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DOI
10.1016/j.trf.2015.04.014

Publication date
2015

Document Version
Final published version

Published in
Transportation Research. Part F: Traffic Psychology and Behaviour

Transportation Research Part F 32 (2015) 127–140

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Public opinion on automated driving: Results of an international questionnaire among 5000 respondents

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ARTICLE INFO

Article history:
Received 22 September 2014
Received in revised form 29 January 2015
Accepted 30 April 2015
Available online 15 June 2015

Keywords:
Driverless car
Questionnaire
Personality traits
Cross-national differences
Intent to purchase

ABSTRACT

This study investigated user acceptance, concerns, and willingness to buy partially, highly, and fully automated vehicles. By means of a 63-question Internet-based survey, we collected 5000 responses from 109 countries (40 countries with at least 25 respondents). We determined cross-national differences, and assessed correlations with personal variables, such as age, gender, and personality traits as measured with a short version of the Big Five Inventory. Results showed that respondents, on average, found manual driving the most enjoyable mode of driving. Responses were diverse: 22% of the respondents did not want to pay more than $0 for a fully automated driving system, whereas 5% indicated they would be willing to pay more than $30,000, and 33% indicated that fully automated driving would be highly enjoyable. 69% of respondents estimated that fully automated driving will reach a 50% market share between now and 2050. Respondents were found to be most concerned about software hacking/misuse, and were also concerned about legal issues and safety. Respondents scoring higher on neuroticism were slightly less comfortable about data transmitting, whereas respondents scoring higher on agreeableness were slightly more comfortable with this. Respondents from more developed countries (in terms of lower accident statistics, higher education, and higher income) were less comfortable with their vehicle transmitting data, with cross-national correlations between $\rho = -0.80$ and $\rho = -0.90$. The present results indicate the major areas of promise and concern among the international public, and could be useful for vehicle developers and other stakeholders.

1. Introduction

Road transport is an essential service in society, but the burden of traffic crashes and pollution is immense. US data show that automobile crashes led to 34,080 fatalities in 2012 (NHTSA, 2013a), where about 90% of the cases were attributed at least in part to driver error (Smith, 2013a). In 2012, the US petroleum use for road transportation was about 11 million barrels per day, which corresponds to approximately 60% of the total US petroleum consumption (Davis, Diegel, & Boundy, 2014). Moreover, the average commuter gets delayed 38 h per year due to traffic congestion (Schrank, Eisele, & Lomax, 2012). European data (European Commission, 2014) show that more than 28,000 people died on EU roads in 2012, and that four times as many people were permanently disabled. The fatality rates in high-income countries have been declining for the past decades, but the fatality rates in the low- and middle-income countries are actually increasing (World Health

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http://dx.doi.org/10.1016/j.trf.2015.04.014
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Organization, 2013). Current trends indicate that road traffic injuries will become the fifth leading cause of death by 2030, with the difference between high- and low-income countries further magnified (World Health Organization, 2013).

Automated driving systems have the potential to resolve these problems by increasing safety on public roads while decreasing traffic congestion, gas emissions, and fuel consumption (Anderson et al., 2014). Different levels of automation have been proposed with different definitions of the technological capabilities and human involvement. The most well-known are provided by BASt (Gasser & Westhoff, 2012), National Highway Traffic Safety Administration (NHTSA, 2013b) and SAE (On-Road Automated Vehicle Standards Committee, 2014), as shown in Table 1.

All three classifications start from the manual driving mode, where the driver executes all driving tasks, and each moves toward the fully automated driving mode, where no manual interaction is involved. In theory, fully automated driving (assuming "perfect" sensing of the environment, "perfect" decision-making algorithms, and "perfect" actuators) is the optimal solution in terms of safety, congestion, and emissions.

While automated driving systems have great potential to improve safety and efficiency of road transportation, many challenges have yet to be addressed, including the public perception, legal liability issues, and the security and control of the systems (Howard & Dai, 2014). The public opinion on automated driving determines the extent to which people will accept and purchase such systems, and it will define the way that car manufacturers will have to develop and market automated vehicles, as well as the necessary tax and insurance policies, and any investments in infrastructure.

1.1. Previous surveys on automated driving

Various researchers have previously conducted surveys on automated driving systems (Begg, 2014; Casley, Jardim, & Quartulli, 2013; Howard & Dai, 2014; KPMG., 2013; Payre, Cestac, & Delhomme, 2014; Power, 2012; Power, 2013; Schoettle & Sivak, 2014a, 2014b; Sommer, 2013). An early study by Underwood (1992) explored which intelligent vehicle technology would likely be deployed in North America. Results among 55 experts in the field indicated that, among the listed control systems, adaptive cruise control (ACC) would be the most popular feature. The experts expressed the opinion that the ACC would be installed in 5% of the vehicles by 2004, while it would reach 50% of market penetration by 2015. Automated braking would follow with a lag of 6 to 10 years, while lane-keeping assist would be introduced at an even later date. In addition, it was projected that by 2002 both frontal collision warning systems and back-up warning systems (e.g., blind spot detection) would reach 5% market penetration. Comparing those predictions with today's status, it can be claimed that the predictions were fairly accurate: ACC has been introduced in 1995 and is now available as an option by most car manufacturers (yet it has not reached the predicted 50% market share; Kyriakidis, van de Weijer, van Arem, & Happee, 2015). Advanced Emergency Braking (AEB), Forward Collision Warning Systems (FCWS) and Lane Keeping Systems (LKS) are also currently available on the market. Underwood (1992) found that the experts also believed that fully automated driving ("automatic chauffeuring with auto lane changing & merging") would achieve a 5% market share only between 2040 and 2075, and would *never* achieve a 50% market share.

