, Ashkrof et al., 2019), willingness to purchase an AV (Jardim et al., 2013), as well as the extent to which participants in a simulated driving study chose to engage with the automated driving mode (Molnar et al., 2018). It is noteworthy, however, that there is neither standardized definition nor standardized measurement instrument of trust in AVs. The term 'trust' in the context of AVs is used mainly in relation to vehicle safety, reliability of the system, or to describe affective reactions, such as being nervous or being afraid of using an AV. For instance, Yap et al. (2016) and De Looff et al. (2018) measured 'trust in AVs' with items or indicators, such as 'I trust that a computer can drive my car with no assistance from me', which were borrowed from a study conducted by Jardim et al. (2013), where the authors called the same construct 'safety'. In this sense, measuring trust in the system include also various related aspects which are found to be crucial in choosing riding autonomously (e.g. safety concerns; Gkartzonikas and Gkritza, 2019).

The studies in the context of AVs so far have only measured the effect of trust on the intention to use AVs (Choi and Ji, 2015, Yap et al., 2016, Ashkrof et al., 2019, Zhang et al., 2019, Keszey, 2020). Trust has also been discussed to be a necessary condition to consider using an AV and/or to perceive the benefits of time spent riding autonomously. For instance, Yap et al. (2016) comment that lack of trust in the technology contribute that 'passengers do not fully perceive theoretical advantages of AVs regarding travel time valuation'. Wadud and Huda (2019) suggest that preferences to watch the roadway instead of performing other activities in an AV indicate lack of trust in the system. This aspect was pointed out also by Fraedrich et al. (2016): willingness of potential AV users to focus their attention towards traffic and to remain in the traditional upright seating position was attributed to low level of trust. In other words, lack of trust in AVs potentially will make people feel uncomfortable when riding autonomously and limit the utility of travel time in an AV. But none of the studies so far measured the impact of trust on the travel time preference while driving in an AV, and hence on the VTTS.

Last but not least, regarding determinants of trust in AVs, experience with advanced driving assistance systems (ADAS) was found to play an important role: people who are using or has tested ADAS seems to be more likely to trust the technology (e.g. in Rödel et al., 2014, Kolarova, 2020). Experiences with similar technologies have been also found to influence directly the willingness to use an AV (Kyriakidis et al., 2015, Zmud et al., 2016a). None of these studies, however, has analysed quantitatively both the direct effect of previous experiences on choosing an AV and their indirect effect on this choice trough increasing trust in the technology.

8.3 Methodology

8.3.1. Survey design and sample

In order to analyse the effect of travel experiences and trust on the travel time preferences and hence on the VTTS, an online survey was conducted among commuters aiming to control in this way for the effect of trip purpose on the VTTS. Having a regular commuting trip (to work or to professional school/university) was then a requirement to participate to the survey[2]. Respondents were recruited by a professional online panel provider. The sample was selected to be representative of the population in Germany in terms of age and gender (between 18 and 69 years old). After data cleaning, the final sample for the analyses consists of 484 respondents.

The questionnaire contained the following five parts: (i) information about the current commuting trip, (ii) a SP experiment on mode choices for the reported commuting trip, (iii) attitudes related to the use of autonomous driving, (iv) an individual evaluation of the commuting trip in terms of experiences and time use and (v) questions about socio-demographic and travel behaviour-related characteristics of the respondents.

The information about the current commuting trip included questions about trip length, duration, mode of transport usually used for the trip, level of congestion experienced (for the car users only), satisfaction with the trip, and activities conducted during the trip.

The SP experiment included eight decision situations in which respondents had to choose between five modes of transport for their commuting trip, assuming that all of these alternative modes are available in the market. The alternatives were: walk, bike, public transport and two concepts of AVs: a privately-owned automated vehicle (PAV), and a shared automated vehicle (SAV). The alternatives were described with the following characteristics (attributes): (in-vehicle) travel time, access/egress time (only public transport), waiting time (public transport, PAV and SAV), cost for the trip (public transport,

[2] Besides the insights from previous works that automated driving is considered as an attractive option for commuting, certain characteristics of this type of trip makes it relevant to look at when considering the travel time preferences change due to AVs. These are, among others, the regular nature of the trip, role of habit, higher time pressure on working days, and the higher probability of driving in congestion while commuting because of peak hours.

PAV and SAV), and only for the SAV whether the vehicle was going to be used individually or in a ride-sharing arrangement. The attributes and their levels are presented in Table 13.

Table 13: Attributes and levels of the SP experiment

Mode of transportation	Attribute	Levels
Walk	Travel time	-30%|-10%|+20% from the reference time
Bike	Travel time	-30%|-10%|+20% from the reference time
Privately-owned automated vehicle (PAV)	Travel time	-30%|-10%|+20% from the reference time
	Waiting time	2 Min. | 5 Min. | 10 Min.
	Cost	-30%|-10%|+20% current cost
Shared automated vehicle (SAV)	Travel time	-30%|-10%|+20% from the reference time
	Waiting time	2 Min. | 5 Min. | 10 Min.
	Individual use vs. ride-sharing	Dummy variable
	Cost	-30%|-10%|+20% from the reference costs 'individual use' -30%|-10%|+20% from the reference costs 'ride-sharing'
Public Transport (PT)	Travel time	-30%|-10%|+20% from the reference time
	Access/egress time	2 Min. | 5 Min. | 10 Min.
	Waiting time	2 Min. | 5 Min. | 10 Min.
	Travel cost	-30%|-10%|+20% from the current costs

Before showing the SP experiment, two concepts of AVs were presented to the respondents using short videos that showed how a trip with a PAV or a SAV can looks like. For the SAV, two options were shown: (i) an individual trip in a SAV, i.e. the user ride alone in the vehicle and (ii) a trip in a ride-sharing arrangement, i.e. the user share the ride with other users with the benefit of reducing the trip cost. The PAV was presented as a vehicle that is able to drive fully autonomously and, on request, can be driven manually[3]. In contrast to this, the SAV was presented as a vehicle that can only drive fully autonomously and cannot be override by the user.

A more detailed description of the SP experiment (study design, design optimization methods) and detailed description of the videos that present the two AV concepts, can be found in Steck et al. (2018), Kolarova et al. (2019b).

The next part of the survey included the measurement of the selected psychological factors. The constructs were operationalized using psychometric scales: for the construct trust, a set of items measured on a five-point Likert scale (Likert, 1932) were used; the construct travel experiences[4] was measured instead using a semantic differential (Osgood et al., 1957). The constructs were operationalized relying on existing scales from the literature; they were adapted to the research focus and translated in German. To ensure the quality of the scales after the adaptation and translation, a two-step pre-test was conducted and the items were adjusted based on the results from the test. Trust in an AV, or in the reliability/safety of an AV, was measured using indicators for the construct developed in a study by Jardim et al. (2013) and used also in Ashkrof et al. (2019). The travel experiences in an AV was measures using indicators adapted from the Satisfaction with Travel Scale (STS) developed by Ettema et al. (2011) and from the scale used by Smith (2017) that builds upon the STS. We considered

[3] The reason behind the choice to make the use of PAV on request, similarly to a conventional vehicle, was mainly to focus on the willingness to use automation as a feature, and to avoid mixing a purchase decision for an AV with a mode choice decision.
[4] The measured construct represents the subjective evaluation or satisfaction of travelling in an AV and covers the affective components of the construct commute well-being (see Ettema et al., 2011, Smith, 2017).

in this study only affective components[5], i.e. feelings during a commute with AV. Note that the STS was developed and used to evaluate commute well-being and travel satisfaction with currently available modes of transportation. In this study, it measures the expected travel experiences in an AV or the subjective evaluation of how people imagine a commuting trip to be if they were using an AV. Table 14 gives an overview of the measured constructs, their indicators and Cronbach´s α for each scale.

Table 14: Overview of the latent variables and their indicators

Latent variables	**Indicators/Items**	**M**	**SD**	**Cronbach´s α**
Trust[a]	I trust that a computer can drive my car with no assistance from me. *(trust_01)*	2.88	1.34	.900
Trust[a]	I would be comfortable entrusting the safety of a close family member to an automated vehicle. *(trust_02)*	2.90	1.37	
Trust[a]	I think that the automated driving system provides me more safety compared to manually driving. *(trust_03)*	2.80	1.28	
Travel experiences[b]	My commuting trip would be very … 1 = ... displeasing.; 5 = ... enjoyable. *(travel_experiences_AV_01)*	3.57	1.28	.872
Travel experiences[b]	I would be very … 1 =... stressed.; 5 = …calm. *(travel_experiences_AV_02)*	3.49	1.35	
Travel experiences[b]	My commuting trip would be … 1 =... monotonous and boring.; 5=... very exciting. *(travel_experiences_AV_03)*	3.10	1.23	
[a] All indicator statements were measured on a 5-point Likert scale (1 = strongly disagree;5 = strongly agree)				
[b] Indicator statements 5-point semantic differential				

As part of the individual evaluation of the commuting trip, respondents were asked to report which activity they would have most likely performed while travelling in an AV (Question: *"Which of the following statements would apply to your trip to work if you were using an autonomous vehicle on your commuting trip?"*).

Figure 4 shows the share of the answers for the willingness to perform a certain activity in the AV. The list of activities that can be performed in the AV was borrowed from a study on acceptance of different use-cases of autonomous driving conducted by Fraedrich et al. (2016). Results are in line with previous studies (among others Fraedrich et al., 2016, Cyganski et al., 2015) and how that a higher share of potential users would rather prefer relaxing or enjoying the ride and the landscape when riding in an AV, whereas a small share of people (19%) would prefer using the trip for working. These results underline additionally that improvement in travel experiences in terms of reduced stress or being able to relax or perform more passive activities are perceived as more important benefits of autonomous driving than active or productive time use. This justifies focussing on travel experiences and their impact on VTTS in this study.

[5] The STS measure affective responses to the commute (i.e. feelings during the commute, such as enjoyment, excitement) and cognitive responses (i.e. evaluation of the commute afterwards, such as "worked well", "was high standard") (see Ettema et al., 2011, Smith, 2017).

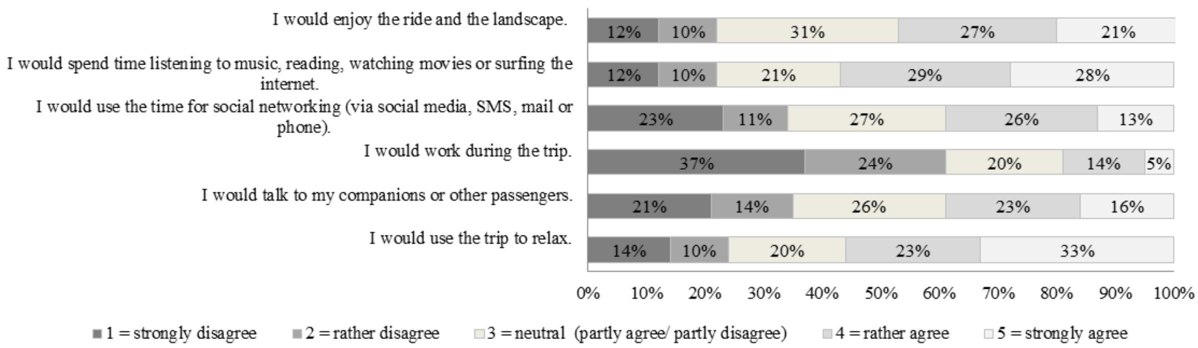

Figure 4: Distribution of the willingness to perform various types of activities in an AV

The final part of the survey was dedicated to collect the following socio-demographic and travel behaviour-related characteristics of the respondents: age, gender, educational level, household income, possession of a driving license and/or public transport pass, car availability in the household, and experiences with advanced driving assistance systems (ADAS). Table 15 summarizes the descriptive statistics for these variables. As the study focuses on commuting trips, we compared the descriptive statistics with representative statistics for the German working population. This comparison shows that the values for the most socio-demographic characteristics in the sample are in the range of the target population. Some differences can only be seen for the age distribution (lower share of people between 30 and 50 years and higher share of over 50 years old people in the sample) as well as in the share of possession of driving licence and car availability in the household (both higher in the sample compared to the reference values).

Table 15: Descriptive statistics of the socio-demographic and mobility-related characteristics

Variable	**Category**	**Relative frequency in the sample (N=484)**	**Relative frequency in the German working population**
Gender	Male Female	50.2% 49.8%	50.8% 49.2%
Age	18-29 years old 30-50 years old over 50 years old	17.4% 42.1% 40.5%	19.1% 48.8% 32.1%
Educational level	Lower than university University or higher	65.7% 34.3%	68.8% 31.2%
Household income	Low (< 1.500 Euro/month) Medium (1.500 – 3.000 Euro/month) High (> 3.000 Euro/month)	14.5% 41.7% 43.8%	13.9% 41.6% 44,5%
Possession of driving license	No Yes	6.0% 94.0%	15.8% 84.2%
Possession of public transport pass	No Yes	68.0% 32.0%	73.0% 27.0%
Car availability in the household	No Yes	11.2% 88.8%	17.2% 82.8%
Experiences with ADAS	No *(= no experiences)* Yes *(= use them or have tested them)*	63.4% 36.6%	*no information*

8.3.2. Demand Model specification

In the *first* step, the data was analysed using a mixed logit (ML) model (Train, 2009, Hensher and Greene, 2001). The ML used as a baseline model includes a set of error components to measure correlation across decision situations (i.e. the correlation among choices of the same individual) and a set of interactions between socioeconomic characteristics and travel times to measure systematic heterogeneity in travel time.

