What Drives the Adoption of Autonomous Cars?

Completed Research Paper

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Abstract

Despite widespread expectations of a disruptive change in society's mobility though autonomous cars, scholarly research in the field is scarce. By combining theory-building, in-depth research among experts with established theories, the authors develop and test a model to understand adoption drivers of autonomous cars on a sample of 642 respondents representative to the German population in terms of age, gender and geographical distribution. Results suggest that factors related to potential users' adoption intention for autonomous cars may not be precisely the same as those suggested by experts. In addition, moderator analyses provide insights into how different types of users process autonomous cars. Stakeholders both from academia and managerial practice may find these results useful when evaluating usage behaviors in the future market for autonomous cars.

Keywords: autonomous cars, self-driving cars, barriers, benefits, consumer survey

Introduction

Established car manufacturers as well as companies from other industries are developing a new type of vehicle referred to as autonomous car (Harris 2015; Silberg 2013). While the required technologies have been around for several years (e.g. image recognition, sensor technology, actuators), only highly specialized projects, such as the "Rocky 7 Mars Rover" Prototype (Volpe et al. 1996), realized such a product. However, it seems that time has come for this idea to enter the mass market: A recent study from the Boston Consulting Group asserts that "in the auto industry's most significant inflection in 100 years, vehicles with varying levels of self-driving capability —ranging from single-lane highway driving to autonomous valet parking to traffic jam autopilot—will start to become available" (Mosquet et al. 2015). This is echoed by KPMG's Gary Silberg who notes that "in some ways, the industry is moving even faster than we predicted. Rarely does a day go by without another announcement about a new technological breakthrough or a new joint venture" (Silberg 2013, p.1). However, the diffusion of a technology that is not fully mature comes at a cost, as several deaths in early 2018 illustrate and that were related to software errors (Hiltzik 2018).

Despite these widespread expectations of a disruptive change in society's mobility scholarly research in the field is scarce. Yet, both manufacturers and policy makers as well as several other stakeholder groups could profit from differentiated and reliable insights into the transformations to come. For example, the way how potential users adopt autonomous cars will be of high relevance to car manufacturers, insurance companies, media, traffic law specialists and the like to make predictions about usage forms, traffic density, risk forms and levels, etc. Against this background, this study focuses on potential users.

Prior research allows understanding many facets of users' decision making with respect to traditional cars (e.g. Farrell and Dawson 1996; Herrmann and Wricke 1998; Odekerken-Schröder et al. 2003; Pauwels et al. 2004). In addition, theories such as the technology acceptance model (Davis 1989) or the diffusion of innovation model (Rogers 2003) explain how and why users react to new technologies. But are these theories applicable to autonomous cars? Some of these theories do not capture potential risks associated with driverless transportation, including accidents or being victim of cyber-attacks. In addition, autonomous driving changes the user's role from being an active driver to be a more passive passenger who can engage in various other activities while 'driving' or being driven. Finally, different user groups may show different reactions to autonomous driving.

We suggest that academic research on autonomous mobility is needed to better understand the adoption of autonomous cars. The objective of this study is to contribute by improving knowledge on user's potential reactions to autonomous cars. Thus, we draw on prior technology acceptance and risk research models (Bagozzi 2007; Davis 1989; Venkatesh and Davis 2000). We enrich these models using theory-building qualitative in-depth data collected in two pilot studies from industry experts. This study combines the expert perspectives and established theories to provide a framework that, in line with the title of the "Practice-oriented Demand-driven IS Research" track, puts a focus on the managerial importance and implications of the findings. The framework is used to answer the following two research questions:

- RQ1: What drives potential users' adoption intention of autonomous cars?
- RQ2: Do effects differ between user groups?

To provide answers to the research questions, this study uses cross-sectional data collected through a professional market research company and tests the proposed framework using structural equation modeling. Findings contribute to theory and practice in several ways. Our results suggest the relevance of several benefit and risk factors not taken into consideration in prior adoption research. Our research also suggests that factors related to potential users' adoption intention for autonomous cars may not be precisely the same as those suggested by experts. Moderator analyses provide insights into how the strengths of these factors differs among user groups. Stakeholders both from academia and managerial practice may find these results useful when evaluating usage behaviors in the future market for autonomous cars.

Theoretical background

Definition and literature on autonomous cars

Autonomous cars (syn: self-driving cars, driverless cars, robotic cars, smart cars) are a subset of intelligent vehicles and reflect the latest step in a long evolution of mobility. They have been enriched with technology to support the driver (Little 1997; Winter et al. 2014). They may offer the potential to fully eliminate the risks of human error from the driving process (Gogan et al. 2005). Autonomous cars strongly rely on permanent online connectivity which they also provide to passengers (Dery and MacCormick 2012). Data generated through connectivity as well as built-in sensors and systems allows companies' R&D departments to improve their understanding of mobility, traffic, and user behavior (Whelan et al. 2010).
To the best of our knowledge, there is no established definition of the term 'autonomous car'. Taking prior research into account (e.g., Gehrig and Stein 1999), we propose a working definition for our research:

> Autonomous cars are vehicles that can fully operate the entire driving process, that is, perceiving the environment, planning routes, and executing navigation without a human driver's involvement during the ride.

We used the qualitative studies presented subsequently to validate this definition with industry experts. Full operation means that the autonomous car can perform the entire spectrum of activities required to steer the vehicle to a predefined target location. This includes compliance with traffic regulations and appropriate action in any possible situation (e.g., reactions to new traffic constellations). Perception of the environments relies on various sensors installed in the car, such as cameras, radar, GPS, and odometers. Planning includes any action related to driving-decisions. Execution of navigation concerns the actuating of the steering wheel, throttle, and other instruments required to reach the intended target location (Thrun 2010). Depending on the model, some autonomous cars also offer the alternative to be operated by a driver. Without a driver's involvement during the ride implies that a user needs to program a target location before the drive. However, while driving, the driver's role changes, at least to a certain extent, to a passenger who can avert his attention and turn to other occupations.

However, "autonomous" is an attribute that exists on a continuum, ranging from driver-dependent to fully autonomous (i.e. 'self-driving') vehicles. For instance, the US government uses a classification of five levels, each level being more automated than the previous one. Level 0 of vehicle automation is a car without any assisting systems at all, leaving the driver in control always. A car at level 1 possesses one or more systems that automate functions (e.g., cruise control), but these features do not interact with each other. Automated vehicles on level 2 encompass two or more assistance systems that interact with each other, for example, a lane-centering assistant combined with cruise control. Level 3 represents a car designed to temporarily and conditionally take full control of the driving process, for example, on an interstate with less traffic. However, in complex situations, the driver must be notified with appropriate time in advance to retake control over the vehicle. A car on level 4 is fully enabled to drive autonomously, not requiring a driver at all. Mercedes-Benz introduced a level 4 prototype called "S 500 Intelligent Drive Research Vehicle" in 2013 (Bender et al. 2014). Recent announcements indicate the first commercially available autonomous cars that equate to abilities at level 4 may be sold in 2020 (Preisinger 2013). We provide our definition for ease of understanding, especially to respondents, as the level-logic applied by US-agencies would have required further explanations.