Also before the turn of the twenty-first century, Bekiaris et al. (1996) studied user needs and their acceptance of technological systems that could assist drivers who are in an impaired state. A questionnaire was distributed to 407 people in nine European countries, and results showed that although most users would welcome being warned by a supportive assistance system, they expressed "a definite rejection of automatic driving".

Recent studies (Begg, 2014; Casley et al., 2013; Howard & Dai, 2014; KPMG, 2013; Missel, 2014; Payre et al., 2014; Power, 2012; Power, 2013; Schoettle & Sivak, 2014a, 2014b; Sommer, 2013; Youngs, 2014) display a somewhat more positive picture of the public opinion on fully automated driving. Nevertheless, people also indicate a non-negligible level of reluctance. Specifically, the global market research company Power and Associates have recently conducted various surveys on the willingness of US vehicle owners to purchase automotive emerging technologies. Their first study (Power, 2012), conducted in March 2012, surveyed 17,400 vehicle owners regarding their intention to purchase an autonomous driving mode, defined as "a feature that allows the vehicle to take control of acceleration, braking and steering, without any human interaction". 37% of the respondents answered that they "would definitely" or "would probably" be interested in purchasing such technology. However, the positive responses dropped to 20% after the respondents were informed about the estimated market price of $3000. The study also revealed that those vehicle owners with the highest interest in fully autonomous driving at market price were males (25%), those between the ages of 18 and 37 (30%), and those living in urban areas (30%). The second

Table 1
Alignment among BASt, NHTSA and SAE levels of automation (Smith, 2013b; Wending, 2014).

Source	Levels of automation					
BASt	Driver only	Assisted	Partly automated	Highly automated	Fully automated	Not addressed
NHTSA	No Automation (Level 0)	Function-Specific Automation (Level 1)	Combined Function Automation (Level 2)	Limited Self-Driving Automation (Level 3)	Full Self-Driving Automation (Level 4)	
SAE	No Automation (Level 0)	Driver Assistance (Level 1)	Partial Automation (Level 2)	Conditional Automation (Level 3)	High Automation (Level 4)	Full Automation (Level 5)

and third studies were conducted in March 2013 (Power, 2013) and March 2014 (Youngs, 2014) respectively, both with over 15,000 respondents. Results of these two surveys were in close agreement with the original survey.

A survey carried out by Continental AG (Sommer, 2013) in Germany, China, Japan, and US pointed out that 59% of the respondents considered automated driving a useful advancement. However, respondents were rather scared about driving in an automated vehicle: 31% of the respondents stated that they are unnerved by the development of automated vehicles, and 54% claimed that they do not believe that such vehicles will function reliably. The results by Continental AG also suggest that the concept of automated driving is not equally known in all countries. Specifically, people in Germany (67%) and China (64%) were more aware of automated driving developments compared to those in Japan (29%). About 40% of the respondents expected automated vehicles to be on public roads within the next 10 to 15 years, while most of the respondents expressed the intention to use such technology more on long freeway journeys (67%) and in traffic jams (52%), and less on rural roads (36%) and in city traffic (34%).

Ipsos MORI (Missel, 2014) recently published the results of their study on peoples' opinion on the importance of driverless cars for the car industry. The study was conducted in June 2014 among 1001 British people between 16 and 75 years old. The results showed that only 18% of the British public found it important that car manufacturers focus on driverless technologies, whereas 41% found this unimportant. The study also explored the public opinion in relation to the gender and age of the respondents. Findings showed that men are more likely to deem driverless vehicles important than women (23% of men vs. 13% of women). Nearly half of the women (47%) found driverless vehicles unimportant compared to just over a third (36%) of men. Furthermore, the study suggested that half of the older respondents (aged 55+) believed that driverless technology is not important compared to under a third of the respondents between 16 and 24 years old. Results also indicated that people who live in congested cities (e.g., London) found automated driving technology more important than those who live in a non-urban environment.

In June 2013, the advisory services company KPMG (2013) carried out a 10 focus-group study with 32 people from Los Angeles (CA), Chicago (IL), and Iselin (NJ). All participants were at least 21 years of age and owned at least one vehicle, and all had completed high school and college or vocational school. Results showed that women (median = 8.5 on a scale from 1 to 10) were more willing to use self-driving vehicles than men (median 7.5), while Californians were more open (median = 9) to such vehicles than others (Chicago median = 4; Iselin median = 6). The KPMG report also showed that the public opinion on automated driving cars is different from that of regular cars, where the discussion topics for fully automated cars are more on handling, safety, innovation, and trust and less on the engine, transmission, and styling.

Howard and Dai (2014) explored peoples' ($N = 107$) opinion on self-driving cars in Berkeley (CA) using a questionnaire and a video. Results showed that safety (75%) and convenience (61%) were the most attractive features about automated driving, whereas 70% and 69% of the respondents indicated liability and cost respectively, as the least attractive elements. In addition, 46% of the respondents believed that self-driving cars should operate with normal traffic, 38% in separate lanes, while 11% expressed no opinion. More than 40% of the respondents were positive to either purchasing self-driving technology in their next vehicle or equipping their current vehicle with such technology. Finally, 35% of the respondents were in favor of a subsidized scheme for self-driving cars, whereas 22% expressed being against it.