The utility function of the baseline ML model is formulated as follows:

$$U_{int} = \beta_x \cdot X_{int} + \beta_s \cdot SE_n + \beta_{s,TT} \cdot (SE_n \cdot TT_{int}) + \eta_{in} + \varepsilon_{int} \quad (1)$$

In equation 1, the utility U_{int} associated with alternative i as evaluated by the individual n in the choice situation t. is represented by (i) a vector of explanatory variables X_{int} (characteristics of the alternatives, including travel time TT) and SE_n (socio-economic characteristics of the individuals), (ii) a vector of parameters associated to these variables (β_x, β_s, $\beta_{s,TT}$) that includes also parameters for the interaction between the socio-economic variables and travel time, and (iii) two additive stochastic terms: a random term η_{in} normally distributed with a zero mean and standard deviation σ_η to be estimated (capturing the correlation across the multiple choice situations) and a random term ε_{int} distributed iid extreme value type 1.

In the *second* step, a hybrid choice model (HCM) was estimated, to test the effect of the latent attitudes (Ben-Akiva et al., 2002, Walker and Ben-Akiva, 2002). Differently from the common HCM applications, in this paper we interact the latent attitudes with the travel times, to account for systematic and random heterogeneity in travel time due to respondents' attitudes toward trust and perceptions of travel experiences. The utility of the HCM is formulate as follows:

$$U_{int} = \beta_x \cdot X_{int} + \beta_s \cdot SE_n + (\beta_{s,TT} \cdot SE_n + \beta_{LV,TT} \cdot LV_{in}) \cdot TT_{int} + \eta_{in} + \varepsilon_{int} \quad (2)$$

where $\beta_{LV,TT}$ is a vector of parameters associated to the interaction between the LV and TT, to be estimated; all other terms are the same as in equation (1).

The LVs cannot be directly measured as other variables, but information about them can be inferred from observable (measurable) indicators, such as the answers on the Likert scale questions. The latent variables are explained by observed explanatory variables (typically characteristic of the individual SE_n) through *structural equations,* which take the following form:

$$LV_{nl} = \alpha_l + \alpha_{l,LV} \cdot SE_n + \nu_{nl} \qquad l = 1,2 \quad (3)$$

Where, in our case, l=1,2 as we have two LV (trust and travel experiences), α_l is the intercept, $\alpha_{l,LV}$ is a vector of coefficients associated to the explanatory attributes and ν_{nl} is a random term normally distributed with a zero mean and standard deviation σ_ν to be estimated.

On the other hand, the latent variable explains the indicators I_{nlp} through *measurement equations,* formulated as follows:

$$I_{nlp} = \gamma_{lp} + \gamma_{lp,LV} \cdot LV_{nl} + \zeta_{nlp} \qquad p = 1,...,P_l \quad \& \quad l = 1,2 \quad (4)$$

P_l is the number of indicators for each latent variable l, γ_{lp} is the intercept, $\gamma_{lp,LV}$ is the coefficient associated to the latent variable and ζ_{nlp} is a random terms normally distributed with zero mean and standard deviation σ_ζ to be estimated.

Let be, P_{int} the multinomial logit probability of individual *n* choosing alternative *i* in the choice situation *t*. The conditional probability of individual *n* choosing the sequence of choices **t**=(1,..., *T*) is given by:

$$P_{in}(LV(v_n),\eta_n) = \prod_{t=1,...T} P_{int}(LV(v_n),\eta_n) \tag{5}$$

The unconditional probability of individual *n* choosing the sequence of choices **t** is the integral of P_{in} over the density functions of v and η.

The log-likelihood function for the HCM can be expressed as follows:

$$L = \int_{\eta,v} P_{in}(LV(v_n),\eta_n)\prod_{l=1,2} f_{LV}(v_{nl}) \prod_{p=1,..,P_l} f_I(I_{lnp} \mid LV(v_{nl}))f(v_{nl})f(\eta_n)d\eta dv \tag{6}$$

Where f_{LV} is the probability density function of the latent variables, and f_I is the probability density functions on the indicators. The log-likelihood function is given by the log of the product across the sample of the unconditional probabilities in equation (6).

All model estimations were performed using the software package PythonBiogeme (Bierlaire and Fetiarison, 2009). The HCM were estimated simultaneously; Monte Carlo integration is used and random numbers are generated using 2.000 modified Latin hypercube sampling (MLHS) draws (Hess et al., 2006).

8.3.3. VTTS simulation

The value of travel time savings (VTTS) represents the individual willingness to pay for saving travel time. It can be directly calculated from the estimated models as the ratio between the marginal utility of travel time and the marginal utility of cost. In case of utility linear in the attributes, the marginal utility equals the coefficient estimated. In case of utility non-linear in the attributes, the marginal utility needs to be computed as the partial derivative of the utility with respect to the attribute of interest. In our models, the utility is linear in the cost but not linear in travel time.

For the ML in equation (1), the average VTTS takes then the following expression:

$$VTTS_{SE_n} = \frac{(\beta_{TT} + \beta_{s,TT} \cdot SE_n)}{\beta_{\cos t}} \cdot 60 \quad \left[\frac{Euro}{hour}\right] \tag{7}$$

For the HCM in equation (2), the average VTTS takes the following expression:

$$VTTS_{SE_n} = \frac{(\beta_{TT} + \beta_{sTT} \cdot SE_n + \beta_{LV} \cdot LV_{in})}{\beta_{\cos t}} \cdot 60 \quad \left[\frac{Euro}{hour}\right] \tag{8}$$

As shown in equation (3), the two LVs, trust and travel experience, follow a Normal distribution. Confidence intervals for the VTTS with both models (ML and HCM) were computed considering the mean values of the LV. To reproduce the distribution of the coefficient estimated, we used Monte Carlo simulation with 5,000 draws from a multivariate truncated Normal distribution.

Let be $VTTS_g(r)$ the value of time for the segment *g* (with g=1,…,G) and draw r (with r=1,…,R), where each group is defined as a function of socio-economic characteristics g(SE_n) the population average and standard deviation for the value of time were computed as:

$$E(VTTS) = \frac{1}{R}\sum_{r=1}^{R}\sum_{g=1}^{G}\left(VTTS_g(r) \times w_g\right) \quad (9)$$

$$st.dev(VTTS) = \sqrt{\frac{1}{R-1}\sum_{r=1}^{R}\sum_{g=1}^{G}\left[\left(VTTS_g(r) - E(VTTS)\right)^2 \times w_g\right]} \quad (10)$$

Analogously, the average value of time and standard deviation in each group was computed as:

$$E(VTTS_g) = \frac{1}{R}\sum_{r=1}^{R} VTTS_g(r) \times w_g \quad (11)$$

$$st.dev(VTTS_g) = \sqrt{\frac{1}{R-1}\sum_{r=1}^{R}\left[\left(VTTS_g(r) - E(VTTS_g)\right)^2 \times w_g\right]} \quad (12)$$

The t-test of the VTTS were then computed as the ratio between the mean and the standard deviation (H0: VTTS=0) and the confidence intervals were then computed as the 0.025 and 0.975 percentiles.

Finally, the distribution of the VTTS around the mean LVs was also computed for each representative segment in the sample using Monte Carlo simulation (5,000 draws were used for each LV). The 95% range of variation of the VTTS due to the latent variables, was then computed as the 0.025 and 0.975 percentiles.

8.4 Models results and discussions

Table 16 summarized the results of the models estimated. Overall, the parameters estimated in both models are at 5% level of significance and they are the same in the ML and the HCM with the exception of travel time by PAV and SAV because in the HCM these are interacted with the LV. We also note that the parameters of all the attributes that have a linear effect in the utility have the right sign in agreement with the microeconomic theory. The comparison between the travel time parameters in the ML and HCM and the microeconomic conditions for the attributes with non-linear effects will be discussed in the next section, when we will discuss the VTTS.

Different potential effects due to SE characteristics were considered: (i) direct effect of SE, and (ii) interaction effect between SE and travel time. In both the ML and the HCM, results show that gender and age significantly affect directly the choice of PAV, SAV, and walking. Specifically, men have a higher preference than women for the AVs, but have also a higher marginal disutility for travel time spent while travelling within an AV. Respondents 50 years or older prefer other modes of transport than AV and walking. Furthermore, in line with results on inertia effect (Gärling and Axhausen, 2003), possession of a public transport card increases the probability to choose public transport.

As discussed in the literature, previous studies on qualitative (Silberg et al., 2013) and quantitative user acceptance (Rödel et al., 2014, Schoettle and Sivak, 2014, Kyriakidis et al., 2015) found that the autonomy level of the respondents' current vehicle positively affects the stated intention to use an AV. Our results from the ML model confirm this effect. In the ML model, we found that having experience with ADAS has a positive effect on the preference for both PAV and SAV. However, the results from the HCM show that this is indeed a spurious effect. In fact, in the HCM, where the experience with ADAS is specified to affect the utility of PAV and SAV also indirectly through the trust on the technology, the direct effect is significant only in PAV but not in SAV. This is correct, because in the SAV drivers cannot take control of the vehicle, hence having experience with ADAS has also an indirect impact on the use of SAV as increases the trust on the technology.

Results also show that almost all these SE have also a significant impact in explaining heterogeneity in the preference for travel time, though interestingly, this interaction effect is generally more significant in the HCM than in the ML, due to the fact that in the HCM we are accounting for the role of attitudes in explaining the heterogeneity in travel time preferences. Specifically, results show that male, with experience with ADAS and a high education have lower marginal utility of travel time by PAV, while being 50 years or older decreases the marginal utility of walking time, as expected.

Looking at the impact of trust and travel experiences on the preference for travel time, results from the HCM model show a significant positive interaction effect between the two psychological variables and travel time in both PAV and SAV. Confirming our initial assumptions that the disutility of travel time by AV would depend on the individual attitudes. Firstly, we note that the expectation of positive travel experiences when riding autonomously (or anticipated subjective commute well-being in relation to the use on an AV) influences positively the preference for time spent in an AV. This result provides empirical evidences that potentially improved travel quality and increased comfort are crucial determinants of the willingness to use AVs and preferences for travel time. Moreover, they underline the important role of well-being benefits in the context of autonomous driving, discussed in previous theoretical and qualitative works (e.g. Singleton, 2018, Kolarova, 2020, Mokhtarian, 2018). Secondly, trust in the technology of AVs influences the preference for travel time by AV. People who stated to entrust the driving system perceive travel time in an AV less negatively than those who do not. These results are in line with previous qualitative studies which found that trust is an important component of the acceptance of AVs, i.e. willingness to use such vehicles (e.g. Molnar et al., 2018, Ashkrof et al., 2019). Our results quantify this effect allowing for these effects to be correctly included in the estimation of the VTTS and the welfare measures.

Regarding the factors that influence respondents' attitudes, as discussed previously, results show that experience with ADAS affects strongly the trust in the AV technology. Specifically, people who have used such systems or at least have tested them trust more the reliability and safety of the AV technology. These findings are in line with previous qualitative and quantitative researches on the impact of trust on user acceptance of AVs (Rödel et al., 2014, Kolarova, 2020). Moreover, men are found to trust the technology more than women; also, people who are between 18- and 30-years old trust the technology more than people who are older than 30 years. Our findings align with the results of the few qualitative studies that found that men (Schoettle and Sivak, 2014, Schoettle and Sivak, 2015) as well as young respondents (Schoettle and Sivak, 2015, Seapine Software, 2014) are less concerned or worried about riding in a fully automated vehicle. The age of potential users plays also an important role in the evaluation of the travel experiences in an AV. Again, people under 30 years old have more positive expectations regarding the committing time spent riding autonomously compared to people older than 30 years.

The results of the measurement equations are also in line with the expectation that the selected indicators are positively associated with the LVs: higher agreement with the statements indicates that people hold the corresponding attitude.

Finally, results show also that the travel time coefficient values for the active modes of transport (walk, bicycle) are higher than for the motorized modes of transport, which appears a plausible finding given the differences in comfort level and speed between motorized and non-motorized alternatives.