Extant Research on Autonomous Cars

Academic research conducted to understand potential users' reactions to autonomous cars is scarce. We searched several academic databases (such as Google Scholar and the Web of Science with its ICCSI index) for peer-reviewed articles in academic journals and international conferences. Search terms included "self-driving car", "autonomous car", "robotic car" and "driverless car", and various alternative terms and spellings. For the Web of Science, no adoption-related research results were identified. Google Scholar yielded few peer-reviewed articles focusing on adoption intention and behavior of users for autonomous cars. Table 1 provides an overview.

Table 1: Key Studies on Autonomous Cars

Study	Research Question	Theory	Research Design	Core Findings
Bansal et al. (2016)	• Understanding the evaluation and reactions to autonomous cars	• n/a (exploratory research)	• Internet-based survey (n = 347), USA	• Core concern is the risk of equipment failure, core benefits are expectations of fewer crashes • Additional willingness to pay up $ 7253 (level 4 cars). • Most interested users in autonomous cars are male, high income and tech-savvy.
Bazilinskyy, et al. (2015)	• Exploration of perceptions and evaluations of autonomous cars	• n/a (exploratory research)	• Content analysis of open-ended survey questions (n = 1952), manually coded by workers of an online crowdsourcing platform.	• About half of the analyzed posting did not include any meaningful information, the remaining posts include more positive than negative statements. • The results indicate heterogeneous opinions on autonomous cars
Carsten et al. (2012)	• Understanding people's usage of/reaction to vehicles with different degrees of automation	• n/a (exploratory research)	• n=49, England (simulator study)	• Higher levels of automation increases individuals' shift to other activities
Hutchins, N. and Hook, L. (2017)	• Extending TAM for safety-critical applications	• Safety-critical Technology Acceptance Model	• conceptual	• Next to EOU and PU, safety expectancy drives attitude towards using • Safety expectancy is driven by Trust, Reliability, Transparency and Approval by Authority
Kyriakidis et al. (2015)	• Understanding individuals' reactions to autonomous cars	• n/a (exploratory research)	• online survey (n = 4886) in various countries, with some country n<25 • analyses: correlations	• A majority of respondents believe in autonomous cars, but had concerns on data risk/misuse, legal or safety cultural differences.
Payre et al. (2014)	• Focus on a priori acceptability and intention to use of fully automated driving	• n/a (exploratory research)	• online survey (n = 421), France • regression analysis	• Most respondents have a generally positive attitude towards autonomous cars. • contextual factors and the attitude both relate with intention to use an autonomous car
Rodel et al. (2014)	• TAM for five-stage model of vehicle automation with focus on user experience and user acceptance • Differences in gender, age, driving frequency	• Technology Acceptance Model and extension	• online survey (n = 336), Austria • Analysis of Variance	• Experienced users of driver assistance systems feel more at ease using autonomous vehicles • Increases in autonomy detract from User Experience • Men favor extremes of autonomy (none/full) over medium levels
This study	• Understanding the factors that influence the intended adoption of autonomous cars	• Technology Acceptance and Risk Theories • Theory-building qualitative research based on experts' tacit knowledge	• Two qualitative pilot studies (in-depth interviews and focus group) with experts. • Survey n=643 (quota sampling, Germany) • Analysis: SEM and Multi-group causal analysis	• Ease of use and social influences are positively related to adoption intention of autonomous cars. • Usefulness can be explained by technological risk, but not data risk, and various instrumental benefits. • Ease of use is not directly (but indirectly, mediated by usefulness) related to adoption intention. • Results remain stable after controlling for various factors.

Table 1: Key results of Literature Review

Overall, extant studies generally found that people's positive evaluations outweigh negative reactions. In addition, many users tend to echo recent market forecasts and expect that autonomous vehicles will be a future standard of mobility. However, not all individuals react to autonomous cars in the same way. Excluding the work of Rodel et al. (2014), the studies reported in table 1 did not take inter-individual differences into account. In the very early stage of research, these studies used exploratory ad hoc approaches to identify potential factors whose influence on adoption was then assessed through quantitative research.

In conclusion, the literature provides a basis of exploratory research. However, future studies should integrate these findings and propose theoretical framework explaining user adoption. The purpose of our research is to develop such a framework. For this purpose, we build upon extant research, complete this research with theory-building in-depth research derived from qualitative pilot studies with experts, and develop a theoretical framework. This study then tests the framework using cross-sectional survey data. Specifically, we use the robust technology acceptance model as a core for our framework and enrich it with situational, product-specific factors. By doing so, we acknowledge criticism of the technology acceptance stream of research (Bagozzi 2007; Benbasat and Barki 2007) and attempt to develop managerially relevant findings.

Technology Acceptance Literature

The acceptance of technology is a topic extensively discussed and researched in the field of management information systems (MIS) (King and He 2006). Over the decades, researchers have put forth various theories and approaches to address the issue, with roots in information systems, psychology, and sociology (Venkatesh et al. 2003; Rogers 2003). Prominent examples are the Technology Acceptance Model (TAM), which is one of the most widely used models in MIS (King and He 2006), and the diffusion model by Rogers (2003). While TAM serves as a primary reference model for studying the acceptance of new technologies in other disciplines including psychology (e.g., Gentry and Calantone 2002), education (e.g., Selim 2003), operations management (e.g., Olson et al. 2003), and many other management fields (King and He 2006), the diffusion model originates from communication theory and describes the proliferation of innovations in a population, segmenting adopter groups by innovativeness (Rogers 2003). Even though both frameworks possess substantial explanatory potential regarding adoption, we choose TAM for our research, as we focus on the potential drivers of adoption of autonomous cars at the individual level.

The TAM has its theoretical roots in behavioral research about behavior formation and psychology research about behavior regulation and change (Davis 1989; Davis et al. 1989). The core TAM postulates that one's behavioral intention to adopt/use a certain technology is determined jointly by two important perceptions: First, the perceived ease of use, defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis et al. 1989, p. 320). Second, the perceived usefulness, of a technology, defined as "the degree to which a person thinks that using a particular system would enhance his or her job performance" (Davis et al., 1989, p. 320). In addition, various extensions of TAM highlight the importance of social influences, defined as the degree to which a person thinks that his/her peers expect him/her to use a specific technology (Venkatesh et al. 2003).