Casley et al. (2013) carried out a survey on the public opinion of fully automated vehicles among 467 students at Worcester Polytechnic Institute. When the students were asked to rank the most influential feature determining their desirability of fully automated vehicles, 82% choose safety, 12% legislation and 7% cost. In addition, although most of the students (40%) expected that a fully automated car would cost $5000–9999 on top of a regular car, more than 71% would not be willing to spend more than $4999 to purchase it. Casley et al. (2013) showed that about 58% of people were not familiar with current laws regarding the testing and operation of automated cars. Nonetheless, a large share of respondents (57%) expressed concern about legislation. Finally, men were more likely to adopt and enjoy self-driving cars than women.

Begg (2014), conducted a survey of London transport professionals to ascertain their perceptions of whether, and how soon, they expected driverless transport to become a reality. The study targeted over 3500 people, incorporating a broad cross-section of transport experts. The key findings indicated that about 35% of the respondents believed that Level-2 automated vehicles (resembling the NHTSA definition) will be commonplace on UK roads by 2025, while 10% believed that this would never happen. 28% of the respondents indicated that the Level-3 automated vehicles will be commonplace on UK roads not earlier than 2040, while the number of those believed that this would never happen increased to 20%. In addition, 20% of the respondents believed that the Level-4 automated vehicles would be commonplace on UK roads by 2040, while 30% expressed the belief that this would never be the case. Finally, the respondents were asked to indicate their opinion regarding the increase in safety of all road users due to automated vehicles. Results revealed that 36% and 24% of respondents agreed and strongly agreed, respectively, that automated vehicles would improve safety for all road users.

A recent study by Schoettle and Sivak (2014a) investigated the public opinion ($N = 1533$) about autonomous and self-driving vehicles in the US, the UK, and Australia. The study showed that 60–70% of people had heard of autonomous or self-driving vehicles before, while 57% of the respondents had an overall positive (on a 5-point Likert scale from "very negative" to "very positive") opinion on those vehicles. The main expected benefits of self-driving vehicles included crash reduction (70% of responses), reduction of emissions (64%), and reduced fuel consumption (72%). People did not seem to believe that such technology would improve traffic congestion (48%) and travel time (43%). A large number of respondents expressed concerns about the technology of self-driving vehicles. In particular, 26% of the US respondents were "very concerned" about system/equipment failure and vehicle performance in unexpected situations, while the corresponding percentages for UK and Australia were 15% and 16% respectively. However, this number increased to 75% for all the countries when all levels of concerns (‘‘very/moderately/slightly concerned’’) were taken into account. Legal liability, hacking of the automated systems, and privacy due to data sharing were other areas of concern. For instance, more than 90% of the respondents expressed at least some concern (on a scale ‘‘very concerned’’, ‘‘moderately concerned’’, ‘‘slightly concerned’’ regarding the legal liability of drivers/owners of self-driving vehicles. Finally, the study indicated that females expressed higher levels of concern regarding self-driving vehicles than males did, and were more cautious about their expectations concerning benefits from using self-driving vehicles. Schoettle and Sivak (2014b) also explored the public opinion ($N = 1722$) about self-driving vehicles in China, India, and Japan. This study found that more than 84% of the respondents in China and India, but only 43% in Japan, have positive opinions regarding self-driving vehicles. Furthermore, a large number of Chinese and Indian respondents (76% and 80% respectively) expressed interest in acquiring such technology on their personal vehicles, compared to only 41% of the Japanese respondents.

Payre et al. (2014) studied the opinion of French drivers on fully automated driving using an online questionnaire. The study examined the attitudes and a priori acceptability of fully automated driving technology among 421 drivers (153 males, mean age = 40.2 years, age range = 19 to 73). The results indicated that 68% of the sample scored above 4 (i.e. the median point of the 7-point Likert scale) on the fully automated driving acceptability scale. Furthermore, it was found that men, and those scoring highly on the driving-related sensation seeking scale, were more willing to use a fully automated vehicle, and that they were more inclined to purchase one. Older people seemed less likely to pay for such technology, but showed higher acceptance. Respondents preferred to use fully automated vehicles on highways, in traffic congestion, and for automatic parking. 71% of the respondents reported interest in fully automated driving when impaired (e.g., alcohol, drug use, medication), despite awareness of their responsibility for both the vehicle and the driving.

Lastly, Underwood (2014) investigated the opinion of 217 experts on automated vehicles who participated in the Automated Vehicles Symposium 2014. 80% of the population held a MSc or PhD degree, while 31% worked for research or academic institutions, 24% in the automotive industry, 13% in consulting firms, and 17% in governmental bodies. The respondents’ main areas of expertise include active safety systems, automated vehicle systems, connected vehicle systems, and traveller behavior. Respondents considered legal liability and regulations as the most difficult barriers toward the deployment of fully automated driving vehicles (SAE Level 5), whereas social and consumer acceptance were regarded as the least difficult barriers. Median responses regarding the year of deployment of automated freeway driving (SAE Level 3), high automation (SAE Level 4), and full automation (SAE Level 5) were 2018, 2025 and 2030 respectively. However, the majority of respondents indicated that SAE Level 3 (in which the driver is expected to intervene quickly if needed) is not practical.

1.2. The aim of our survey study

As described above, experts and the public are often positive about automated driving, but also exhibit essential concerns. Some studies pre-date the recent public exposure of automated driving by Google and by the automotive industry, whereas most studies are limited to one or two automation levels, and a small number of countries.