Table 16: Discrete choice models results

	Mixed Logit model with EC		Hybrid choice model	
Coefficients	**Est. value**	***t*-stat.**	**Est. value**	***t*-stat.**
ASC $_{walk}$	5.830	*4.54*	5.110	*4.80*
ASC $_{bicycle}$	-1.060	*-1.62*	-0.557	*-1.09*
ASC $_{PT}$	-2.110	*-4.35*	-2.060	*-5.05*
ASC $_{SAV}$	-0.746	*-2.44*	-0.694	*-2.4*
ß $_{travel\ time\ walk}$	-0.295	*-7.37*	-0.264	*-7.48*
ß $_{travel\ time\ bicycle}$	-0.123	*-13.42*	-0.128	*-14.60*
ß $_{travel\ time\ PT}$	-0.058	*-8.79*	-0.060	*-9.28*
ß $_{travel\ time\ PAV}$	-0.035	*-3.08*	-0.191	*-10.12*
ß $_{travel\ time\ SAV}$	-0.042	*-5.09*	-0.204	*-9.50*
ß $_{access/egress\ time\ (PT)}$	-0.057	*-2.77*	-0.050	*-2.47*
ß $_{waiting\ time\ (PT,\ PAV,\ SAV)}$	-0.072	*-8.27*	-0.071	*-8.17*
ß $_{ridesharing\ (SAV)}$	-0.593	*-4.64*	-0.609	*-4.78*
ß $_{cost\ (PT,\ PAV,\ SAV)}$	-0.662	*-18.63*	-0.643	*-18.54*
τ $_{travel\ time\ PAV\ *\ travel\ experiences}$			0.029	*4.64*
τ $_{travel\ time\ SAV\ *\ travel\ experiences}$			0.031	*4.46*
τ $_{travel\ time\ PAV\ *\ trust}$			0.017	*2.98*
τ $_{travel\ time\ SAV\ *\ trust}$			0.014	*2.54*
ß $_{pt\ pass\ (PT)}$	3.160	*6.95*	3.040	*9.23*
ß $_{male\ (PAV)}$	0.627	*2.01*	0.596	*1.96*
ß $_{male\ *\ travel\ time\ PAV}$	-0.022	*-1.94*	-0.028	*-2.41*
ß $_{50+\ years\ old\ (PAV)}$	-0.468	*-2.41*	-0.386	*-2.09*
ß $_{50+\ years\ old\ (walk)}$	-12.60	*-5.35*	-12.40	*-6.11*
ß $_{50+\ years\ old\ *\ travel\ time\ walk}$	0.247	*5.81*	0.227	*6.26*
ß $_{university\ education\ level\ *\ travel\ time\ PAV}$	-0.033	*-3.39*	-0.032	*-3.46*
ß $_{university\ education\ level\ *\ travel\ time\ SAV}$	-0.020	*-1.84*	-0.021	*-2.11*
ß $_{experience\ with\ ADAS\ (PAV)}$	1.440	*3.08*	0.927	*2.37*
ß $_{experience\ with\ ADAS\ (SAV)}$	0.814	*2.04*	0.130	*0.42*
ß $_{experience\ with\ ADAS\ *\ travel\ time\ PAV}$	-0.013	*-1.13*	-0.024	*-2.05*
σ_{walk}	4.890	*6.11*	-5.170	*-7.12*
$\sigma_{bicycle}$	-4.820	*-11.4*	-4.160	*-11.67*
σ_{PT}	-3.850	*-13.6*	-3.150	*-15.42*
σ_{PAV}	-1.030	*-4.06*	-1.110	*-7.83*
σ_{SAV}	-1.110	*-4.76*	1.030	*6.90*

Table 17 (Ctd'): Discrete choice models results

		Hybrid choice model	
Structural equations - coefficients		**Est. value**	***t*-statistic**
LV: Trust in the technology of automated vehicles			
$Intercept_{trust}$		2.390	*30.38*
α_{male}		0.450	*4.59*
$\alpha_{18\text{-}30\ years\ old}$		0.409	*2.61*
$\alpha_{experience\ with\ ADAS}$		0.470	*4.73*
σ_{trust}		1.210	*27.67*
LV: Travel experiences (for riding autonomously)			
$Intercept_{travel\ experiences}$		3.720	*24.58*
α_{male}		0.133	*1.26*
$\alpha_{30\text{-}50\ years\ old}$		-0.393	*-2.33*
$\alpha_{50+\ years\ old}$		-0.434	*-2.59*
$\sigma_{travel\ experience}$		1.190	*24.82*
Measurement equations - coefficients			
LV: Trust in the technology of automated vehicles			
$Intercept_{trust\_02}$		0.398	*3.24*
$Intercept_{trust\_03}$		0.090	*0.91*
γ_{trust_02}		0.869	*21.77*
γ_{trust_03}		0.941	*28.84*
ζ_{trust_01}		0.525	*14.78*
ζ_{trust_02}		0.861	*26.47*
ζ_{trust_03}		0.556	*18.56*
LV: Travel experiences (for riding autonomously)			
$Intercept_{travel\_experiences\_AV\_02}$		-0.316	*-2.23*
$Intercept_{travel\_experiences\_AV\_03}$		2.240	*11.77*
$\gamma_{travel\_experiences\_AV\_02}$		1.070	*27.67*
$\gamma_{travel\_experiences\_AV\_03}$		0.285	*5.60*
$\zeta_{travel\_experiences\_AV\_01}$		0.515	*14.03*
$\zeta_{travel\_experiences\_AV\_02}$		0.512	*11.99*
$\zeta_{travel\_experiences\_AV\_03}$		1.250	*30.91*
Model fit			
Cte log likelihood	-5383.23	-5383.23	
Log likelihood (final)	-2863.43	-8963.672	
Nr. of estimated parameters	29	82	
AIC	5785	13980	
BIC	5831	14071	
Sample size	3872	3872	
Nr. of individuals	484	484	
Nr. of draws	2000	2000	

8.5 Calculated VTTS for PAV and SAV

8.5.1. VTTS distribution among user groups

Table 18 reports the average VTTS, along with the statistics, computed using the estimated coefficients in the ML and the HCM, and Monte Carlo simulation (equations (9) and (10)), where marginal utilities of travel time for PAV and SAV account for systematic heterogeneity due to (i) the effect of SE and (ii) the effect of the psychological factors travel experiences and trust (only for the HCM). The statistics for the hybrid choice model were computed considering the average values of the latent constructs. We will discuss later the distribution of the LV. Draws were taken from an MNL, however only the covariance between TT_SAV and the interaction TT_SAV*TE was significantly different from zero. We made then the assumption to set to zero all other covariance elements. Since the VTTS is a ratio between estimated coefficients, differences in VTTS between the ML and the HCM are not attributable to difference in scale but only to the effect of the heterogeneity of the sample. We also note that for all the observations in the sample the VTTS is always positive. Considering the simulated distribution, we found negative VTTS for only 3% of the population in the ML model and for 5% in the HCM, which is negligible.

Table 18 shows that in both models (the ML and HCM) the average VTTS for SAV is lower than for PAV; this difference is about 28% in the ML and 18% in the hybrid choice model. However, it is important to note that our results show also that in both cases, the difference is not statistically significant (in the ML *t-test*[6]*=0.54, p>0.05;* in the HCM *t-test=0.24, p>0.05)*. The t-test of the VTTS are significant at 95% (one tail, because VTTS>0) in both models. The confidence intervals of the VTTS in the HCM is wider than in the ML, which seems to reflect the additional heterogeneity in the attitude toward trust and travel experiences. But the confidence interval estimated with the HCM includes the mean value estimated with the ML model and vice versa.

Table 18: Simulated value of travel time savings (VTTS) in euro per hour

Mode of transport		**Mixed Logit Model**	**Hybrid Choice Model**
Privately-owned automated vehicle (PAV)	Average	5.65	7.35
	t-test	2.25	1.88
	confidence interval	[0.73,10.58]	[-0.29,14.99]
Shared automated vehicle (SAV)	Average	4.42	6.23
	t-test	3.42	1.70
	confidence interval	[1.87,6.96]	[-1.04,13.32]

More interesting results are obtained looking at the VTTS for specific user segments. Based on the SE characteristics included in our models, we identified 24 segments or groups. Table 19 provides a description of these user segments, along with the simulated mean VTTS for each group and its statistics, (t-test against zero) and [confidence interval]. In terms of the distribution of the sample among groups, groups 2, 3, 5 and 6 account for 37.5% of the sample. The remaining 62.5% is relatively evenly distributed among the other 21 groups. Unless differently specified all the VTTS in this section are computed using the HCM and the average value of the LV.

Figure 5 visualizes the mean VTTS reported in Table 19. As mentioned above, the population VTTS for PAV are higher than for SAV, but not significantly different. If we look at each group, even though the mean VTTS is quite different between PAV and SAV (see e.g. groups 16, 17, 18, 22, 23 and 24) none of them is significantly different. This result can be affected by the low significance of the SAV VTTS in groups 16, 17, 18 and 22. However, in groups 23 and 24 the SAV VTTS is significant. Differently from previous funding, our results suggest that there is not indeed difference in the VTTS between PAV and SAV.

We then turn our attention to the difference among SE groups. Looking at the effect of single SE, we see a trend that indicates higher VTTS (for both PAV and SAV) as age increases, higher for people with university degree than for those without, lower for people who had experience with ADAS than for those without and higher for men than for female (for the last one, this applies especially in the case of PAV). Some of these effects (such as age and university degree) might be related also to the level of income (we do not have this information to control for it), but can also reflect a different propensity to accept new technology. People with university education level or higher are more reserved when it comes to AVs and younger people (18 to 30 years) are typically more open to the technology.

[6] This is the t-test for generic coefficients that accounts for the simulated covariance between VTTS-PAV and VTTS-SAV, that is equal to 1.33 in the ML and 3.34 in the HCM.

Table 19: Segment-specific VTTS

Group	Distr.	Gender	Age	Edu: univ. or higher	ADAS exp.	PAV - VSST Mean	PAV - VSST t-test	PAV - VSST Confidence interval	SAV - VSST Mean	SAV - VSST t-test	SAV - VSST Confidence interval
		Characteristics of the user group									
1	3.7%		18-30			4.34	1.23	[-2.57,11.24]	5.47	1.51	[-1.63,12.56]
2	10.5%	Female	30-50	No	No	5.54	1.81	[-0.47,11.24]	6.82	2.08	[0.38,13.26]
3	10.5%		50+			5.62	1.85	[-0.32,11.57]	6.90	2.12	[0.51,13.30]
4	3.1%		18-30			5.71	1.52	[-1.65,13.07]	4.84	1.22	[-2.92,12.60]
5	8.1%	Male	30-50	No	No	7.03	2.06	[0.35,13.70]	6.01	1.72	[-0.83,12.85]
6	8.7%		50+			7.14	2.11	[0.51,13.77]	6.11	1.77	[-0.67,12.09]
7	1.9%		18-30			6.72	1.99	[0.09,13.36]	7.18	1.98	[0.06,14.29]
8	4.1%	Female	30-50	Yes	No	8.24	2.62	[2.08,14.40]	8.64	2.58	[2.08,15.20]
9	3.7%		50+			8.36	2.68	[2.24,14.48]	8.76	2.61	[2.17,15.35]
10	2.1%		18-30			5.55	1.52	[-1.60,12.70]	5.07	1.33	[-2.43,12.56]
11	3.7%	Female	30-50	No	Yes	6.88	2.08	[0.41,13.34]	6.31	1.85	[0.38,12.99]
12	3.7%		50+			6.99	2.13	[0.57,13.41]	6.39	1.89	[-0.23,13.00]
13	1.0%		18-30			8.24	2.21	[0.94,15.55]	6.39	1.66	[-1.14,13.92]
14	3.3%	Male	30-50	Yes	No	9.81	2.80	[2.95,16.66]	7.79	2.21	[0.89,14.68]
15	4.8%		50+			9.93	2.85	[3.11,16.76]	7.79	2.26	[1.04,14.54]
16	1.9%		18-30			6.98	1.77	[-0.74,14.70]	4.46	1.06	[-3.75,12.66]
17	5.4%	Male	30-50	No	Yes	8.41	2.30	[1.26,15.56]	5.50	1.53	[-1.56,12.55]
18	4.3%		50+			8.52	2.35	[1.41,15.63]	5.57	1.57	[-1.39,12.52]
19	1.7%		18-30			8.10	2.23	[0.99,15.21]	6.57	1.78	[-0.65,13.79]
20	2.3%	Female	30-50	Yes	Yes	9.67	2.84	[3.00,16.33]	7.99	2.35	[1.32,14.66]
21	1.9%		50+			9.78	2.89	[3.16,16.41]	8.09	2.40	[1.48,14.70]
22	2.1%		18-30			9.63	2.43	[1.86,17.41]	5.87	1.49	[-1.86,13.60]
23	4.8%	Male	30-50	Yes	Yes	11.24	2.99	[3.88,18.60]	7.17	2.00	[0.13,14.21]
24	2.9%		50+			11.37	3.04	[4.04,18.70]	7.26	2.04	[0.28,14.23]

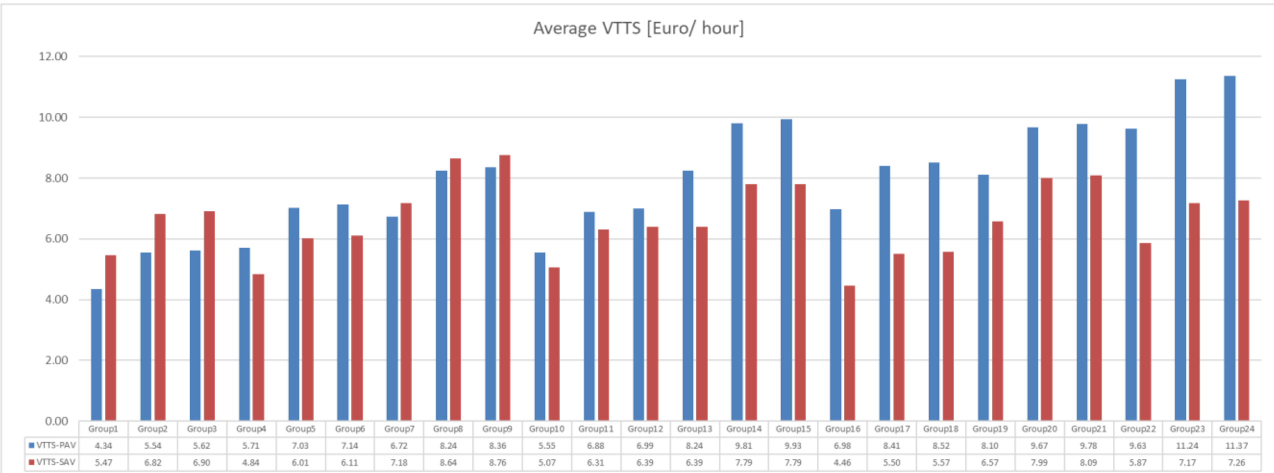

Figure 5: Average VTTS for different user segments

However, despite the difference in the average values, the VTTS is significantly different only between few groups. Table 20 reports t-test for the difference in the PAV-VTTS between groups. The table reports only the cases where the H0 that the VTTS of two groups is equal was rejected at 5% level of significance[7]. Comparing all groups that have the same characteristics except for a particular SE, results suggest that the main differences in the VTTS for PAV between groups depends, with few exceptions, on the education level of the potential users (higher education level is associated with higher VTTS). The VTTS for people with university or higher education level (groups 8, 9, 14, 15, 20-24) is higher and statistically different from the VTTS for people with lower education level (groups 1-6, 10-12, 16-18). Among people with the same level of education, youngers have VTTS significantly different from medium age and older people; compare group 7 (young) with groups 8 (medium age) and 9 (50+), which are equal in all other characteristics (female with university education and no ADAS experience); compare also group 13 (young) with groups 23 (medium age) and 24 (50+ years old), which are all male with university education and ADAS experience.