The TAM is seen as easy to understand and simple (King and He 2006; Bagozzi 2007). Researchers have compared the TAM with other theoretical models and found that the parsimony of the TAM does not impair its predictive power; indeed, the TAM often outperforms other models in explaining users' intentions of adopting new technologies (Gentry and Calantone 2002; Taylor and Todd 1995; Venkatesh et al. 2003). A meta-analysis concludes that the TAM explains an average of 50% of the variance in behavioral intention across different technologies (King and He 2006).

While acknowledging the significant impact of the TAM in technology acceptance research, scholars have also discussed its limitations. Some criticisms, for example, address the methodological (e.g. student samples) and theoretical ground of the theory. Bagozzi (2007) criticized the TAM for overlooking many essential determinants of decisions and action, arguing that "It is unreasonable to expect that one model, and one so simple, would explain decisions and behavior fully across a wide range of technologies, adoption situations, and differences in decision making and decision makers (p. 244)." Benbasat and Barki (2007) questioned the true insightfulness of key determinants especially the perceived usefulness: "the knowledge that 'usefulness is useful' has, in fact, provided little in terms of actionable research and hence a paucity of recommendations to direct design and practice (p. 213)." Against this background, this study uses the TAM as a starting point for studying the adoption of autonomous cars among potential users with an emphasis on the formation of perceived usefulness. However, it includes additional aspects that are not part of the original TAM to account for the complexity of adoption considerations concerning autonomous driving.

Model Development

The TAM is a very robust framework that can be applied to various contexts and that can be extended with various exogenous factors (King and He 2006). Hence, we build our model around the basic TAM. H1-H4 reflect this. We expect that:

> H1: Perceived ease of use is positively related to adoption intention.
>
> H2: Perceived usefulness is positively related to adoption intention.
>
> H3: Perceived ease of use is positively related to perceived usefulness.
>
> H4: Social Influences are positively related to adoption intention.

The Formation of Perceived Usefulness

Empirical studies have repeatedly demonstrated that the most influential predictor of one's intention to adopt a new technology is the perceived usefulness (King and He 2006; Venkatesh et al. 2003). However, existing TAM literature falls short on the mechanisms that explain how users form beliefs about the usefulness of a target technology (Bagozzi 2007). "Opening the black box of usefulness" is particularly important for the study of new technologies (Benbasat and Barki 2007).

> "When TAM is applied to a new technology, it is not clear which component or components of the particular technology are perceived to be useful and which ones are not, even when a user labels it as useful, thus leading to a lack of practical lessons for design." (Benbasat and Barki 2007, p.214).

In the current study, we attempt to examine how potential users perceive and evaluate the offerings of innovative product features of autonomous cars in terms of usefulness. Based on the transaction cost theory, which presumes that economic actors behave with bounded rationality and self-interest (Simon 1976), we contend that when adopting the new technology, people will carefully examine autonomous cars in terms of technical benefits (i.e., how useful are the new functions/features provided by the technology) and costs (the associated risks of using the technology). Autonomous cars will be perceived as a useful technology if the perceived benefits of new product features overweight the perceived risks of using the technology.

Risk Factors

Researchers have long noticed that the use of new information technologies is often associated with risks to individual users. One risk suggested by the literature resides in data-related issues or privacy concerns (Collier 1995; Mason 1986). As pointed out in Collier (1995), "(privacy concerns) is about the perceived threat to our individual privacy owing to the staggering and increasing power of information-processing technology to collect vast amounts of information about us... outside our knowledge, let alone our control" (p.41). As technologies become increasingly personal, ubiquitous, and pervasive (Collier 1995), privacy concerns are often amalgamated with the design and development of new technologies. "In these highly personalized technological settings, talking about technology without considering the privacy implications, and vice versa, will be fruitless" (Junglas et al. 2008).

Another risk associated with the use of a new technology is related to the fear of technology. Scholars studying the role of new technologies have studied user's fear of being controlled for decades (e.g., Park et al., 2012), often in the context of users' perceived autonomy (e.g. Walter and Lopez 2008). The self-service technology literature suggests that perceived control over a technology will affect one's tendency of adopting/using the technology. Perceived control refers to users' confidence of using technology at their disposal to achieve desirable outcomes (Lee and Allaway 2002). For self-service technologies such as airline ticketing machines, automatic teller machines, and computer-based shopping services, enhancing customers' feelings of control over a service innovation will increase customer satisfaction with the service (Meuter et al. 2000), alleviate risk concerns of the technology, and lead to increased numbers of users making use of that innovation (Lee and Allaway 2002). Accordingly, a sense of losing control over a technology, such as being provided with inaccurate information and led to undesirable outcomes, will be negatively related to technology adoption and use.

This perceived loss of control seems to be plausible for autonomous cars. This is likely true after several deadly incidents involving vehicles under machine control, involving other vehicles, pedestrians and structures (Hiltzik 2018). Thus, we propose that:

> H_5: Risk Factors (H_{5a}: technological risk & $H_{5b:}$data security) are negatively related to perceived usefulness.

Instrumental Benefits of Autonomous Cars

As shown in table 1, prior research found that people generally tend to react positively to autonomous cars. However, the actual technical features that explain why people value autonomous cars remain ambiguous.

It has long been established in the MIS literature that the design of IT artifacts influences the way users conceive an information technology (Benbasat and Zmud 2003; Orlikowski and Iacono 2001). Studying product design and perceived usefulness ranges from mobile applications (Shen 2015), web site development (Bilgihan and Bujisic 2015), to the general industrial design of new products (Park et al. 2015). We propose that in the context of autonomous cars, innovative product features, if they are judged by potential users as beneficial or useful to their driving experience, will lead to the formation of perceived usefulness of the new technology. However, pilot studies, as in this study, are necessary to identify these factors. Thus, before discussing these factors in detail, we broadly hypothesize:

> H_{6a-n}. The perceived benefits of product features are positively related to perceived usefulness.

The conceptual model is depicted in Figure 1.