This study investigates user acceptability, concerns, and willingness to buy for all levels of driving automation (i.e., manual driving, partially automated driving, highly automated driving, & fully automated driving). Second, as current research (Howard & Dai, 2014; KPMG, 2013; Power, 2012; Power, 2013; Schoettle & Sivak, 2014a, 2014b; Sommer, 2013) focus primarily on Western countries, this study also captures the opinion in other countries, and assesses the determinants of cross-national differences. Specifically, for this research we implemented a 63-question online survey among 5000 respondents in 109 countries, and we assessed correlation coefficients with the countries’ objective road safety statistics and countries’ developmental status in terms of education and gross domestic product (GDP) per capita. We used the CrowdFlower crowdsourcing service, a tool which has been used for previous traffic psychology survey research as well (De Winter, Kyriakidis, Dodou, & Happee, 2015). Third, since the previous survey studies on automated driving did not investigate how personality traits associate with the opinion of people on automated driving, this study explores associations with a well-known personality test, the Big Five Inventory (John & Srivastava, 1999). This is a potentially relevant contribution as the findings could explain the opinion of people on automated driving based on the type of their personality.

It is important to note that our present findings should be interpreted carefully, because highly and fully automated vehicles are not currently available on the market. Hence, the results of our survey rely to a large extent on people’s imagination regarding the operation of automated cars in the future. Although it is certainly not unusual for Human Factors scientists to use a variety of methods (including expert opinions and surveys) to predict the future of human–machine interaction, we caution that one ‘‘cannot foresee what machines can be built to do in the future’’ (Fitts, 1951, p. 7).

2. Methods

2.1. Survey

A 63-question survey was created on http://www.crowdflower.com. The research was approved by the Human Research Ethics Committee (HREC) of the Delft University of Technology (TU Delft). The information recorded for the study was anonymous. The survey instructions informed the respondents about the aim of the survey and provided definitions of manual driving, partially automated driving, highly automated driving, and fully automated driving, representing the definitions of BASt (Gasser & Westhoff, 2012) in plain language as follows:

- *Manual driving = The human driver executes the driving task him/herself using the steering wheel and pedals.*
- *Partially automated driving = The automated driving system takes over both speed and steering control on all roads. However, the system cannot handle all possible situations. Therefore, the driver shall permanently monitor the road and be prepared to take over control at any time.*
- *Highly automated driving = The automated driving system takes over both speed and steering control on all roads. The driver is not required to permanently monitor the road. If automation cannot handle a situation it provides a take-over request, and the driver must take-over control with a time buffer of 7 s.*
- *Fully automated driving = The system takes over speed and steering control completely and permanently, on all roads and in all situations. The driver sets a destination via a touchscreen. The driver cannot drive manually, because the vehicle does not have a steering wheel.*

The survey asked for age, gender, driving frequency, mileage, accident involvement, and preferences/worries regarding manual driving, partially automated driving, highly automated driving, and fully automated driving. In addition, the questionnaire measured the conditions under which people would be willing to use automated driving vehicles, and the secondary tasks that they would be willing to carry out per driving mode. Finally, the personality characteristics of the respondents were measured using a 10-item version of the Big Five Inventory (BFI) introduced by Rammstedt and John (2007), which in turn was derived from John and Srivastava (1999). The full survey is included as supplementary material.

2.2. CrowdFlower settings

In the instructions, the respondents were informed that they would need approximately 15 min to complete the survey. The task expiration time was set at 60 min. In order to collect data from an as large and diverse as possible population, no requirements regarding the respondents' country of residence were set. Furthermore, we opted for 'Level 1 contributors', which is the lowest of the three available levels, accounting for 60% of CrowdFlower's monthly completed work. For the completion of the survey a payment of $0.30 was offered, and 5000 responses were collected.

2.3. Analyses at the individual level

Descriptive statistics (i.e., means, medians, standard deviations, and frequencies) were calculated for each of the variables, as shown in the Supplementary Materials (Table S1). In turn, Spearman correlation coefficients were calculated (criterion for statistical significance at $p < 0.001$) between age, gender, mileage, driving frequency, computer use, education, income, accidents, disability, ACC use, and personality, on the one hand, and the level of enjoyment, comfort, willingness to pay, and worries about automated driving, on the other.

2.4. Analyses at the international level

Various correlational analyses were conducted on the country level, with the country information provided by CrowdFlower by default, based on the respondents' IP addresses. Specifically, Spearman correlation coefficients were calculated between the nationwide averages for the variables in Table S1 and (1) the countries' number of fatal road traffic accidents per 100,000 inhabitants, (2) the countries' number of fatal road traffic accidents per 100,000 vehicles per year (World Health Organization, 2013), (3) the countries' educational test performance (the adjusted "all cognitive ability sum" reported in (Rindermann, 2007), (4) the countries' GDP per capita, and (5) the countries' GDP/capita per Purchasing Power Parities to account for differences in the cost of living between countries, with GDP data taken from (Gapminder World, 2014).

3. Results

3.1. Number of respondents and respondent satisfaction

In total, 5000 people completed the survey. The responses were gathered between 4 July 2014 08:00 and 7 July 2014 04:26 Central European Time. CrowdFlower allows respondents to provide satisfaction ratings regarding the completed

Table 2
CrowdFlower respondents satisfaction ratings completed by a subset of respondents ($N = 2861$).

Item	Mean score
Overall	4.4/5
Instructions clear	4.5/5
Test questions fair	4.2/5
Ease of job	4.3/5
Pay	4.2/5

job. Table 2 shows that the respondents were generally satisfied with both the overall survey and its specifics. The respondents took on average 13.1 min to complete the survey (SD = 8.3 min, median = 10.9 min).