Gender alone seems not to play overall an important role. However, our results show that this is due to the sum of two opposite effects. In line with previous literature, men are found to trust the technology more than women and also to have potentially higher technology affinity. However, our results show that they also perceive higher marginal disutility for travel time. Hence, overall the VTTS for PAV is not statistically different between male and female. For similar reasons, ADAS does not seem to have either a significant impact in the VTTS for PAV. In fact, both male and ADAS have a negative direct impact on the marginal utility of travel time for AV but also a positive impact on trust, which in turn affects positively the marginal utility of travel time.

We performed the same analysis for the VTTS computed using the ML model (i.e. without accounting for the latent effect of trust and travel experiences). Results are very different and clearly confirm the importance of accounting for the above latent effects. We found in fact that the VTTS is significantly different only between female with no high education and no ADAS experience (groups 1, 2 and 3) and male with high education (groups 13, 14, 15, 22, 23 and 24).

Table 20: T-test for differences between PAV-VTTS

	Group 8	Group 9	Group 14	Group 15	Group 20	Group 21	Group 22	Group 23	Group 24
Group 1	-2.09	-2.15	-2.51	-2.55	-2.49	-2.54	-2.16	-2.83	-2.87
Group 2	-2.49	-2.24	-2.67	-2.52	-2.68	-2.54	-1.90	-2.90	-2.80
Group 3	-2.10	-2.57	-2.44	-2.71	-2.44	-2.73	-1.87	-2.73	-2.93
Group 4			-2.61	-2.68	-1.81	-1.87	-2.13	-2.94	-2.99
Group 5			-2.76	-2.42				-2.83	-2.66
Group 6			-2.27	-2.84				-2.56	-2.87
Group 7	-1.82	-1.95	-2.25	-2.31	-2.22	-2.30		-2.58	-2.63
Group 10			-1.90	-1.95	-2.61	-2.68	-2.14	-2.94	-2.98
Group 11					-2.75	-2.41		-2.80	-2.63
Group 12					-2.31	-2.88		-2.58	-2.87
Group 13			-2.06	-2.19				-2.33	-2.41
Group 14							-2.09	-3.10	-3.17
Group 16								-2.95	-2.55
Group 17								-2.38	-3.00
Group 18					-2.05	-2.17		-2.36	-2.42
Group 19			-1.90	-1.95	-2.61	-2.68	-2.14	-2.94	-2.98
Group 23								-2.21	-2.34
Group 24									-2.49

The t-test between groups was also computed for the VTTS for SAV. We do not report the table, but we found that the VTTS was statistically significant only between groups 8, 9 (women over 30 years old, without experience with ADAS and higher education level) and groups 1, 4, 10, 17, 18, and 19 (mostly

[7] The t-test between almost all other groups lower than 1.00

younger women under 30 years old or people with ADAS experience). Group 8 is additionally statistically significantly different from groups 5 and 10, and group 9 from group 6. There is not a clear pattern in these results with small exceptions. Groups 8 and 9 are the user segments with the highest VTTS for SAV in the sample and significantly higher than the VTTS of group 19, which represents women under 30 years old, which have higher education level, but also experience with ADAS.

Given that (i) the SAV is introduced as a vehicle that drive fully autonomously while the PAV can be driven manually and (ii) the strong positive effect of ADAS experience on trust in the technology of AVs, our results underline the impact of experiences with similar technology on the VTTS for AVs.

8.5.2 Impact of Trust and TE distribution on VTTS

Since the latent variables, trust and travel experiences, are random variables distributed Normal (see equation 3), the VTTS is also distributed Normal. We first looked at the simulated average values and the distribution characteristics of both LVs, then at the impact of the LV distribution on the VTTS. The average values for the sample are summarized in Table 21. Figure 6 displays the average values for each user segment.

Table 21: Average values for the LVs travel experiences and trust in the sample

				Percentiles			
Latent variable	**Mean**	**t-test**	**Confidence interval**	**10%**	**25%**	**75%**	**90%**
Travel experiences	3.44	12.24	[2.89;3.99]	3.20	3.32	3.57	3.68
Trust in an AV	2.86	7.16	[2.07;3.64]	2.73	2.79	2.93	2.99

Generally speaking, the higher the average values of the LVs, the more respondents hold positive attitude toward AVs, i.e. evaluate travel experiences (TE) more positively or trust the technology more compared to people with lower LV values. Trust is significantly different (at less than 5% significance) among almost all groups (with few exceptions), but it is not possible to recognise a pattern. In the travel experiences instead, there is a striking difference between groups with young respondents (less than 30 years old) and the groups with respondents older than 30.

Looking at the anticipated travel experiences in an AV, women who are 50 years old or above (groups 3, 9, 12, 21) have more negative attitude about AVs than men and women under 30 (groups 4, 10, 16, 7, 13, 19, 22; except of women with education level lower than university and without experience with ADAS, i.e. group 1). Men under 30 years old (groups 4, 16, 13, 22) indeed have the highest TE values among all potential user segments, i.e. evaluate potential travel experiences in an AV most positively. Women over 30 years old without any experiences with ADAS (groups 2, 3, 8, 9) have the lowest values for the LV trust, while men who are under 30 years old and have experiences with ADAS (groups 16, 22) have the highest values. Summarising, young men with experiences with similar technologies trust AVs more than the other potential user segments.

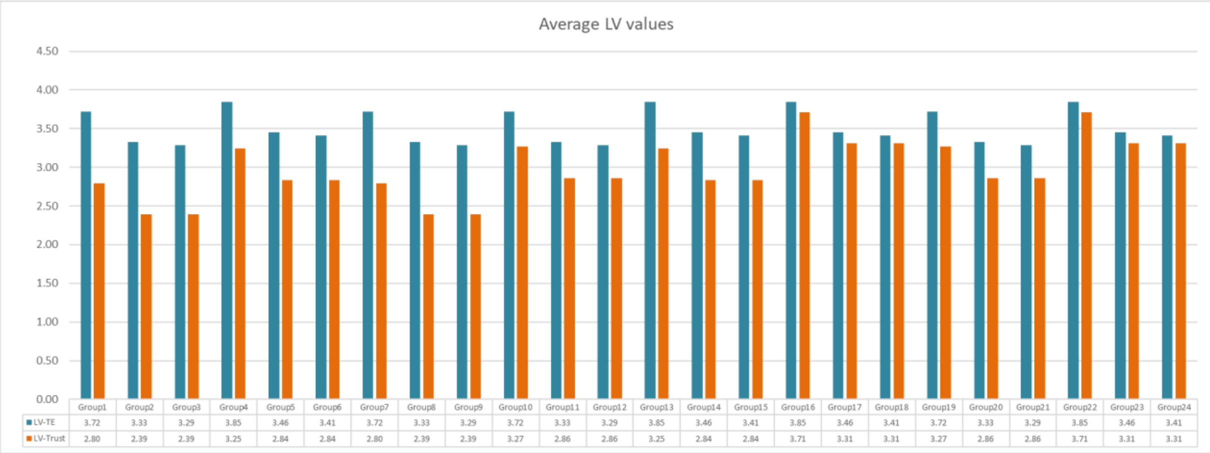

Figure 6: Average values of the latent variables Travel experiences (TE) and Trust for different user segments

Finally, we analysed the impact of trust and travel experiences on the VTTS. Table 22 summarizes the mean VTTS values for PAV and SAV using the LV values that define the different percentiles of the distribution of the LVs (see the values in Table 21). Simulation was used to build the distribution around the mean value of the estimated coefficients. In squared brackets we reported also the confidence interval for each of them. The results in Table 22 show that high LV values lead to a reduction in the VTTS. Moreover, we note that having the highest value on the LVs in the sample lead to higher number of negative VTTS. In this case, for the PAV, 9.4% of the values are negative and for the SAV 13.13%.

Table 22: VTTS computed using the values of the trust and TE in the different percentiles of the distributions of the LVs

AV concept	**Percentiles of the LVs**				
	10%	**25%**	**50%**	**75%**	**90%**
PAV	8.14 [0.30,15.98]	7.79 [-0.08,15.65]	7.35 [-0.29,14.99]	6.85 [-1.14,14.84]	6.41 [-1.69,14.45]]
SAV	7.11 [0.51,13.70]	6.70 [0.08;13.32]	6.23 [-1.04,13.32]	5.82 [-1.00,12.64]	5.40 [-1.60;12.40]

A comparison between the mean VTTS among people holding relatively negative attitude (10th percentile of the LVs distributions) and those holding relatively positive attitude (90th percentile of the LVs distributions) shows that the VTTS of the first group are about 24% higher than the values of the second one. However, these are not significantly different. This suggests that differences in VTTS among respondents holding different attitudes for trust and travel experiences are not explained by random effects but by the characteristics that define the user segments. These findings underline the impact of the considered LVs on VTTS and the importance of considering individual characteristics, such as attitudes when analysing the effect of new mobility concepts on VTTS.

A comparison of the results from the group-specific analyses of the LV values with the group-specific VTTS reveals in fact the following insights: the groups with highest TE and Trust values have low VTTS, and some groups also show negative VTTS for AVs, excepts of in the group of men with university education level (groups 16 and 22). This result suggests that high trust and travel experiences compensate for the disutility due to travel time. These two groups are statistically significantly different than the following segments: (i) women over 50 years old with educational level lower than university and with experiences with ADAS, (ii) men under 30 with educational level lower than university and with experience with ADAS, and (iii) women and men over 30 years old with experience with ADAS and at least university education level.

The low and partly negative VTTS for the AVs result potentially from the positive utility of travel time spent in an AV perceived by the part of the sample with strongly positive attitudes toward the technology. In other words, the results suggest that people who expect riding in an AV to be a positive experience and trust the technology might not perceive time spent in the car as 'lost time' which they seek to minimize, but as potentially beneficial.

8.6 Conclusion

This study discusses and provides empirical evidence on the impact of *Trust* on technology and *Travel Experiences* (besides individual preference for activities conducted during travelling) in travel time preferences for AVs. Understanding the sources of variation in travel time preferences for AVs is crucial for developing more realistic and differentiated scenarios about the impact of autonomous driving on mode choices and travel demand.

An online survey with a stated choice experiment and psychometric scales was conducted. Besides currently available transport modes, also a privately-owned AV (PAV) and a shared AV (SAV) were included in the choice sets. The data was analysed using a hybrid choice model, including (i) direct effect of several socio-economic (SE) characteristics, (ii) interaction effect between SE and travel time and (iii) interaction between the two psychological statements and travel time. Different VTTS depending on user segments defined by their socio-economic characteristics were calculated. T-test and confidence intervals of the estimated VTTS are computed to assess if the VTTS are statistically significant and statistically different among user groups.

The results of the study show firstly that the two selected psychological factors have a significant effect on the VTTS for the two concepts of automated vehicles, a PAV and an SAV, and consequentially on mode choices for such vehicles. Positive evaluation of travel experiences when riding autonomously and trust in the AVs, i.e. in the system and its safety, influence the valuation of travel time in an AV positively. Secondly, various socio-demographic factors affect personal attitudes. Experience with ADAS, gender (male) and age (being under 30 years old) influence trust in the technology of automated vehicles positively. The same age group is also the one that is more likely to evaluate potential travel experiences in an AV as a positive one. Thirdly, VTTS vary between different user segments defined by their socio-economic characteristics and considering the direct as well as the indirect (trough their influence on the attitudes) effect of the socio-economic factors. Younger people (under 30) tend to have lower VTTS compared to older persons. Also, higher education level is associated with higher VTTS and experience with ADAS with lower VTTS. These findings underline not only the importance of considering individual attitudes when analysing user preferences for AVs, but also looking specifically at different user segments.