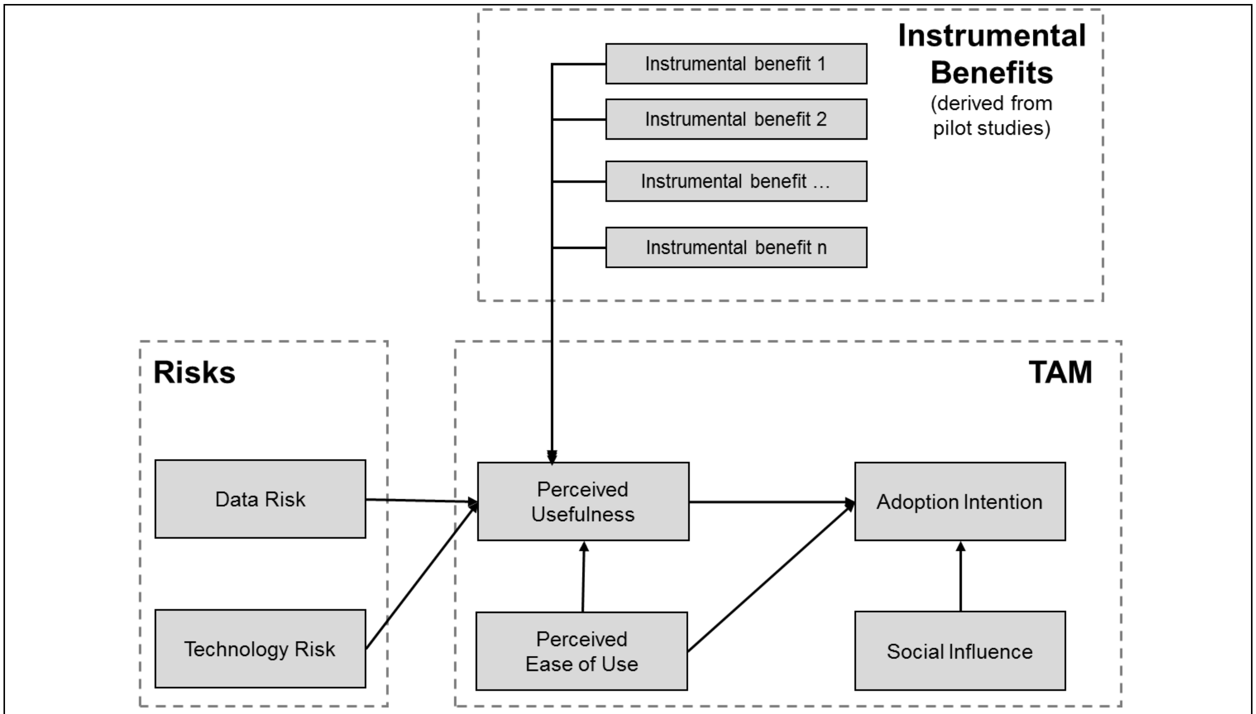

Figure 1. Modified Research Model of Instrumental Benefits and Risks

The extant literature does not discuss product features or specific technical risks that may characterize future autonomous cars. Hence, we designed two pilot studies to specify items and constructs in the two categories of beneficial product features and technical risks. Based on these two pilot studies we develop sub-hypotheses to test the effects of each type of instrumental benefits and risks.

Empirical Research

Pilot Studies

Because fundamental research on autonomous cars is still scarce, we conducted two pilot studies to better understand this new technology. Particularly, the objectives of this pilot research were to (1) identify potential acceptance drivers (respectively instrumental risks) and (2) to better understand the nature of these constructs, as well as how they can be operationalized in a survey. Both pilot studies used qualitative approaches, and informants had an industry expert background. The underlying rationale for conducting using experts is that they can contribute "managerial wisdom" by providing their own tacit knowledge from their professional experience (Leeflang and Wittink 2000). In this paragraph, we provide an overview of the pilot studies. We discuss and integrate the findings of these studies subsequently in the hypotheses section.

Pilot Study 1: Expert interviews

The first pilot study was based on semi-structured in-depth interviews (Fontana and Frey 2013) with seven experts in the autonomous car industry who possess broad experience due to their consulting and management background. We employed a purposive sampling strategy (Lincoln and Guba 1985) to recruit experts based on their experience with the management of autonomous car projects. All informants were male with ages ranging from 25 to 53. All of them have a graduate degree (Master's or PhD), are occupied in different positions (e.g. senior consultants, analysts, managers) and have sufficient knowledge on autonomous cars. This was guaranteed by self-reports and a careful inspection of their profiles (e.g. publications). Additional information on the informants' backgrounds is available upon request.

Looking for depth rather than breadth, the sample size of seven was appropriate with the qualitative research paradigm (Patton 2015). Phone interviews were conducted with the informants, who all agreed to audiotape the interviews (between 15 and 35 minutes), resulting in 82 pages of verbatim transcripts (Maxwell 2002).

Both the interviewer and another author of the study not involved in the data collection read the transcripts from the interviews and used labels to identify emerging topics and concepts. Both researchers discussed their findings as an iterative process. Both analysts incorporated suggestions from thematic analysis (Sayre 2001) to identify and report themes derived from the data. As a result, we identified various factors that were closely related to prior research in technology acceptance (i.e., data risk as related to privacy risk, technological risk as related to loss of control). In addition, informants mentioned various benefits and risks of autonomous cars, and discussed various age and gender differences among target groups.

Pilot Study 2: Expert Focus Group

Based on this, we conducted a focus group with nine experts. The objective of the focus group was to (1) ensure that our interpretations from the pilot study 1 matched with the informants' view, (2) to gather additional information on the factors, and (3) to identify suggestions how these factors can be operationalized. An advantage of focus groups is the potential to generate rich experiential data, as participants' group interactions offers deeper access to attitudes and perceptions (Asbury 1995).

Among the expert informants from pilot study 1 we identified three to participate in the focus group study to contrast the experts' interpretations and the research team's interpretations of statements made. Additionally, based on these experts' recommendations and applying the same sample logic as in pilot study 1, we identified 6 other experienced experts that were willing and able to take part in this focus group. We applied a structured mediating style that allows for a great coverage of themes (Greenbaum 1988). The focus group lasted approx. 30 minutes. The focus group started with a general open discussion on automotive cars, its strengths and weaknesses. The discussion then shifted more towards the model. An author of the study presented various hypotheses and suggestions of how to measure the constructs, and all experts received a list of possible measures. We integrated non-verbal observations with verbal responses. Therefore, the entire focus group was audiotaped and transcribed while non-verbal notes in order to increase interpretative accuracy (Krueger and Casey 2009).

Main Study

Six hundred and forty-two respondents (48.8% male; age: m=49.9; SD=15.9; min=18; max=83 years) were surveyed with the help of a professional market research company and involving financial compensation. A quota sampling strategy representative for the German adult population regarding age, gender and local distribution at federal state level was applied. We included several filter questions to control for the quality of data to avoid biased results regarding our tested hypotheses, ensuring that our respondents were adults, knowledgeable in terms of driving and understood autonomous cars. In addition, we controlled for numerous factors (as discussed) to further minimize any inconsistencies or unusual distributions. The German car market, as it is the home market to most of the world's premium car manufacturers, is highly competitive. Thus, German users are often familiar with high-tech elements in cars and experienced in adopting global technology trends, such as driver support systems (Di Bitonto and Friedrich 2015; DVR 2015).