3.2. Data filtering

The respondents who did not indicate that they had read the instructions ($N = 102$) were excluded from the analyses. Those who indicated they were under 18 ($N = 13$), thereby not adhering to the survey instructions, were also excluded. In addition, one person whose responses were not stored correctly in the CrowdFlower database had to be discarded. Accordingly, 114 unique respondents were removed, leaving 4886 respondents for further analysis. Based on the user IDs, we determined that 836 of the 4886 respondents had previously completed an exploratory traffic psychology survey on CrowdFlower ($N = 1517$) conducted by De Winter et al. (2015). An internal validity check revealed good correlation between self-reported age and self-reported birth date (Spearman's $\rho = -0.99$; after excluding 3 people who reported they were over 115 years old, and 49 people who reported they were born before 1900 or after 2010).

3.3. Analyses at the individual level: responses

Descriptive statistics for the 4886 respondents are listed in Table S1. The majority of respondents (3510 out of 4886 people) strongly agreed with the statement "The definitions given in the instructions are clear to me". The respondents' mean and median age were 32.46 and 30 years, respectively, and 69.2% of them were male (3355 men vs. 1490 women). 52.2% of the respondents had heard of the Google Driverless Car before, which is a slight increase compared to the findings (49.9%) obtained by De Winter et al. (2015).

Respondents indicated that manual driving is the most enjoyable mode ($M = 4.04$, SD = 1.06, on the scale from 1 = disagree strongly to 5 = agree strongly, Q16), while fully automated driving would be the least enjoyable mode of driving ($M = 3.49$, SD = 1.41, Q19). Nevertheless, most of the respondents (3643 people) found the idea of fully automated driving fascinating (i.e., agree or strongly agree with the statement, Q15). Regarding enjoyment, a fair portion of respondents strongly agreed that fully automated driving will be enjoyable (Fig. 1). Considering the large sample size, virtually all of the differences in means between pairs of questions were statistically significant. For example, even for the very small difference between Q18 ($M = 3.54$, SD = 1.21) and Q19 ($M = 3.49$, SD = 1.41) a paired t-test revealed formal statistical significance at $p = 0.00013$ ($df = 4827$). Since almost all the effects were statistically significant, we refrained from reporting p-values.

Respondents indicated that fully automated driving would be easier than manual driving ($M = 4.05$, SD = 1.17, Q27, on a scale from 1 = disagree strongly to 5 = agree strongly), whereas partially automated driving ($M = 3.81$, SD = 1.05, Q25) and highly ($M = 3.94$, SD = 1.07, Q26) were regarded as somewhat more difficult vs. manual driving. Respondents did not seem to be very comfortable with the idea of entirely removing the steering wheel ($M = 2.94$, SD = 1.42, Q29). A majority of the respondents (2505 people, 51%) indicated that automated driving would be so advanced in 30 years that they would not even be allowed to drive manually (Q31).

People were also asked to express their comfort in allowing their vehicle to transmit data for safety and efficiency purposes. Results revealed that people, on average, were not extremely concerned about data transmission (Fig. 2).

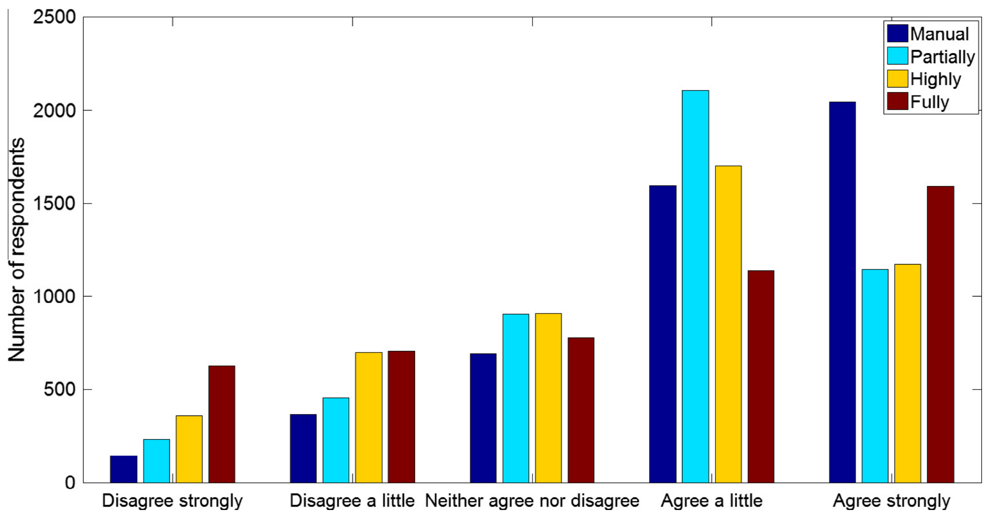

Fig. 1. Number of respondents regarding the statement that driving is/would be enjoyable, per response option and per driving mode (Q16–19).

Nevertheless, they were quite reluctant to share data with insurance companies (Q34), and especially with tax authorities (Q36).

From the five questions that polled people about their concerns in fully automated driving, respondents were most concerned about software hacking and misuse, but also about legal issues and safety (Fig. 3). Privacy was their smallest concern, yet people were still quite concerned about it.

Respondents, on average, were willing to pay more for fully automated driving (M = 4.56, SD = 2.88 on an ordinal scale from 1 to 11, Q45) than for partial (M = 4.11, SD = 2.57, Q43) and highly automated driving (M = 4.28, SD = 2.70, Q44). Fig. 4 shows the distribution of responses for Q43–45, where 22% indicated that they were willing to pay nothing ($0) for fully automated driving (see also Fig. 1). However, 240 respondents (4.9%) indicated they would be willing to pay more than $30,000 for fully automated driving, compared to only 117 and 154 respondents for partially and highly automated driving, respectively.