On the methodological side, our results confirm the importance of (i) measuring these impacts quantitatively, (2) disentangling the role of SE through the latent attitudes from the direct role in the VTTS and (3) using statistical tests the significance of the VTTS. For example, in line with previous funding our results show that the average VTTS for SAV is between 18% and 28% lower than for PAV. However, our results show also that in both cases, the difference is actually not statistically significant. In addition, in line with almost all the qualitative literature, our results show that men trust the technology more than women and they also to have potentially higher technology affinity. However, our results show also that they perceive higher marginal disutility for travel time. These two effects have opposite direction and overall the VTTS for PAV is not statistically different between male and female. Nevertheless, having estimated both effects is critical to be able to address policies correctly.

Our results also show that not considering attitudinal effects might lead to false conclusions about the impact of ADAS. In fact, we found that having experience with ADAS has a positive effect on the preference for SAV. However, when we included in the model also the impact of ADAS indirectly through the trust on the technology, the direct effect in SAV became insignificant This is correct, because in the SAV drivers cannot take control of the vehicle, hence having experience with ADAS has also an indirect impact on the use of SAV as increases the trust on the technology.

Lastly, we like to mention that the descriptive analyses of the effect of different activities which people would perform in an AV shows that relaxing or performing rather passive activities affect decreases the disutility of travel time spent in car. Simultaneously, working is among the least preferable activities in an AV. These results support focusing more on benefits of AVs related to individual well-being instead of only potential productivity gains, discussed in early theoretical works in the context of autonomous driving.

Several implications for policy and deployment strategies for AVs can be derived from the results. First, the empirical insights from the study underline the importance for developing communication strategies for autonomous driving targeting different segments considering also attitudes of potential users. Second, the results support the importance of the role of experience with the technology (or in this case with ADAS) to increase the trust and positive evaluation regarding automated driving. One strategy can be enabling gaining experience with automated systems, for instance on test fields or under real-world conditions (if feasible). Such tests are already part of government funded research activities (e.g. in Germany BMVI, 2017a). Third, the findings underline the need to target different groups of the population, including for instance elderly people, in order to reach also people currently less in favour of the new technology and increase acceptance of AVs. Furthermore, the expectation of people that autonomous driving would improve the experience of their commuting trip suggest that future tests can focus on analysing whether these expectation holds under real-world conditions and which implication they have on vehicle design and mobility services in the context of AVs. Last but not least, even though the results of this study suggest that people would prefer rather relaxing or passive activities in an AV, previous studies found also a positive effect of office interior on the travel time perception in an AV (Correia et al., 2019). Thus, the implications for future interior concepts of AVs are ambiguous, but the results suggest in general that comfort level as well as infotainment features might be important elements of such concepts.

Overall, this study provides empirical evidence for the important role of attitudes when analysing VTTS for new mobility options, such as AVs. It is therefore a valuable contribution to the research of potential impact of autonomous driving on user preferences as well as to the literature on determinants of VTTS and consideration of the effect of LVs on VTTS. A limitation of the study is the focus on selected LVs and their individual effect on VTTS and mode choices. The complex relationship between the single psychological factors was not in focus of the analyses although it is plausible to assume that anticipated travel experiences in an AV are related to trust in the technology.

Further studies have to continue looking into effect of attitudes on VTTS. Also, we show that considering various user segments depending on their socio-economic characteristics together with the effect of these characteristics on attitudes allows more differentiated analyses of the impact of AVs on user preferences than calculating only average values. Thus, future research as well as AV development works may look deeper into the requirements and concerns of different user segments as this can be a key factor to increase acceptance of the technology.

Author contribution statement

Viktoriya Kolarova: conceptualization of the study, methodology, formal analysis, investigation, data curation, writing – original draft; **Elisabetta Cherchi:** supervision of conceptualization of the study, methodology, data analyses and writing – original draft, review and editing.

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9 Summary of the main results of the thesis

This thesis focuses on measuring, analysing and explaining the VTTS for autonomous driving. The three studies described within the thesis directly build on one another. Consequently, the findings from these studies reflect the construction of an in-depth understanding of the VTTS for potential AV users:

Study 1 revealed that positive aspects of car driving today, including enjoyment of driving, various activities performed in the car and driving as an activity, will partially counterbalance the effects of the benefits of autonomous driving. The perceived benefits of autonomous driving or the utility of travel time in an AV are related to affective aspects, such as stress-relief and increased comfort, rather than to the new opportunity of productive time use. Furthermore, the travel time utility in an AV depends on (i) context-related characteristics, such as the trip purpose or traffic situation, and (ii) individual travel and work-related needs and attitudes, such as the schedule, trust in the technology or desire for control.

Study 2 provides empirical evidence for a reduction in the VTTS during autonomous riding compared to using a conventional car (by 41% on average) for commuting trips but not for leisure or shopping trips. Furthermore, the results suggest that a shared autonomous vehicle (SAV) is perceived as a less attractive option than a privately-owned autonomous vehicle (PAV). Significant heterogeneity across the respondents was found concerning the perception of the time spend riding autonomously. The results are consistent with the findings of the first study regarding potential differences between the VTTS for AVs compared to conventional cars and the role of the trip purpose as a determinant of these differences. Additionally, the study measured the effect of the option to drive autonomously on the VTTS and therefore provides input for travel demand models that allow quantification of the potential impacts of vehicle automation on travel behaviour and the transport system. Furthermore, different values were estimated depending on the income group study respondents belonged to, considering differences in cost sensitivity: people with high income were more willing to pay for saving travel time compared to people with average or low incomes. Besides the effect of the trip purpose, no further determinants of travel time during autonomous riding were analysed in this study.

Study 3 suggests that positive evaluation of the travel experiences during autonomous riding (or subjective well-being improvements) and trust in AVs both positively affect the valuation of the travel time in an AV. These findings are consistent with the results from the qualitative analyses performed in Study 1 and also quantify these effects on the VTTS. Various socio-demographic factors were found to affect attitudes and perceptions towards AVs and car use: young (under 30 years old) study respondents, men and those who had experience with ADAS tended to express trust in AVs more than their counterparts. The same age group was also more likely to evaluate travel experiences when (imagining) riding autonomously more positively than older adults. Moreover, VTTS for various user segments, defined by their socio-demographic characteristics and the relation of these socio-demographics to individual attitudes, were calculated. The results show, in line with the results mentioned above, lower VTTS for people under 30 years old and people with experiences with ADAS and interestingly, higher VTTS for people with university education level. In this study, other than in Study 2, there were no statistically significant differences between the VTTS for PAV and those for SAV. In considering potential activities while travelling, the results support the insights from Study 1 that passive activities and relaxing during the trip affect the utility of time during autonomous riding more strongly than productive activities, such as working. Generally, in Study 3, it was shown that the selected psychological variables influence significantly the travel time valuation for AVs. This underlines the important role of considering these factors when aiming to understand travel time preferences for autonomous driving and allows developing more differentiated scenarios about the impact of the technology on travel behaviour. Moreover, the findings stress the need for considering different potential user groups of AVs depending on their attitudes and perceptions rather than solely depending on their socio-demographic characteristics.

Lastly, a comparison between the results of the model estimations in Study 2 and Study 3 regarding the SAV provides an interesting insight: In Study 2, no differences were found between the valuation of time when using an SAV individually and using it in a ride-sharing arrangement. In contrast to this, the results of Study 3 suggest that people do not want to share their ride with strangers (and perceive therefore time spent in such an arrangement more negatively than riding alone in an SAV). This can be attributed to the improved presentation of the ride-sharing option in Study 3 (see Annex I) - showing this use case with a short video led to it receiving more attention in the choice situations. Consequently, better user preferences were captured regarding this service attribute.

10 Discussion, conclusions and outlook

The studies in this thesis measured the VTTS for autonomous driving compared to other (currently available) transport modes and considered the reasons for these differences. For this purpose, they used explorative qualitative research and quantitative methods, mainly SP techniques and discrete choice models. The interdisciplinary nature of the research, which combines, among others, theories on time allocation, consumer psychology or acceptance of innovations, and travel behaviour, provides a broader view of the topic. The main contribution of the thesis is providing empirical evidence for travel time valuation changes due to introduction of autonomous driving and insights on the effects of various factors that influence these changes, including individual attitudes and perceptions.

The following sections discuss the main findings in the thesis with regard to their contribution to the research on the topic and their implications for policy and practice. The chapter then concludes with recommendations for future empirical studies by reflecting on the lessons learnt from my work and discussing future research avenues for autonomous driving and similar new mobility options.

10.1 General discussion on the results and research contribution of the thesis

The measured VTTS for autonomous driving compared to manual driving varies from no difference to about 40% reduction in the values for AV users. The highest reduction in the VTTS for autonomous riding compared to driving a conventional car was measured for a PAV on commuting trips, whereas no reduction was found for shopping or leisure trips. Regarding differences between the AV concepts, although similar trends were found in both quantitative studies described in this thesis, the proportion of the reduction and the values for PAV and SAV are inconsistent. Riding in an SAV, for instance, is perceived in the first quantitative study as a less attractive option than autonomous driving in a privately-owned car. This trend could not be confirmed in the following study, where the calculated VTTS for PAV and SAV are not statistically significantly different from each other.

The findings are partially consistent with the results (or assumptions) of previous studies on the VTTS for AV users and provide additional empirical insights into the potential range and direction of changes in the VTTS resulting from vehicle automation. Simulation studies that analysed various scenarios for the impact of changes in the VTTS on travel demand assumed a reduction in the VTTS for AV users for at least 25%-50% of car drivers (Gucwa, 2014, Childress et al., 2015, Auld et al., 2017, Kockelman et al., 2017). The values estimated in the thesis are in the same range; however, the findings clarify that a reduction in the VTTS does not apply to all situations, and more precise scenarios are required that consider trip purposes, vehicle concepts and the individual characteristics of potential users. In this sense, this supports the discussed possibility of a more modest impact of AVs on the VTTS than expected or even no impact (Singleton, 2018, Mokhtarian, 2018, Rashidi et al., 2020) and provides additional empirical insights on when this might be the case. Furthermore, a theoretical discussion on the potential 'zero value of time' (e.g. Fosgerau, 2019), or 100% reduction in the VTTS compared with a conventional car, could not be confirmed. Other studies also suggested greater user benefits for autonomous driving during commuting, as commuters might be more likely to use the time spent in the car, due to the long distance and routine nature of the trip, and suffer less stress when stuck in traffic (Trommer et al., 2016). Another empirical study, conducted by Correia et al. (2019), found a reduction in the VTTS of 26% compared to the values for a conventional car on commuting trips; however, this depended indirectly on preferred activities (a reduction in the VTTS was found for an AV with an office interior but not for AVs with leisure ones). For the SAV, the findings in this thesis align with the results of a study conducted by Krueger et al. (2016) relating to the differences between using this alternative individually and in a ride-sharing arrangement. Both options were perceived differently by potential users, and the time valuation in a ride-sharing arrangement was found to be more negative than for individual use.

In the last few years, the number of studies on mode choices and the VTTS for autonomous driving has increased. However, when Study 2 was conducted, it was among the first few empirical studies that estimated the VTTS for AV users. To date, to my best knowledge, only a small number of SP studies have been published that address the topic (Becker and Axhausen, 2018, Correia et al., 2019, Yap et al., 2016, Krueger et al., 2016, Winter et al., 2017). Other than the existing studies on the VTTS for AVs, the studies conducted within the thesis have the following strengths: (i) they consider a PAV and an SAV, while most of the studies focus strongly on SAV concepts (e.g. Yap et al., 2016, Krueger et al., 2016, Winter et al., 2017, Alonso-González et al., 2020); (ii) active modes of transportation are included in the choice set, whereas most of the other studies include only motorised transport modes (except of, for instance, Becker and Axhausen, 2018); (iii) Study 2 incorporates two choice experiments, one of which is on user preferences for only currently available transport modes, whereas the other studies consider only a future scenario with available AVs. Specifically, in contrast to other research in this field, the studies conducted in this thesis estimate the VTTS for various AV concepts, capture preferences for AVs compared to all available transportation modes (also the active one) and allow a baseline for potential changes in the values comparing directly current and (potential) future user preferences.

The quantitative studies in the thesis follow a commonly used approach for analysing mode choices and estimating the VTTS for various transport modes that are an important basis for transport demand models (for the German context, see Axhausen et al., 2014). Given their above-mentioned strengths, integrating the results of the analyses in existing transport demand models enables differentiated scenarios to be developed (for different trip purposes as well as for various AV concepts and user segments) and the potential impact of vehicle automation on travel behaviour to be scaled up. The results from Study 2 are already utilised, for instance, in the DLR[8] research projects 'NGC - FiF'[9], 'UBA-Digital'[10], 'Automover'[11] and 'VW-DM'[12] for model-based simulations and scenarios relating to the impact of the introduction of various AV concepts into the transport system. The results from model-based simulation analyses based on the data from Study 2 can be found in a study by Cyganski et al. (2018), among others.

As regards **analysing and explaining the VTTS in the context of AVs**, the results of the thesis suggest that the variation in the values depends on (i) context-related characteristics, especially the trip purpose, (ii) individual characteristics of potential users, including attitudes and perceptions, and (iii) the considered concept of autonomous driving (PAV, individually used SAV, SAV used in a ride-sharing arrangement) and how these concepts are introduced to potential users.