When developing the survey instrument, we adapted established multi-item scales from the literature where possible. Where necessary, items were discussed and adjusted to the context in discussions with experts in pilot study 2. The revised version of scales was assessed in a pretest among 50 users that led to some minor adjustments of the wording. Specifically, we identified various instrumental benefits of autonomous cars through the two pilot studies. These instrumental benefits include specific (i.e. less abstract) activities that 'drivers' of autonomous cars can engage in during a ride. These include working, internal socialization (i.e. interacting with other people in the car), external socialization (i.e. interacting with people not physically present in the car), consumption of entertainment (i.e. watching TV, movies, etc.), reading, eating, and sleeping. As we will discuss later, eating and sleeping were dropped from the analyses due to psychometric issues.

While we used multi item measures for all established constructs, single items were chosen for instrumental benefits. There is a discussion around the appropriateness of using single items (e.g. Sarstedt et al. 2015). Yet, even critics argue that single items can be used "when the survey length or questionnaire format is restricted" (Sarstedt et al. 2016, p. 4), or in somehow novel areas of research. All items were measured with 7-point Likert scales, where higher values represent more positive evaluations or higher levels of agreement. Various standard tests for discriminant validity and common method bias did not indicate any concerns.

All multi item constructs were subject to a series of exploratory and confirmatory factor analyses. These analyses revealed appropriate psychometric characteristics. Table 2 provides an overview of the constructs, items, sources, and reliability statistics. Having established the measurement model, we modeled the proposed SEM in Mplus 7.1. As prior research on the consumers' acceptance of technologies suggests that demographic variables might explain variation of the focal constructs (Venkatesh et al., 2003), we included age and gender as controls in the model. Also, prior research revealed experience with product use as a significant control which we could not include in a verbatim way due to lack of product existence. Instead, we included the counterfactual variant of this question, asking for knowledge on self-driving cars as a control (Venkatesh et al., 2003). The overall model fit was satisfactory (χ^2=949.771, 304 d.f.; CFI=.95; TLI=.94; RMSEA=.06). The results are presented in figure 2 and in table 4.

As the results show, findings support most of the proposed TAM hypothesis, such as the effect of perceived usefulness (ß=70, p<.001) and social influence (ß=.22, p<.001), supporting H2 and H4. At the same time, perceived ease of use is not directly related to adoption intention (ß=.03, p=.34), leading to rejection of H3. However, in line with H3, the construct relates directly to perceived usefulness (ß=.33, p<.001). Among the risk factors, a negative and significant effect exists for technology (ß=-.41, p<.001), which is in line with H5a. However, contrary to our hypothesis, data risk is not significant (ß=.01, p=.86). The instrumental benefits of working (ß=.12, p<.001), internal socialization (ß=.19, p<.01), external socialization (ß=.10, p=.03), and reading (ß=.11, p<.01) are significant and this supports H6a, b, c, and e. Although the effect of consuming entertainment is in the hypothesized direction, it is not significant (ß=.06, p=.12).

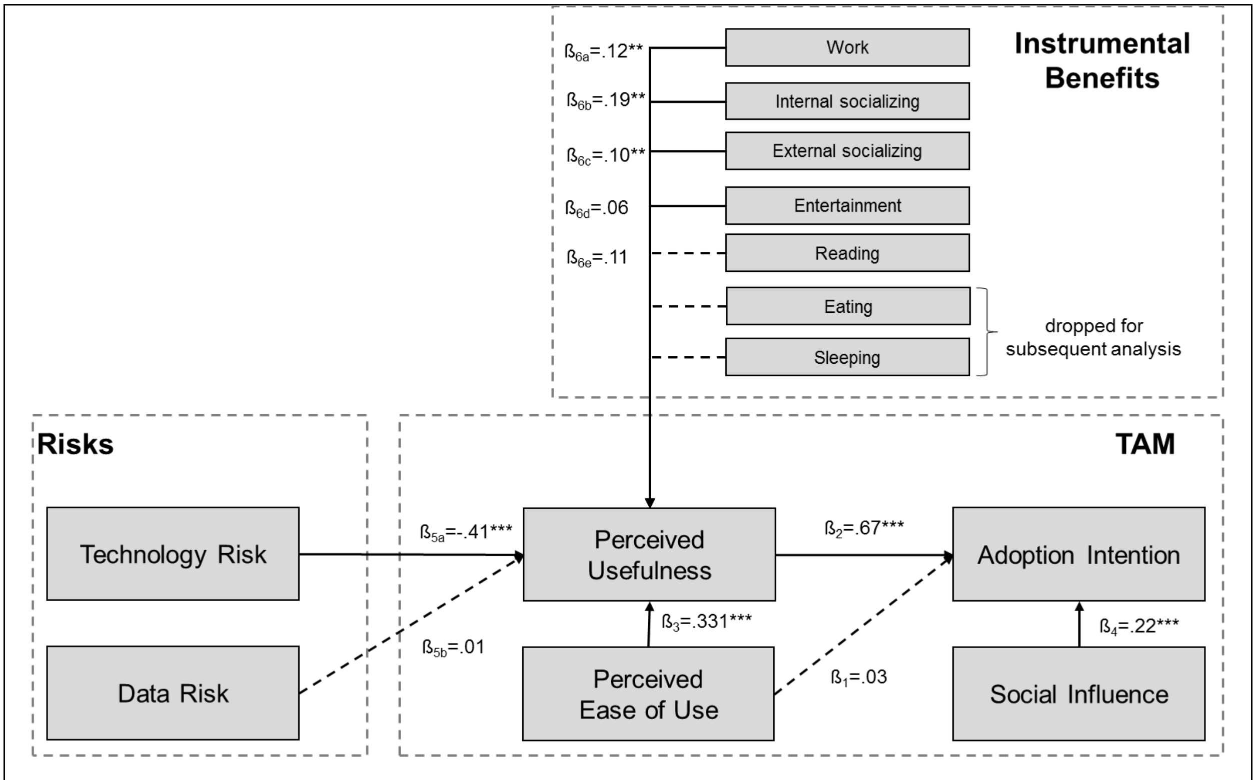

Figure 2. Graphical Representation of SEM Results.