The higher the level of automation, the more secondary tasks the respondents would be inclined to engage in (Fig. 5, Q59–62). The results reveal a substantial increase in the number of the people who would intend to rest/sleep, watch movies, or read, while driving in fully automated mode compared to the highly automated driving mode. The other tasks show a more linear increase with increasing level of automation, while only the task of "radio listening" indicates a slight decrease compared to the manual driving mode.

Fig. 6 shows that people expect most of the vehicles to be driving fully automated on public roads around 2030 (median response on Q24). This finding is in close agreement with the findings reported by De Winter et al. (2015), in which the same question was asked to 1517 respondents.

3.4. Correlational analyses at the individual level

Table 3 summarises the correlation matrix of the variables. In general, it can be seen that most of the correlations are weak. Neither clear age effects (Q7) nor gender effects (Q8) were identified (absolute correlation coefficients were mostly smaller than 0.10). Nevertheless, men would be willing to pay more for automation than women (Q43–45). Men seemed also to be somewhat less worried about fully automated driving vehicles than women (Q37–41). These findings mirror the literature, as presented in the introduction.

Among the available dependent variables, the willingness of people to pay for automated driving technology was the variable that could be best predicted. Perhaps not surprisingly, people with higher income (Q21) would be willing to pay more for their next vehicle (Q42), as well as for vehicles equipped with automated driving features (Q43–45). Additionally, the respondents who drive more (Q10, Q11) were also willing to pay more (Q42–45), for both their next vehicle and for automated driving vehicles.

It was also found that people who currently use ACC (Q28) would be willing to pay more for automated vehicles (Q43–45). ACC users were also found to be more comfortable about driving without a steering wheel (Q29), and more comfortable about data transmitting (Q34, 36).

Finally, the results revealed that personality factors are not substantially predictive of the public opinion on automated driving (most coefficients are between −0.10 and 0.10). Nonetheless, it was found that respondents who scored higher on

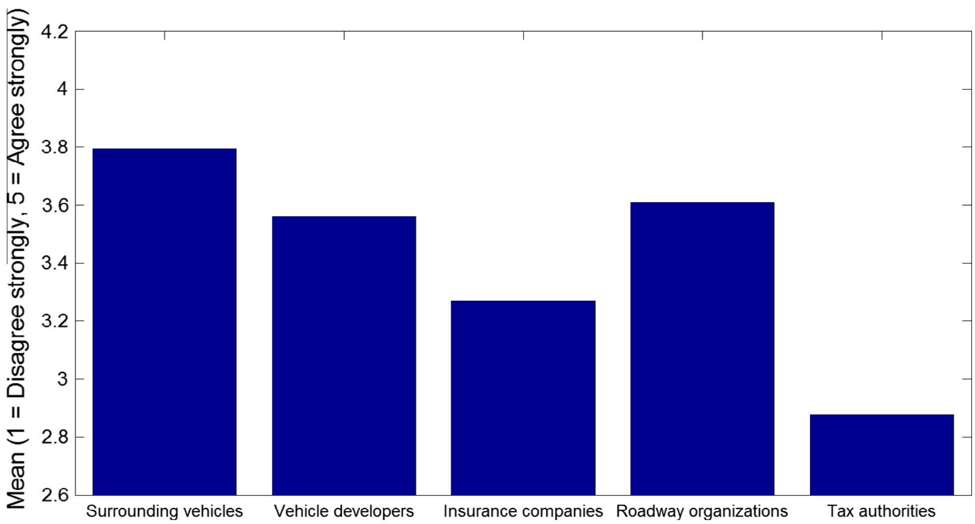

Fig. 2. Mean response on a scale from 1 = Disagree strongly to 5 = Agree strongly, regarding respondents' comfort in transmitting data to automotive stakeholders (Q33–36).

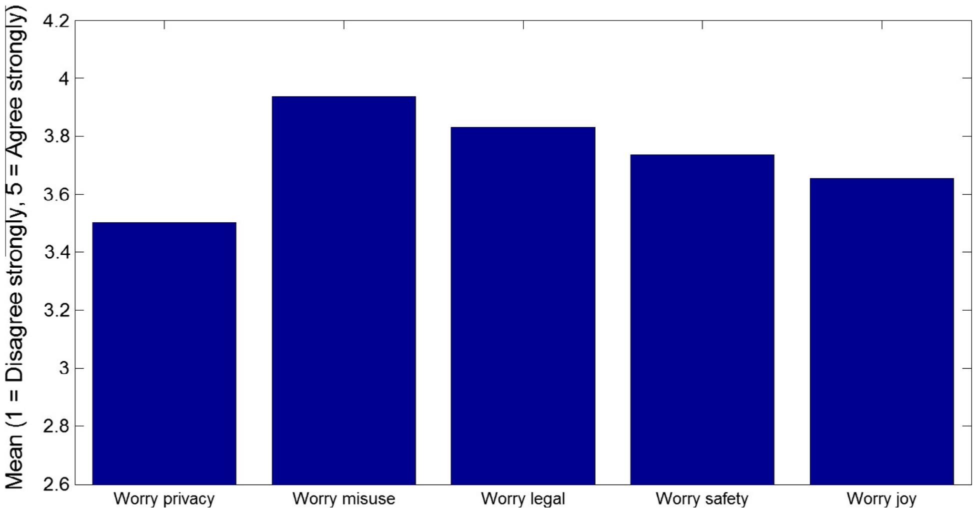

Fig. 3. Mean response on a scale from 1 = Disagree strongly to 5 = Agree strongly regarding respondents worries about fully automated driving (Q37–41).