Firstly, a lower VTTS for autonomous driving users was found for commuting trips but not for leisure or shopping trips. These findings are consistent with insights from user acceptance studies suggesting that commuting is among the most attractive use cases of AVs (e.g. Wadud and Huda, 2019, Fraedrich et al., 2016, Continental, 2013, Trommer et al., 2016). Other SP studies on the VTTS for autonomous driving considered only commuting trips (e.g. Correia et al., 2019, Krueger et al., 2016, Winter et al., 2020, Zhong et al., 2020). An exception is a recently published study conducted by Ashkrof et al. (2019) in which the authors compared different distances and trip purposes. They conclude that AVs might be a preferable option for long-distance leisure trips compared to short commuting trips. While the attractiveness of autonomous riding on long-distance trips is also confirmed by related work (Kolarova and Steck, 2019), a direct comparison with the results from Study 2 is limited due to the focus of this thesis on everyday trips. Therefore, considering only everyday mobility, the thesis provides, to my best knowledge, the first empirical evidence for variation in the VTTS for autonomous driving depending on the trip purpose.

[8] The acronym refers to German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.; DLR).
[9] The project NGC-FiF ('Next Generation Car – Fahrzeugintelligenz und mechatronisches Fahrwerk') is funded by DLR's programmatic research funds as part of the Helmholtz Association.
[10] The project UBA-Digital ('Digitalisierung im Verkehr – Potenziale und Risiken für Umwelt und Klima') is funded by UBA (Umweltbundesamt; the Germany's central environmental authority).
[11] The project Automover ('Zukunftsbilder eines automatisierten integrierten Verkehrssystems') is funded by DLR's programmatic research funds as part of the Helmholtz Association.
[12] The project VW-DM ('Volkswirtschaftliche Auswirkungen der Digitalisierung in der Mobilität') is funded by the Swiss Federal Office for Spatial Development (Bundesamt für Raumentwicklung ARE; Bundesbehörde der Schweizerischen Eidgenossenschaft).

Secondly, individual characteristics, including several socio-demographic factors, attitudes and time use preferences of potential users, affect travel time sensitivity in an AV. Age, gender and experience with ADAS were found to indirectly affect the value of time by influencing trust in an AV, and some of them also affect the evaluation of travel experiences in an AV (significant effect of age). Experience with ADAS has also a direct positive effect on travel time valuation. Regarding the role of psychological factors, the results of the thesis show that a higher level of trust in AVs and positive evaluation of travel experiences in an AV positively influence the perception of time spent on autonomous riding. Conversely, enjoyment of driving decreases the utility of autonomous driving.

Empirical studies on AVs have so far considered only the direct effect of socio-demographic characteristics and psychological factors, such as attitudes, on the willingness to use an AV but have not measured their impact on travel time sensitivity. Moreover, in transport research in general, only a few studies address the effect of attitudes and perceptions on the value of time (e.g. Abou-Zeid et al., 2010, Thorhauge et al., 2019, Bahamonde-Birke et al., 2017, Li and Kamargianni, 2020). The analyses in the thesis are therefore, to my best knowledge, the first that measure the effect of selected psychological factors on the variability of the VTTS for autonomous driving. The findings provide empirical evidence for the importance of considering such factors when analysing potential preference changes due to new mobility options.

Regarding age and gender effects on the willingness to use an AV, previous empirical studies provide contradictory results. However, most of them suggest that men and younger people are more open to this technology (Becker and Axhausen, 2017). Experience with ADAS were found to positively influence trust in the technology (Rödel et al., 2014). The results of the thesis are therefore highly consistent with literature findings. Additionally, they also suggest that, for AVs, it is important to consider the effects of these variables on the travel time perception in an AV and on individual attitudes. This allows segment-specific calculation of the VTTS and therefore the development of more differentiated scenarios of the impact of AVs on travel demand.

In considering the role of attitudinal factors, trust in the technology of AVs is consistently found to be among the most important (psychological) determinants of their acceptance (Yap et al., 2016, Molnar et al., 2018, Ashkrof et al., 2019). The thesis findings confirm this and additionally quantify the impact of trust on VTTS for AVs. Regarding the positive utility of time spent in an AV compared to driving a conventional car, theoretical discussions suggest that well-being improvements or ability to relax during travelling will affect the value of time more strongly than the possibility of productive time use (Singleton, 2018, Mokhtarian, 2018). However, the utility of car driving in terms of driving enjoyment is considered to potentially diminish the benefits of autonomous driving (Singleton, 2018). The latter aspect is also highlighted by empirical studies showing that passion for driving negatively affected the willingness to use (or on stated choice of) an AV (Ipsos MORI, 2014, Silberg et al., 2013, Asgari and Jin, 2019, Haboucha et al., 2017, Ashkrof et al., 2019). The analyses described in this thesis provide empirical evidence for theoretical considerations of the role of the positive utility of travelling in an AV (improved travel experiences) and the role of trust in the technology by quantifying the effects of these aspects on the variability in the VTTS for potential AV users. The impact of passion for driving on travel time valuation was analysed using a qualitative approach allowing in-depth analyses of the mechanism behind user evaluation of AVs with regard to this aspect.

Thirdly, the VTTS for AV users depends on the considered vehicle or mobility service concept. A lower VTTS was found for a privately-owned AV compared to values for conventional cars. For the SAV, the findings suggest that using SAV in a ride-sharing arrangement is a less attractive option compared to an individually used SAV. Furthermore, the differences in the findings of the quantitative studies in the thesis regarding the VTTS comparison between PAV and SAV underline the high variability in user preferences for SAVs and suggest that future perceptions of this mobility option by potential users in the future remain highly uncertain. Simultaneously, the analyses identified also several influencing factors for the variation in VTTS for SAV including individual characteristics of the respondents as well as type of presentation of this alternative in the studies.

The majority of SP studies on mode choice and the VTTS regarding AVs focus only on PAVs (e.g. Correia et al., 2019) or only on various forms of SAV (Krueger et al., 2016, Winter et al., 2020, Yap et al., 2016, Ashkrof et al., 2019). Exceptions are two SP studies on mode choices (Becker and Axhausen, 2018, Zhong et al., 2020)[13] as well as a study on vehicle ownership preferences (Haboucha et al., 2017); these studies included both a PAV and an SAV as alternatives in an SP experiment. The results from two out of the three studies suggest that an SAV is currently a less preferred option than a PAV (Haboucha et al., 2017, Zhong et al., 2020), whereas one found almost the same VTTS for a PAV and an SAV (Becker and Axhausen, 2018). Regarding the findings in this thesis, these results emphasise the high preference variability and uncertainty regarding more novel concepts, such as an SAV where, besides automation, the willingness to share a vehicle or a ride with strangers plays an important role in the perception of the alternative.

In contrast to other research works, the identical study design of both quantitative studies in this thesis with the small changes in the presentation of the novel alternatives allows additionally an analysis of potential differences between the results of these studies. For the SAV, the comparison shows that the type of presentation of this novel concept appears to strongly influence the user preferences captured in the SP experiments. Clearer presentation of the SAV use cases (in this case, presenting the use in a ride-sharing arrangement in a short video, as for the individual use of SAV) led to increased participant awareness of certain attributes of the alternative in the choice situations. These findings emphasise that variation in the VTTS found for AVs depends not only on the considered concept but also on how novel options are presented to study respondents.

Overall, **the main strengths of the thesis** are that (i) it considers various AV concepts in comparison with all other available transportation modes (including active modes); (ii) it also analyses user preferences for currently available modes, especially conventional cars, establishing a baseline for comparison of potential changes arising from AVs; (iii) additionally, it uses an explorative qualitative approach to gain initial deeper insights into the user evaluation process for autonomous driving. It is noteworthy that, so far, only a few other qualitative studies have addressed user perceptions of AVs (Silberg et al., 2013, Fraedrich, 2018, Pudāne et al., 2019). **The main contributions of this thesis** to the research on the VTTS for autonomous driving are (i) measuring and analysing the VTTS for AV users depending on the trip purpose, individual characteristics (including socio-demographics and attitudes) and considered AV concept, and (ii) providing an empirical basis for segment-specific analyses and more differentiated scenarios that can quantify the impact of the technology on travel behaviour and the transport system.

The limitations of the work are as follows: (i) a hypothetical bias intrinsic to SP experiments which was, however, partly overcome by creating more realistic scenarios for participants by using one of their current trips and introducing currently available alternatives (in Study 2). Moreover, (ii) in the quantitative studies, the PAV was introduced as a vehicle that on request can drive autonomously or be driven manually to focus on the autonomous driving function and avoid mixing purchase and mode choice decisions. This can be seen critical as the choice of a PAV presented in this way might not represent the user preferences for level 4 or 5 vehicle automation accurately. Nevertheless, the comparison with the data from the SP experiment on user preferences for currently available modes of transportation suggests that people who prefer a manually driven PAV perceived this option as similar to a conventional car, which supports the appropriateness of the chosen approach. Therefore, adding a conventional car to the choice set for future mode choices can, depending on the study focus, be considered in future research, but it is not necessary. Lastly, (iii) the analyses in the thesis emphasise the importance of the type of presentation of novel concepts in empirical studies. Therefore, a generalization of the results of the thesis are limited to the presented AV concepts and use cases. Improving how new concepts are presented to study respondents and even providing a first real experience of the concepts in future studies can be crucial to continue monitoring and analysing user preferences for AVs in order to anticipate the potential behavioural impact of the technology *(further implications for future empirical studies are discussed in* *section 10.4**).*

[13] Note that, to my best knowledge, only the results from a pilot study have been published so far by the Becker and Axhausen (2018).

10.2 Policy implications of the results of the thesis

The results of the thesis have several important implications for policy strategies and measures related to the development, implementation and deployment of AVs. Some of these policy recommendations have already been discussed in Study 2 (Chapter 7) and Study 3 (Chapter 8). However, in this section, I again emphasise important aspects and discuss them based on existing strategy approaches and also the insights from Study 1 (Chapter 6).

Generally, the results in the thesis provide empirical evidence for a reduction in the VTTS due to the autonomous driving option for privately-owned cars on commuting trips and, therefore, for a potential increase in the attractiveness of car use. Furthermore, high variation and thus uncertainties exist regarding preferences for SAVs, as well as higher acceptance barriers for ride-sharing. Simultaneously, SAVs are often considered as a more sustainable solution than PAVs, as long as they do not grow at the cost of public transport and are used (primarily) as ride-sharing services (Pakusch et al., 2018a, Bahamonde Birke et al., 2018). Hence, policy intervention that actively shapes the integration of different forms of AVs into the existing traffic system is required. Otherwise, there is a risk of a substantial shift to individual motorised transport and an increase in vehicle kilometres travelled, which could either lessen or eliminate the potential benefits of autonomous driving for the traffic system, including more efficient traffic or increased road capacity (Bahamonde Birke et al., 2018, Gruel and Stanford, 2016, Pakusch et al., 2018a, Agora Verkehrswende, 2020).

Following an existing strategy approach for improving the sustainability of the transport system, such policy can focus on measures that aim to (i) avoid or reduce travel demand, (ii) shift demand to more efficient modes or maintain the use of such modes and (iii) improve vehicles using new technologies (Eckermann et al., 2015, GIZ, 2019). Furthermore, transport policy measures can be divided into 'hard' measures, such as infrastructure improvements, cost increases or prohibitions of car use, and 'soft' measures, such as strategies based on increasing awareness or dissemination and persuasion techniques (Bamberg et al., 2011). The following discussion on the implications of these results is structured based on the relevant parts of the *avoid-shift-improve* approach and considers potential hard and soft policy measures derived from the findings of the thesis.

Firstly, as mentioned above, it is unlikely that autonomous driving can avoid or reduce the travel demand: conversely, it can increase it. It is therefore important that policy measures contribute to preventing potential extended car use and **shifting demand from individual motorised transport to shared forms of transport**. This can be achieved by combining measures that support the operation and use of SAVs, including their integration into the public transport system, with measures that restrict individual car use.

Hard measures that facilitate the use of shared services are improving service attributes, including cost, waiting time for a vehicle and availability of the service. These may be especially useful in areas where shared rides are already accepted but where public transport in its current form is difficult to maintain due to limited economic sustainability, mainly due to the relatively high cost of drivers in the overall cost structure (e.g. in suburban areas). Automated vehicles could then be used, for instance, for shuttle services – on-demand or scheduled – for the first or last mile, thus improving the quality of public transport as a viable and reliable door-to-door mobility option. In urban areas, SAVs can potentially contribute to reducing the use of individual vehicles; to achieve this, active support of attractive and efficient SAV concepts is required. Given the variation in user preferences for SAVs and acceptance barriers for ride-sharing described in this thesis, further research on user requirements and suitable policy strategies is required. Measures that focus on the restriction of private car use, however, include (i) limiting car access in certain districts or urban centres and (ii) pricing policy, such as toll systems (discussed for instance by Bahamonde Birke et al., 2018, Gruel and Stanford, 2016). For the latter strategies, however, high levels of public opposition can be expected.