Note: $\chi 2$ = 949.771, 304 d.f.; Comparative Fit Index (CFI) = .95; Tucker-Levis Index (TLI) = .94; Root Mean Squared Error of Approximation (RMSEA) =.06; ***= p<.001; **= p < .05; dotted lines: not significant

We modeled the effects of the three control variables on the two endogenous variables, perceived usefulness and usage intention. Age is negatively related to usage intention (ß=-.08, p<.01) and positively related to perceived usefulness (ß=.10, p<.01). Product knowledge has a significant positive effect on usage intention (ß=.08, p<.01). All other effects are not significant (all p>.31). The model explains 67% of the variation of usage intention and 51% of perceived usefulness.

Table 2. List of Constructs, Items, Reliability Indices and Average Variance Extracted

	factor loading	AVE	C.R.	α
Adoption Intention (Davis et al. 1989; Davis et al. 1992)				
I can imagine using an autonomous car.	.96	.89	.96	.96
I can imagine using an autonomous car privately (e.g. Vacation, visits, etc.)	.97			
I can imagine using an autonomous car for extended trips (e.g. interstate, freeway, long haul, etc.).	.90			
Perceived Ease of Use (Davis 1989; Venkatesh et al. 2003)				
It will be easy for me to learn how to operate an autonomous car.	.89	.80	.92	.92
It will be easy for me to quickly make progress in operating autonomous cars.	.88			
It will cause no major difficulties to me operating an autonomous car.	.91			
Perceived Usefulness (Davis 1989; Venkatesh et al. 2003)				
I would perceive an autonomous car as useful.	.94	.89	.96	.96
I would perceive an autonomous car as valuable.	.96			
Autonomous cars are a good idea.	.93			
Social Influences (Venkatesh and Davis 2000; Venkatesh et al. 2003)				
People who influence my behavior would welcome it (e.g. friends, family, acquaintances), if I drove an autonomous car.	.95	.94	.97	.97
People who matter to me would welcome if I drove an autonomous car.	.99			

Technology Risk (Grunwald 2015; pilot studies)				
There are too many open questions and unresolved concerns with regard to autonomous cars.	.64	.57	.72	.69
The risk of driving an autonomous car from a technical point of view appears to me as too high at the moment.	.86			
Data Risk (Pilot studies)				
The risk of having an autonomous car hacked deters me from using an autonomous car.	.93	0.79	.88	.88
I fear that cybercriminals could gain control over autonomous cars.	.85			
Product Knowledge (Peters and Hoffmann 2011; Huijts et al. 2012; Achterberg et al. 2010)				
I know a lot about autonomous driving.	.81	0.60	.86	.85
I would consider myself an expert on autonomous driving.	.75			
I know more about autonomous driving than my friends and acquaintances.	.77			
I pursue news on autonomous driving with interest.	.76			
Instrumental Benefits of autonomous cars (pilot studies)				
If the car drove autonomously, I would use the time…	n/a			
WORK: for work, if I get the efforts refunded.	n/a			
INTERNAL SOCIALIZING: to talk with another passenger on the car.	n/a			
EXTERNAL SOCIALIZING: to communicate with others via mail and phone.	n/a			
ENTERTAINMENT: to watch TV, movies, and similar.	n/a			
READING: to read something (book, newspaper, etc.)	n/a			
EATING: to eat something [dropped, as discussed later]	n/a			
SLEEP: to sleep [dropped, as discussed later]	n/a			

Table 2. List of Constructs, Items, Reliability Indices and Average Variance Extracted

Note: AVE: Average Variance Extracted; C.R. = Composite Reliabilities, Alpha = Cronbach's Alpha; n/a: not available as no reflective multi item measurement was conducted; properties: χ^2 (296d.f.) = 807.589; CFI=.96; TLI=.95; RMSEA=.05

Robustness Tests

To assess the stability and robustness of the findings, we conducted several post-hoc tests. First, we modeled all instrumental benefits as one latent construct. Although this construct, probably due to its formative nature, did not meet all thresholds of fit measure, this construct was positively related to perceived usefulness and adoption intention. Second, we re-analyzed the model using different estimators. The results remained stable. Third, one could argue that users' knowledge about autonomous cars does not only explain variance in usefulness and adoption intention; it could affect the relationships between variables. A consequence would be a limited generalizability of the findings. To assess this potential limitation, we split the sample in two equally large groups based on the composite knowledge score's median value. Results were stable among both sub-groups, indicating the stability of the framework.

Further Insights into Peoples' Adoption of Autonomous Cars

Prior technology acceptance research suggests that the formation of the intention to use a technology differ between different people. To investigate this among potential users of self-driving cars, we studied the role of two established moderators in the technology acceptance literature: Age and gender. Additional support for this investigation was derived from the pilot studies. Experts discussed the role of different target segments and suggested differences in terms of age and gender.

The results of the multi-group SEM are presented in table 4, and fit indices in its footnote. To assess for significant differences, we first calculated the base model (table 4) in which we freely estimated the structural path to vary between groups, followed by a second model in which this path was fixed. For age, we used the median-value (median=.51) to split the sample. Significant differences exist when the $\Delta\chi^2(\Delta d.f.)$-value reaches significance. We then tested for differences among all 22 effect sizes. Although some effect sizes show 'large' differences between the groups, only few of them reached significance on a 10%-level. That is, overall, the effects were quite similar among all sub groups.

While ease of use did not reach significance in the entire sample (H1), sub-group analyses show that it is significant among older individuals (β=.13, p=.04), but not among younger consumers (p<.07). In addition, among young individuals, working in the car is more (p<.10) impactful (β=.16, p<.001) than it is for older people (β=.01, p=.85). Only the difference on a 10%-level was found for females (β=.17, p<.001), as the relationship between the benefit of working is stronger (Δ: p<.10) than it is for males (β=.05, p=.31).

Discussion

This study attempts to contribute to addressing a research gap that is both theoretically and managerially important. It works towards explaining individuals' adoption intention of autonomous cars. For this purpose, this study builds on established acceptance theories (Venkatesh et al. 2003) and draws upon extant exploratory research on autonomous cars as well as on findings from two pilot studies. It proposes a new framework. In a large-scale quantitative survey study, this research tests the suggested framework empirically. The results provide rich insights, for example with respect to user perceptions of instrumental benefits and potential barriers.