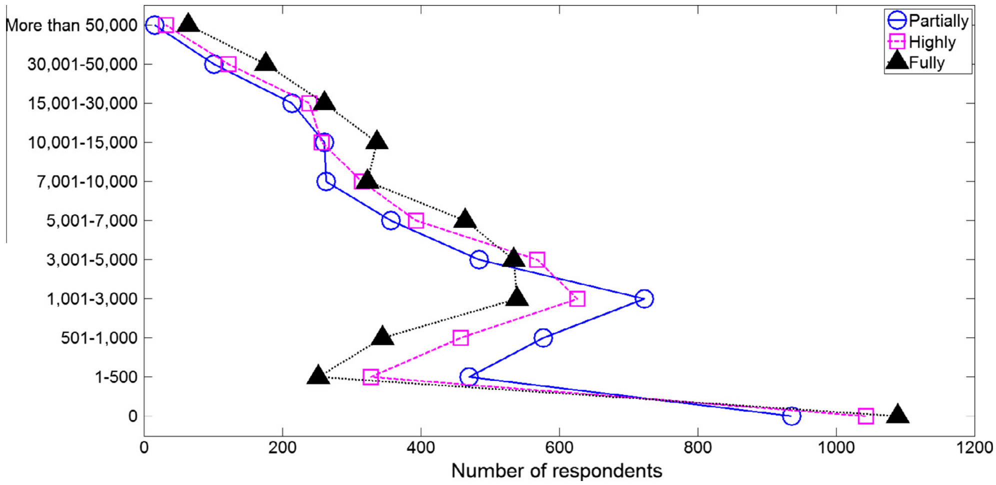

Fig. 4. Number of responses regarding the question how much money (in US $) people were willing to pay for automated driving technology installed in their next vehicle, on top of the base price of that vehicle (Q43–45).

neuroticism were less comfortable with data transmitting (Q32–36), while respondents who scored higher on agreeableness were more comfortable with that, and believed that automation is less silly (Q30).

3.5. Correlational analyses at the national level

The 4886 respondents were from 109 different countries. To avoid erratic effects due to sampling error, the 40 countries with 25 or more respondents were selected ($N = 4379$). The same threshold of 25 respondents per country was adopted in an exploratory CrowdFlower study by De Winter et al. (2015). Overall, the developmental status of a country (either expressed in accident statistics, educational performance, or GDP per person) is predictive of various automation-related results (Table 4).

There is strong evidence that people in higher-income countries are less comfortable about data transmission (ρ up to -0.90). Not surprisingly, people of high-income countries are inclined to pay more for their next vehicle ($\rho = 0.59$; Q42). However, there are no statistically significant relationships between the countries' income level and the respondents' willingness to pay for partially, highly, or fully automated vehicles (Q43–45).

Further cross-national correlations indicate that in countries with higher educational performance and income, there were more female respondents (Q8) and respondents of greater age (Q7). It can also be seen that the actual income (i.e., GDP/capita) is predictive of self-reported income ($\rho = 0.83$; Q21), which provides a validation of the self-reports obtained

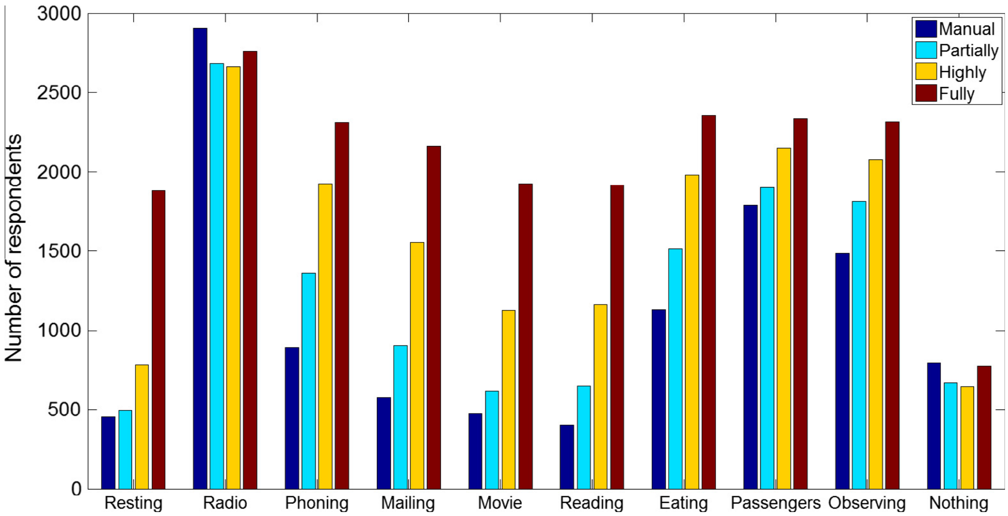

Fig. 5. Number of respondents who indicated that they would engage in secondary tasks, for different driving modes (Q59–62). People could select multiple secondary tasks per question in a checkbox question.