Soft policy measures can be used to increase acceptance of hard measures and support a voluntary shift to more sustainable modes of transportation (Richter et al., 2009, Bamberg et al., 2011). Regarding AVs, such measures can (i) start and facilitate public dialogue on the potentials and risks of autonomous driving and (ii) increase trust in AVs by enabling experience with the technology. Public dialogue means in this case that communication with the general public is not required to take the form of an information or marketing campaign, usually discussed as a viable soft measure in the transportation field (Richter et al., 2009, Chorus and Kroesen, 2014). Instead, it must focus on involving various potential user segments in a discussion, addressing their requirements and concerns regarding AVs and especially shared mobility services and discussing potential chances and risks of AV use. A viable policy strategy is facilitating field tests under real-world (or 'living lab') conditions that allow potential users to gain experience with the new technology and thus increase trust in AVs. Such measures are already part of national and international government strategies (e.g. BMVI, 2017a, European Commission, 2018). Based on the above arguments, they must be accompanied by research on the user perspective and utilised as a dialogue platform with the public.

Secondly, autonomous driving can contribute to **improving individual motorised travel demand** that cannot be avoided or shifted. For instance, automated vehicles can (i) be designed to have better fuel economy than conventional cars (Wadud et al., 2016, Lee and Kockelman, 2019), (ii) facilitate the use of alternative power trains (e.g. electric vehicles or hybrid engines; (e.g. electric vehicles or hybrid engines; Lee and Kockelman, 2019) and (iii) potentially improve traffic flow (Wadud et al., 2016, Lee and Kockelman, 2019). Simulation studies show, however, that the benefits of AVs for the traffic systems can only be achieved in combination with vehicle connectivity, and at a higher market penetration rate of connected and automated vehicles (e.g. Hartmann et al., 2017, Lee and Kockelman, 2019). Thus, user acceptance of the technology is crucial to realising their potential.

Deriving implications for hard policy measures that facilitate market deployment of the technology in private (or shared) cars based on the results of this thesis is difficult, as neither vehicle connectivity nor other technical requirements for implementing the technology in the existing system were included in the analyses. However, some are worth mentioning, as establishing the appropriate technical conditions for the use of AVs is crucial for providing mobility options that meet the needs of potential users. Hard policy measures include (i) establishing funding programs for research, development and testing of sustainable technological solutions, (ii) financial investment in the development of physical and digital infrastructure and (iii) supporting the development of affordable technology.

Suitable soft policy measures for increasing user acceptance of AVs are consistent with those discussed above: public dialogue is required to identify desirable use cases for AVs and the requirements of potential users as well as to increase awareness of the potential impacts of AVs. As shown in this thesis, user preferences differ strongly between the various user segments. This has to be considered in the communication with the public by developing measures that target different population groups and their needs. Part of the discussion involves also finding a balance between user requirements (e.g. regarding vehicle comfort, individual and flexible vehicle use and the wishes of some user groups to drive manually) and the need for a transition to a more sustainable traffic system using the potential of vehicle automation. Furthermore, the empirical findings from the thesis support the importance of the subjective well-being benefits of AVs for users. Therefore, when developing policy measures for AVs, further societal benefits of autonomous driving that transcend the potential increase in road safety must be considered.

Finally, in considering general policy challenges related to creating a sustainable future transport system, it must be acknowledged that automated driving or the implementation of AVs in the existing traffic system is only one element of the potential solution. Facilitating the use of active modes and public transport remains an important part of it.

10.3 Implications of the results of the thesis for the development of autonomous driving concepts

The results of the thesis also provide directions for further development of automated vehicles and mobility concepts. Generally, for automated and connected vehicles, the perception of travel time spent in the car has gained high importance for the automotive industry and mobility service providers. Some premium vehicle manufacturers focus on developing future concepts envisioning the car as a '*third place […] in addition to home and office'* (Daimler AG; Zetsche, 2015) or as a '*favourite space – a new place for quality of life'* (BMW AG, 2020). In these visions, the car is serving various needs besides mobility:

'*In the future, the car brings access to the single most important luxury goods of the 21st century: private space and quality time'* (Zetsche, 2015). Research on user preferences provides insights into whether these visions meet the requirements of the general public.

The results of the thesis show firstly that improved travel experiences, the ability to relax during the trip and perform passive activities (e.g. watching movies, listening to music) are important elements of the utility of riding autonomously. Productive time use was not found to play an important role in the positive evaluations of autonomous driving (at least for the majority of the respondents). In Study 1, this use case was found to be relevant only for a certain user segment, particularly people who have flexible working times or are self-employed with a job that is suitable for teleworking. Therefore, these findings suggest that, of various proposals for future vehicle interiors, depending on individual user needs, a high comfort level (and the required equipment, seat designs or vehicle driving modes) and infotainment features are among the most important elements.

Secondly, the analyses show that manual driving also provides certain benefits to car users, including enjoyment of driving, various activities that can currently be performed in cars and car driving as an activity itself, which partly counterbalances the benefits of autonomous driving. These findings suggest that in the transition phase from manually driven to fully automated vehicles, control and intervention options might still play an important role for potential users (given that the safety of the vehicles is guaranteed when enabling overriding it). Furthermore, autonomous driving is currently perceived by potential users as an attractive option only for certain use cases and particularly commuting trips. Focusing on various AV types that serve a certain purpose rather than all purposes at once might be a viable strategy[14] for the further development of autonomous driving. Following such a strategy can also facilitate the use of SAVs, that is, the use of a vehicle on demand that fits the user needs for a particular trip. Vehicle right-sizing (i.e. providing SAVs in various sizes depending on user demand) can additionally contribute to optimising energy demand (Lee and Kockelman, 2019).

Regarding SAV concepts, despite variation in user preferences regarding this alternative across the studies described in the thesis, the findings suggest that (i) the objective attributes of the service, including waiting time and cost, determine the choice of an SAV and (ii) privacy issues might be an important acceptance barrier to such services (as ride-sharing was a less preferred option than individual use of an SAV). The development of shared autonomous concepts must therefore focus primarily on ensuring acceptable waiting times and affordable fares for the services. Second, for ride-sharing services, the privacy needs of the users must be considered, for instance, by developing interior design solutions that ensure certain private space for each passenger in the vehicle[15].

Building on the discussion in section 10.2, the development of sustainable future AV concepts and services must consider individual user preferences and requirements as well as the requirements for a sustainable future traffic system. This includes developing attractive use cases of shared mobility concepts, including integrating sharing services in the public transport system as well as facilitating the use of alternative power trains and fuel-powered vehicles.

10.4 Recommendations for future empirical studies on autonomous driving and other new mobility concepts

Based on the methodological challenges and solutions identified during the research process described in this thesis, various recommendations are suggested for future research, not only on autonomous driving but regarding new mobility options in general.

Firstly, for novel topics, such as autonomous driving, using explorative qualitative research in the studies provided valuable and deeper insights into potentially relevant determinants of user preferences. Combined with the applied quantitative methods, the effect of the identified factors was then quantified and could be used to analyse more detailed potential scenarios of the impact of new mobility options.

[14] An example of a research project that focuses on analyses and development of potential future vehicle concepts is the project 'Next Generation Car' of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V., DLR).
[15] An example of such a vehicle interior concept is the design in the vehicles from the fleet of the (conventional) ride-sharing service provider MOIA (https://www.moia.io/de-DE/hamburg).

As described in Chapter 5, in the research praxis, qualitative and quantitative methods are often used alone or separately. This is mainly because the insights gained from both approaches can stand alone, and they usually focus on different aspects of a research topic (e.g. on measuring a certain phenomenon in quantitative studies versus understanding the phenomenon in qualitative studies). Moreover, applying qualitative and quantitative methods in research requires developing expertise in both methodological fields. However, when analysing a complex phenomenon, such as potential user preferences regarding future mobility options, it is essential to provide a broader view on the topic, which can be achieved by combining the strengths of both approaches.

Secondly, two elements of the chosen study design for the SP experiments are worth discussing because of their relevance for future empirical works: (i) the choice of incorporating two experiments in one survey and (ii) introducing certain characteristics of automated vehicles or services as an attribute rather than presenting distinct alternatives. Regarding the first aspect, using an SP experiment on user preferences for currently available transportation modes before introducing new alternatives proved to be a useful approach for analysing potential changes, as it allows an accurate baseline to be set. Furthermore, first conducting an experiment using currently available options can positively affect learning and improve the quality of the answers: respondents first learn to address a choice situation that is closer to their daily life before being confronted with a hypothetical decision situation that includes new (and unfamiliar) options. This can therefore be a viable option for future SP studies on user preferences for new mobility alternatives.

With regard to describing vehicle or service characteristics as attributes, we introduce a PAV that can drive autonomously but also be driven manually on request and present ride-sharing as an attribute of an SAV rather than having two types of SAV services. For the PAV, the focus was on the willingness to use the automated function and its impact on time evaluation. Presenting autonomous driving as a function avoided mixing the decision to purchase an AV with a mode choice. The baseline experiment in Study 2 enabled validation of the results regarding the preference for the use of a manually driven AV. For the SAV, the analyses focused on the perception of travel time when using the service individually compared to sharing the ride. In both cases, the main benefit of presenting the different usage options as attributes was having a full choice set that consisted of five rather than six to seven alternatives: having more than five alternatives would make the choice situation more complex and potentially overwhelming for the respondents. This could reduce the quality of the answers. Thus, future empirical studies on new mobility options could consider simplifying the introduction of new alternatives (e.g. such as in this case introducing autonomous driving as a feature rather than as a distinct vehicle concept) to focus on the main aspect of interest (e.g. the option to ride autonomously).

Thirdly, the results of the thesis show that the type of presentation of relevant attributes of new concepts strongly influenced the respondents' evaluation of this alternative. In this case, introducing the use of an SAV in a ride-sharing arrangement using a short video rather than only a text description led to significant differences in the user preferences for using an SAV individually compared to sharing the ride with strangers. These findings suggest that visual information in terms of images and videos makes it easier for respondents to understand new concepts and increases awareness of this attribute in the choice situations. The results are consistent with previous research on the impact of images on user preferences in choice experiments. For instance, Rizzi et al. (2012) found that including traffic images in an SP experiment on mode choices to supplement information about attributes substantially influenced travel time valuation compared to verbally described attributes. Harline and Burris (2014) drew a similar conclusion: in their survey on route choice, the authors found a statistically significant effect of traffic images on route choice with regard to VTTS, or the value of time reliability. In future research dedicated to mode choices and VTTS, it is therefore important to carefully consider how information about new alternatives is presented to study respondents. Considering new visualisation and simulation options, besides videos and images, including augmented and virtual reality (AR/VR), can be viable methods or techniques for improving realism in SP experiments. An example of applying the method in SP studies and a discussion of its strengths can be found in the literature (Farooq et al., 2018).

Lastly, the thesis underlines the importance of considering psychological factors, such as attitudes, and their impact on travel time valuation in future studies. Study 3 provides an example of how this can be done: it analyses the direct effect of socio-demographics on mode choices and look also at the interaction effect between individual characteristics, including attitudes, and travel time evaluation. This approach allows segment-specific analyses of the effects of AVs and also developing mode differentiated scenarios about the impact of new technologies on the transportation system and society. An important part of the methodology is using psychometric scales for measuring attitudes and preferences. Along these lines, knowledge and experience in the research field of psychology and social science might become increasingly important in transportation studies.

10.5 Further research needs in the context of autonomous driving

Several future research avenues on travel time perception and time use in an AV can be derived from the results of the thesis and related aspects that were not the focus of the work. The research fields discussed below are consistent with the research topics suggested in recently published papers on travel time valuation in the context of vehicle automation (e.g. Milakis et al., 2017, Mokhtarian, 2018, Pudāne et al., 2019, Singleton, 2018) and complement the research needs in this area. The literature on the topic suggests the following future research areas: the extent to which productive or pleasurable time use determines mode choices, exploring the links between subjective well-being and travel time in an AV (Mokhtarian, 2018, Singleton, 2018), the positive and negative effects of expanding the uses of travel time (Mokhtarian, 2018, Pudāne et al., 2019) and in general more qualitative and quantitative research on understanding travel choices and the role of travel time in the context of acceptance of AVs (Milakis et al., 2017, Mokhtarian, 2018).

Firstly, the thesis provides empirical evidence for a significant effect of an (anticipated) positive travel experiences, or potential subjective well-being benefits, on the travel time sensitivity in an AV. Given the demonstrated importance of this aspect for autonomous driving, future research can address users' requirements on AV concepts and services associated with travel experiences. This also applies to desirable activities during trips in an AV. For instance, in section 10.3, I discuss some potential implications for vehicle interior designs, such as increasing comfort level (with appropriate seat designs and driving modes) or providing time use opportunities (with relevant equipment, such as infotainment features). Studies that aim to analyse desirable AV concepts from a user perspective can focus on such interior design implications drawn from the expected benefits of AVs. Furthermore, the thesis analysed the effect of travel-based activities and (expected) travel experiences on travel time valuation in an AV in general. Further studies can focus, therefore, on identifying potential user segments characterised by their individual utility of autonomous driving (including time use and improved travel experiences). Moreover, besides the importance of well-being improvements as an implicit element of public policy, the relation between subjective well-being and travel is addressed in transportation studies only by a small number of researchers (Mokhtarian, 2019). The results of the thesis emphasise the importance of subjective well-being as a benefit of autonomous driving, that is, the potential indirect effect of travel and mode choices on well-being. Therefore, I join researchers who work in this field (Smith, 2017, Singleton, 2018, Mokhtarian, 2019) in calling for further research on the topic to create a holistic concept of the complex relationship between travel and well-being, including improvement of measuring instruments for this concept.