This study encompasses instrumental benefits including additional work time, time to engage in direct face-to-face-conversation or telecommunication, watching movies or reading, as well as the activities of eating and sleeping. Eating and sleeping we excluded for analysis, as distribution of data strongly implied this. Regarding eating, we observed a highly polarized distribution, for which we suggest idiosyncrasies of car owners to be responsible, as many people apparently follow a "snacks only"-policy in their vehicles. Sleeping in an autonomous car would only be relevant to people who use their cars for longer distances, and furthermore, sleeping could be complexly interrelated with the risk factors. Barriers we included were a technological and data risks associated (Silberg 2013; PWC 2014). However, contrary to these expectations, there was no significant impact of data risk. These insignificant results were replicated when looking at various sub-groups, as to be seen in table 4. This may be due to hyperbolic discounting, which is a tendency of humans to systematically underestimate the urgency and impact of future events the longer the projected time frame is at which the event will occur. This phenomenon is also documented for other technologies that will hit the mass market in the future (e.g. smart glasses; Rauschnabel, He and Ro 2018).

Intuitions of experts were largely confirmed, as respondents perceived the possibilities to use time for working, or engage in internal or external socialization, positively. Interestingly, the coefficient (ß=.185) for direct conversation with a person seated within the car is substantially higher than the coefficient for telecommunication, that is external socialization (ß=.102). This may be explained by the increased mental effort associated with the information richness of direct speech and body language compared to language-only, as is the case for telecommunications. We argue that the bigger the cognitive effort of an occupation, the higher the perceived usefulness of being able to perform it without being distracted by having to pay attention to driving. However, our finding that users would not consider watching movies to be an antecedent to usefulness seems to be contradictory. At second glance, the hedonic character of entertainment consumption comes to mind. Perceived usefulness in turn is a utilitarian construct. A misfit between item and construct can be justified this way. Yet, it leads to a constraint on our generalization attempt. Thus, we adjust our line of argument: it is not just the amount of cognitive effort which determines the perceived usefulness, but the combination thereof with a utilitarian nature of the respective task.

Theoretical Contribution

The current research provides novel insights into the underlying factors that explain how people react to the concept of autonomous cars. By doing so, this research contributes to at least two streams of research:

First, this research contributes to the literature on self-driving cars. This contribution starts with a definition of autonomous cars. As we have shown in the literature review, little research has been done to understand how potential buyers of autonomous cars react to them. Although few exceptions provide a solid foundation to build on, these studies rather look at aspects (such as anthropomorphism) or they are exploratory in nature (table 1). This study combines established theories and theory-developing in-depth research including experts to provide an extended framework. Post hoc analyses show that this framework is very robust and can be applied independently from users' knowledge. Thus, this study extends knowledge on potential user reactions to self-driving cars.

Second, this study incorporates various established theories. For example, while there is consensus that the TAM works in a variety of settings, we observe an inconsistency. We did not identify a direct effect of perceived ease of use on adoption intention. Two possible explanations can be advanced: First, thanks to fast technological changes in several aspects of everyday life, users are familiar with new technologies. They may assume that programming a self-driving car does not represent an important challenge. This assumption is supported by the findings of the group comparisons (table 4). Younger individuals are often more tech-savvy, and ease of use did not reach significance for them. However, a weak effect was identified when only looking at older consumers. Second, ease of use might matter more in cases where people are exposed to a technology. This could be supported by findings from Rossiter and Braithwaite (2013), who show that perceived ease of use is not significant among potential adopters of a technology, but significant among experienced users.

Technology acceptance is characterized by a high level of flexibility for combinations with other theories. For example, prior studies have included risk in this stream of research, like in the form of technology risk (Faqih 2011; Pavlou 2003). Through prior research and the two theory-building pilot studies our research identifies two possible risk factors: First, the risk of getting safely to one's target, that is similar and applicable to any car. Findings support that this risk is directly related to perceived usefulness. Second, data risk remained insignificant in the model. On the one hand, this is surprising as the current literature (Junglas et al. 2008) and media (Eisenstein 2015) extensively discuss privacy and data risk. On the other hand, recent findings on other future technologies indicate that people tend to care less about their privacy (Rauschnabel et al., 2016). This could mean that users do not perceive a loss of personal data as very harming, or do not have the ability to estimate potential consequences for them. Public policy makers might be motivated to examine this finding in more detail. In sum, extending this framework addresses Benbasat and Barki's (2007) call for "Opening the black box of usefulness".

Managerial Contribution

This study provides several contributions that are relevant for managerial practice. First, experts and media discuss the potential threat of data risk, and various potential benefits. One important managerial contribution is that managers', at least the ones we interviewed, assumptions about the drivers and barriers could not be fully confirmed by the data. For example, among the instrumental benefits of autonomous cars, consuming entertainment content (e.g., watching TV) was, contrary to expectation, insignificant. Post hoc analyses indicated that the strength of these effects could differ between different user groups. Hence, managers should carefully identify the instrumental benefits relevant for their chosen target segments.

Second, although results did not indicate a direct effect of ease of use on adoption intention, results support that ease of use determines usefulness, an important antecedent to adoption. Thus, people who perceive that driving an autonomous car is associated with less cognitive effort might be willing to adopt one because this makes it more useful to them. The communication of reducing effort (e.g. arriving relaxed at the target destination) may represent an important element of user value for potential adopters, which can be considered in future marketing communication strategies.

Last, model results at sub-group level implied few differences between different consumer segments. For example, as older people tend to care more about ease of use, emphasizing user-friendliness and intuitive operation to elder consumers seems to be a promising approach. In contrast, when manufacturers communicate with younger consumers, highlighting the benefits of using driving time for work could be effective. This strategy, as our results show, can also be effective to target females. In any way, for manufacturers, these findings imply an adjusted IS design policy for their products, as user behavior varies with age and gender and user-centric design will be a prerequisite for adoption (Brenner et al. 2014).

Limitations and Future Research

We acknowledge limitations of this study that may serve as starting point for future research. First, both the experts and the survey sample were drawn from a German population. As the German market may be different to other markets due to its automotive history and high concentration of car manufacturers, cross-cultural generalizability may be limited. As we used expert interviews and a literature review based on a merely developed line of user research for model development, the user perspective needs strengthening in future studies, because users will develop a new and unique understanding of autonomous cars which then offers new ways for researchers to understand the adoption intentions. This issue will become very relevant once users were able to make their own first experiences to report on, and market research data on usage behavior can be combined with statements collected by different communication experts that reach out to different channels and customer types (Whelan et al. 2010).