Secondly, the thesis addressed various concepts of AVs: a PAV and an SAV used individually or used in a ride-sharing arrangement. However, similarly to the majority of existing studies on AVs, the work focused (i) heavily on the highest level of vehicle automation and (ii) on door-to-door use of SAVs. Simultaneously, it is more likely having a longer transition phase from the advanced driver assistance systems towards high to full vehicle automation, and first use cases that are already tested on public roads include first and last mile SAVs or shuttle services. Thus, exploring travel time sensitivity and other mechanisms behind the willingness to use vehicles with lower levels of automation as well as services integrated into the public transport system is becoming increasingly important. For instance, while the range of feasible on-board activities may be limited to higher automation levels, the perceived comfort and stress-relief might be significant also at the lower vehicle automation levels (e.g. for a stop-and-go pilot). For sharing services, it will be relevant to explore user requirements related to ride-sharing, such as privacy issues, as this option was found to be less preferred than individual use of an SAV in this work. This topic is linked to the roles of vehicle size, trip length and other service characteristics (e.g. whether shuttle services with small automated vehicles and more passengers on board are perceived as safer than sharing a ride in a small vehicle with only one or two other users). Moreover, it could be considered which user groups will be more likely to use such services. Along these lines, the thesis focuses on differences between the preferences for PAVs and SAVs in the context of mode choices. Further research can focus more strongly on the impact of travel time perception and travel time use in an AV on vehicle ownership decisions. Potential changes in car ownership motives in the era of autonomous driving might be considered: for instance, focusing on the role of affective motives, such as enjoyment of driving, or motives related to status benefits associated with car ownership. Future studies might also consider whether the availability of automated vehicles on demand (and potentially also travel time use possibilities with infotainment services in the vehicle) will replace the need and preferences for owning a car.

Thirdly, the results of the thesis show that, besides individual characteristics, the context plays an important role in evaluating the time spent in an AV. The thesis focuses strongly on everyday trips, especially on commutes. The findings of Study 1 as well as those of a related study (see Kolarova and Steck, 2019) suggest, however, that autonomous driving might also be an attractive option on long-distance trips. Moreover, further context-related characteristics, such as congestion level, time pressure and travel duration can also influence the preferences and the VTTS for an AV: these hypotheses are also supported by the results of this thesis. Therefore, future research can further explore vehicle automation under different conditions, including long-distance trips, characteristics of the quality of travel time, including travelling with companions and time use, and traffic conditions.

Fourthly, the thesis addresses the impact of the VTTS for autonomous driving in relation to mode choice decisions. Further research is required, however, on the long-term impact of VTTS changes, once autonomous driving becomes available on the market. Two important research areas within this topic are already addressed in empirical studies: the potential impact of changes in travel time valuation on (i) trip distance preferences and indirectly on residential (or work) location choices (e.g. Kim et al., 2020, Moore et al., 2020) and (ii) daily time use patterns beyond travel time use (e.g. Pudāne et al., 2018). Regarding the first aspect, it can be expected that the decrease in travel time disutility will lead to readiness to tolerate longer commute distances or times, which could be shown for certain user segments in a study conducted by Moore et al. (2020). Moreover, residential location choices can be addressed together with other long-term impacts, such as a change in the car ownership rate (e.g. Kim et al., 2020). Regarding daily time use pattern changes, a recent study (Pudāne et al., 2018) proposed a model that captured the effects of the feasibility of performing on-board activities in an AV on time use or individual daily time schedules. Although initial empirical insights are available on both topics – potential residential location changes and time use implications – further research is required to improve understanding of the dynamics resulting from implementing the new technology. This is especially important based on the impact of such long-term changes on travel patterns, (urban) spatial structures and vehicle ownership rates. Possible research avenues are exploring the factors that shape these effects and developing further modelling frameworks that incorporate hierarchical decisions, such as mid-term decisions (mode choices) and long-term decisions (vehicle ownership and residential location choice).

Finally, several policies and planning strategies can be drawn from the results of the thesis, and these have been discussed in section 10.2. However, research on user preferences and mode choices can also be used to monitor changes when the development and implementation of AVs evolve, to explain these changes and continue to support strategical decision-making in the transition phase towards higher automation. Future research can additionally focus on analysing the effects and efficacy of various policy measures on travel behaviour or to accompany the implementation of policy measures. Suitable methods could be combinations of qualitative and quantitative methods, as in this thesis, as well as longitudinal case studies integrated with field tests or living lab projects.

Overall, various further relevant research topics arise in the context of new mobility options in this era of ever-increasing vehicle automation and connectivity as well as sharing mobility trends. I touched in this section on several topics related to the studies described in this thesis. Furthermore, this thesis supports the importance of using interdisciplinary approaches when considering the impact of introducing new mobility options on mode choices. Similarly, from a methodological viewpoint, a combination of qualitative and quantitative approaches proved useful for obtaining a more comprehensive picture of individual-level changes that are key to anticipating their broader effects on travel demand and society. The demand and relevance of such research are even higher when considering environmental challenges in the transportation sector and the diversity of potential mobility solutions for these challenges (e.g. various mobility service options, integration of active modes in multimodal trip chains). Regarding related developments in the transportation sector, new types of transportation modes, such as e-scooters, car- and ride-sharing services, on-demand buses, or even flying taxis, might challenge currently used methods in further understanding and modelling user preferences. Therefore, research must continue to break the barriers between single research disciplines as well as improve and combine existing methodological approaches.

Annex I: Presentation of the concept of automated vehicle in the two quantitative studies

In Study 2 and in Study 3, respondents were presented with two concepts of automated vehicles before the stated choice experiment: a PAV and an SAV/ 'driverless taxi'. However, there were some differences between the presentation of the SAV which are highlighted below.

Figure 7 shows the storyboard for a trip with a PAV. Mrs. Schmidt calls her vehicle using an app on her smartphone, the vehicle drives by itself out of the garage and pick her up. During the trip, she can decide whether she would like to drive manually or which of the automated function of the vehicle and ride she wishes to set in automated drive mode.

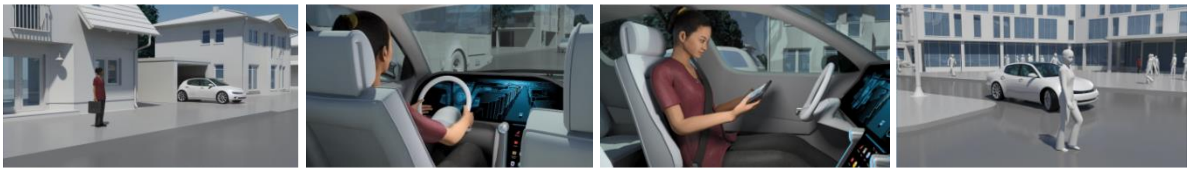

Figure 7: Storyboard of the animated video used to present a trip with a privately-owned automated vehicle (PAV)

Figure 8 presents the storyboard for a trip with an SAV, used individually (i.e. not used in a ride-sharing arrangement). Mrs. Schmidt calls a vehicle using an app on her smartphone, the vehicle picks her up and drives her fully autonomous to her predefined destination. In contrast to the PAV, the SAV is a vehicle without steering wheel or breaks, so it cannot be driven manually.

Figure 8: Storyboard of the animated video used to present a trip with a shared automated vehicle (SAV) - vehicle used individually

The same two videos were presented also in Study 3, plus an additional video to show specifically the use of an SAV in the case that the ride is shared with others. This change of the type of presentation of the concept was done in order to provide a better understanding of the use case to the respondents since the results of Study 2 showed that people did not really paid attention to attribute for ride-sharing in the first survey.

Figure 9 presents the storyboard of an SAV, used in a ride-sharing arrangement. The SAV, as presented in the video, shows Mrs. Schmidt calling a vehicle with her app and then sharing the ride with other user who uses similar routes with the benefit of having lower cost per person for the ride. This video was presented *only in Study 3*. In Study 2, the option to share a ride with other users was presented only using the following short text description:

> *"In the case of driverless taxi, passengers with similar start point and destination can share the ride. The ride becomes consequentially cheaper for the single users. In the following choice situations is therefore always shown whether you will **ride alone** when choosing a driverless taxi or you will be **sharing the ride with other passengers.**"*

Figure 9: Storyboard of the animated video used to present a trip with a shared automated vehicle (SAV) - vehicle used in a ride-sharing arrangement

Annex II: List of related scientific contributions published during the thesis period

The following list contains all scientific contributions on the topic of user preferences and VTTS in the context of autonomous driving which were published during the thesis period. The three scientific papers which are part of the thesis (Chapter 6, Chapter 7, Chapter 8) are not included in the list.

Journal Papers

Year	Title	Journal	Role / Co-author(s)
2018	How autonomous driving may affect the Value of Travel Time Savings for commuting.	*Transport Research Record: Journal of the Transportation Research Board* 2672 (46), 11-20	Second author, including substantial contribution to study concept, data collection, analysis and writing of the paper / Felix Steck, Francisco Bahamonde-Birke, Stefan Trommer, and Barbara Lenz
2018	Estimation of value of time for autonomous driving using revealed and stated preference method.	*Transport Research Procedia,* 31, 39-45.	Lead author, including contribution to study concept, data collection, analysis and writing the of paper / Felix Steck, Rita Cyganski, and Stefan Trommer

Book chapters

Year	Title	Book title	Role / Co-author(s)
2019	Estimating impact of autonomous driving on value of travel time savings for long-distance trips using revealed and stated preference methods.	*Mapping the Travel Behavior Genome.* In: Goulias, K. G., and Davis, A.W. (Eds). Elsevier, ISBN: 9780128173404.	Lead author, including substantial contribution study concept, data collection, modelling and writing the chapter / Felix Steck
2019	Activities while travelling? Travel time perception and time use in an era of automated driving.	*Advanced in Transport Policy and Planning: The evolving impact of ICT on activities and travel behavior.* In: Eran Ben-Elia (Ed). Academic press, An imprint of Elsevier, Vol. 3, ISBN: 9780128162132.	Lead author, including extensive literature review, data collection, data analysis and major contribution to writing of the chapter / Rita Cyganski and Barbara Lenz

Conference contributions

Year	Title	Conference title	Role / Co-author(s)
2019	Assessing requirements and concerns of potential users of automated driving services progressed by Internet of Things using a co-designer approach	*Automated Vehicle Symposium,* 15-18 July 2019, Orlando, FL, USA.	Lead author, including data collection, data analysis and major contribution to the creation of the conference poster / David Ertl, Elina, Aittoniemi, Gillian Harrison, Katerina Touliou, and Yvonne Barnard
2018	Estimating and explaining the value of travel time savings for autonomous driving.	*Automated Vehicle Symposium,* 9-12 July 2018, San Francisco, CA, USA.	Single author
2018	Empirical evidences on the impact of autonomous driving on value of travel time savings and mode choices.	*Automated Vehicle Symposium,* 9-12 July 2018, San Francisco, CA, USA.	Single author
2018	Exploring individual and societal acceptance of automated and connected vehicles.	*Automated Vehicle Symposium,* 9-12 July 2018, San Francisco, CA, USA.	Lead author, including contribution to data analysis and creation of the conference poster / Kerstin Stark, Florian Koller, and Barbara Lenz
2018	Erfassung des Value of Travel Time Savings beim autonomen Fahren.	*Verkehrsökonomik und -politik,* 14-15 June Berlin, Germany.	Lead author, including contribution to data collection, data analysis and creation of the presentation / Felix Steck and Francisco Bahamonde-Birke
2018	Änderung des Value of Travel Time Savings durch autonomes Fahren – empirische Befunde und verkehrliche Wirkungen auf den Fernverkehr in Deutschland.	*Verkehrsökonomik und -politik,* 14-15 June Berlin, Germany.	Second author, including contribution to data collection, data analysis and creation of the presentation / Felix Steck and Christian Winkler
2018	Automated vehicles - game changer for urban mode choice?	*mobil.TUM - International Scientific Conference on Mobility and Transport* 13-14 June 2018, Munich, Germany.	Last author, including contribution to study design, data analysis and writing the paper / Rita Cyganski, Kay Gade, and Felix Steck

Project reports

Year	Title	Project title	Role / Co-author(s)
2020	Projekt 'DiVA – Gesellschaftlicher Dialog zum vernetzten und automatisierten Fahren'. Schlussbericht. Berlin, Germany, Institut für Verkehrsforschung, Deutsches Zentrum für Luft- und Raumfahrt e.V.	DiVA – Gesellschaftlicher Dialog zum vernetzten und automatisierten Fahren	Lead author, including data collection, data analysis and major contribution to the writing of the report / Kerstin Stark and Barbara Lenz
2020	Die Automatisierung des Automobils und ihre Folgen. Chancen und Risiken selbstfahrender Fahrzeuge für nachhaltige Mobilität.	AGORA AVF - Thesen zum automatisierten und vernetzten Fahren	Lead author, including data collection, data analysis and major contribution to the writing the report / Kerstin Stark, Lars Hedemann, Barbara Lenz, Marena Pützschler, and Alexander Jung
2018	Deliverable D4.7. User requirements analysis. Project 'AUTOPILOT – Automated driving progressed by Internet of Things', Grant Agreement Number: 731993.	AUTOPILOT – Automated driving progressed by Internet of Things	Co-author, including data collection, data analysis and contribution to the writing / Elina, Aittoniemi, Yvonne Barnard, Haibo Chen, David Ertl, Gillian Harrison, Fanny Malin, and Katerina Touliou

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