Table 4. Results: Drivers and Barriers to Consumers' Intention to buy an autonomous car

		all respondents		**Age**				**Gender**			
				Young		Old		Male		Female	
Model		**ß**	**p**	**ß**	**p**	**ß**	**p**	**ß**	**p**	**ß**	**p**
H1	Perceived Ease Of Use => Adoption Intention	.03	.34	-.05	.50	.13^{T}	.04	.01	.77	.05	.31
H2	Perceived Usefulness => Adoption Intention	**.70**	<.001	.85	<.001	.73	<.001	.73	<.001	.67	<.001
H3	Perceived Ease Of Use => Perceived Usefulness	**.33**	<.001	.49	<.001	.40	<.001	.36	<.001	.32	<.001
H4	Social Influence => Adoption Intention	**.22**	<.001	.21	<.001	.26	<.001	.20	<.001	.23	<.001
H5a	Technology Risk => Perceived Usefulness	**-.41**	<.001	-.77	<.001	-.84	<.001	-.44	<.001	-.38	<.001
H5b	Data Risk => Perceived Usefulness	.01	.86	.03	.61	.00	.97	-.07	.24	.08	.39
H6a	Work => Perceived Usefulness	*.12*	<.05	.16^{T}	<.001	.01	.85	.05	.31	.17^{T}	.00
H6b	Internal Socialization => Perceived Usefulness	**.19**	<.001	.15	.01	.22	<.001	.20	.00	.18	.01
H6c	External Socialization => Perceived Usefulness	*.10*	<.05	.03	.63	.14	.01	.09	.17	.11	.11
H6d	Entertainment => Perceived Usefulness	.06	.12	.05	.24	.05	.30	.03	.65	.08	.14
H6e	Reading => Perceived Usefulness	*.11*	<.05	.10	.03	.06	.21	.12	.02	.09	.12
Controls											
	Product Knowledge => Adoption Intention	.03	.31	.08	.20	.01	.89	.03	.39	.03	.49
	Age => Adoption Intention	-.08	<.01	n/a	n/a	n/a	n/a	-.06	.06	-.08	.05
	Gender => Adoption Intention	-.03	.33	-.04	.74	-.10	.50	n/a	n/a	n/a	n/a
	Product Knowledge => Perceived Usefulness	.08	<.05	-.02	.83	.19	.00	.03	.55	.13	.02
	Age => Perceived Usefulness	.10	<.01	n/a	n/a	n/a	n/a	.01	.79	.15	.00
	Gender => Perceived Usefulness	-.01	.82	-.21	.13	.11	.48	n/a	n/a	n/a	n/a
R squared											
	Adoption Intention	.67	<.001	.64	<.001	.68	<.001	.72	<.001	.61	<.001
	Perceived Usefulness	.51	<.001	.46	<.001	.55	<.001	.85	<.001	.46	<.001

Notes: variables age and gender were media-split. Coefficients in bold significant at p<.001; numbers in italics significant at p<.05:
Model properties:
Age: χ2 (506d.f.) =1154.86; CFI=.94; TLI=.94; RMSEA=.06; χ2-contribution young: 551.99, χ2-contribution old: 602. with n(young)=329, n(old)=314; median split (median=51 years)
Gender: χ2 (506d.f.) =1113.43; CFI=.95; TLI=.94; RMSEA=.06; χ2-contribution male: 530.93, χ2-contribution female: 582.51, with n(male)=316, n(female)=327
Estimator: Maximum Likelihood in MPlus.
χ2 Difference tests: T p<.10

We also focused on autonomous cars in general and not on a particular vehicle, which may be more important than apparent at first sight: For example, a study has shown that Google Car is highly anthropomorphic, which, depending on the resembling humane expression, causes psychological effects in the perceiving person (Waytz et al. 2014). It would be worth to investigate the determining features which decide over how much individual product design at the early introduction phase does matter to users. Regarding significance of risk, we suspect hyperbolic discounting to be a mechanism at play, as data risk, unlike technology risk, can come in several different forms and with abstract consequences which make is susceptible to becoming systematically underestimated given varying time frames.

Future research may conduct longitudinal studies to see how the effects and the magnitude of the constructs differ, especially as a concentration of autonomous vehicles with corporations rather than private users is forecasted by some. This may indeed become reality, because the possession of a car even today is not a necessity anymore and the advent of autonomous cars will exacerbate this trend of car-sharing (Bardhi and Eckhardt 2012). Therefore, new business models and business processes will emerge, requiring new research projects: For example, as autonomous cars, regardless of the owner, thrive on data to fulfill their task, the amount of driver data to be integrated into the cars' planning efforts requires discussion. Also, the amount of investments into driver data security to be made is a question worthwhile, given a risk that data may fall into the wrong hands for various reasons. As such questions will arise at latest once the technology has reached mass commercialization, preemptive adaptation of extant research is required (Lee et al. 2011). Furthermore, the information to be processed needs to fit the planning process: Operating standards that transgress system boundaries as well as a classification of information with the potential to become actionable knowledge are topics that need discussion from a managerial point of view. Last, discrete product offers may take research a step further in investigating cost-benefit-ratios, for example, by using conjoint-scenarios.

Appendix:

Correlations and Descriptive Statistics on Self-driving Car Adoption

	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Adoption intention	4.47	2.03	-												
2 Perceived Ease of Use	6.00	1.23	*.37*	-											
3 Perceived Usefulness	4.75	1.80	*.79*	*.43*	-										
4 Social Influences	3.12	1.76	*.57*	*.21*	*.55*	-									
5 Technological Risk	5.24	1.27	*-.47*	-.05	*-.41*	*-.30*	-								
6 Data Risk	4.79	1.77	*-.26*	*-.11*	*-.27*	*-.19*	*.49*	-							
7 Product Knowledge	2.75	1.37	*.25*	*.14*	*.24*	*.25*	*-.21*	*-.10*	-						
8 Work	3.26	2.10	*.15*	-.01	*.16*	*.20*	*-.11*	.06	*.09*	-					
9 Internal socialization	5.14	1.74	*.34*	*.31*	*.30*	*.19*	-.03	*-.13*	.02	*.29*	-				
10 External socialization	4.55	1.99	.11	.10	*.16*	.00	-.06	-.04	.04	*.43*	*.64*	-			
11 Entertainment	3.02	2.01	*.11*	-.06	.06	.09	.00	-.02	.06	*.34*	*.35*	*.55*	-		
12 Reading	4.05	2.05	*.19*	*.11*	*.20*	*.16*	*-.17*	-.08	.02	*.33*	*.44*	*.55*	*.58*	-	
13 Age	49.83	15.92	-.10	-.04	-.08	-.06	.10	.08	-.28	*-.29*	*-.12*	*-.27*	*-.31*	*-.15*	-
14 Gender	.51[(a)]	n/a	-.10	-.04	-.08	-.06	.10	.08	-.28	*.03*	*.01*	*.07*	*.04*	*.02*	*-.17*

(a) Gender: percent of females; SD not available for dichotomous variables; p<.05 are in *italics;* n/a: not available

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