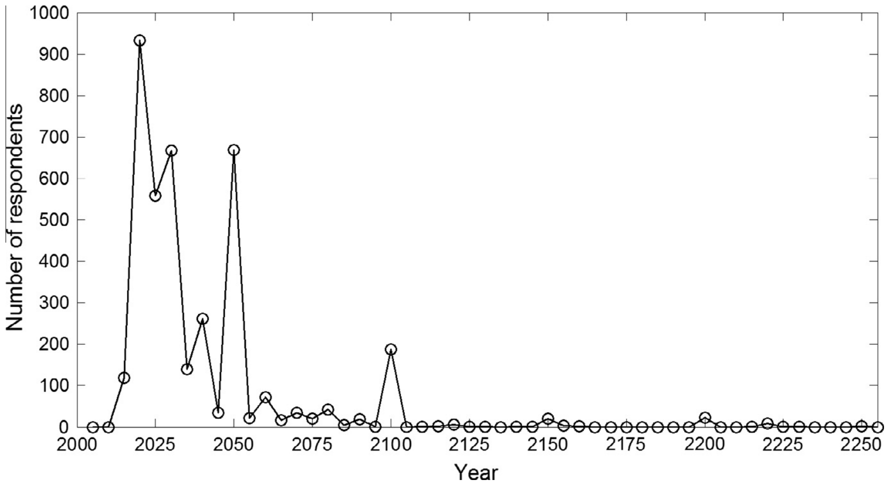

Fig. 6. Number of respondents for the question: "In which year do you think that most cars will be able to drive fully automatically on the roads in your country?" (Q24). Years were divided into 5-year-wide bins.

with CrowdFlower. A further validation of CrowdFlower results is obtained by the correlations between registered accidents and self-reported accidents (ρ = 0.54/0.52, Q22).

4. Discussion

Various recent studies have documented the public opinion on automated driving technology. Most of these studies (Casley et al., 2013; Howard & Dai, 2014; KPMG, 2013; Missel, 2014; Payre et al., 2014; Power, 2012; Power, 2013; Schoettle & Sivak, 2014a, 2014b; Sommer, 2013; Youngs, 2014) focused on measuring the public opinion in Western, higher income countries, and on determining associations with key demographic variables, such as respondents' age and gender. In the present study, we investigated the public opinion on automated driving, not only with respect to these key demographic variables, but also with respect to personality traits, income, mileage, and various other characteristics of the respondents. Furthermore, we assessed cross-national effects for a large number of countries (109 countries, 40 countries of which had more than 25 respondents). We implemented a 63-question survey via the CrowdFlower crowdsourcing service, and we collected 5000 responses, 4886 of which could be included in our statistical analyses.

Our results showed that respondents, on average, found manual driving the most enjoyable mode of driving, yet they found the idea of fully automated driving fascinating. Furthermore, respondents believed that fully automated vehicles

Table 3
Spearman correlation matrix at the individual level ($N = 4886$; correlations were multiplied by 100).

	Q7. Age	Q8. Male gender	Q9. Age license	Q10. How often drive	Q11. Mileage	Q13. Computer	Q14. Heard Google car	Q20. Education	Q21. Income	Q22. Accidents	Q23. Disability	Q24. Year fully	Q28. ACC use	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
Q15. Fascinating	2	3	0	-3	-1	12	13	6	8	-5	-4	-10	-2	-1	10	5	-5	8
Q16. Enjoyable manual	0	10	-2	16	12	-1	3	2	0	-2	-9	3	-6	11	7	9	-14	1
Q17. Enjoyable partial	2	-4	6	2	3	3	0	4	5	2	1	-9	9	7	7	3	-5	0
Q18. Enjoyable highly	-1	0	6	-2	-1	7	3	7	4	2	5	-14	9	4	6	2	-2	1
Q19. Enjoyable filly	-3	4	5	-3	-3	10	6	7	3	1	4	-13	8	3	8	1	-4	0
Q29. Comfortable without wheel	-6	12	11	-1	-3	4	5	11	-4	4	9	-13	15	6	5	-5	-4	-6
Q30. Fully is silly	-2	-7	-4	5	6	-9	-11	-2	1	0	4	1	15	-2	-13	-5	6	-8
Q31. Advanced in 30 years	-4	8	11	3	1	4	2	9	-3	4	7	-24	12	7	8	0	-6	-6
Q32. Comfortable surrounding vehicles	4	9	6	1	0	9	9	9	2	1	-2	-4	-4	2	12	8	-9	5
Q33. Comfortable vehicle developers	3	5	8	3	2	5	0	8	1	4	4	-7	6	7	11	5	-9	1
Q34. Comfortable insurance companies	-4	4	13	3	-1	4	-6	6	-8	6	8	-10	11	7	11	1	-7	-6
Q35. Comfortable roadway organisations	1	5	12	3	0	5	0	9	-3	5	5	-7	3	5	15	3	-10	-2
Q36. Comfortable tax authorities.	-8	5	18	4	-1	2	-6	9	-10	9	13	-9	20	8	6	-3	-4	-12
Q37. Worry privacy	2	-4	1	2	1	-1	-1	0	2	-1	-3	0	1	-3	-4	2	0	-2
Q38. Worry misuse	0	-6	-1	-3	-3	6	1	-2	-1	-2	-6	4	-13	-6	2	2	-2	6
Q39. Worry legal	0	-5	2	1	1	2	-2	2	0	0	-4	1	-5	0	2	8	-2	2
Q40. Worry safety	7	-15	1	1	1	3	-5	-1	2	-3	-5	6	-4	-7	-3	7	4	2
Q41. Worry joy	2	-1	3	9	7	-3	-4	1	-2	2	-3	1	0	6	3	6	-4	-3
Q42. Pay next vehicle	17	1	-15	27	40	1	12	15	54	4	-2	-7	10	6	5	11	-8	4
Q43. Pay partial	-4	4	2	14	19	1	4	14	19	10	10	-15	23	9	3	-2	-2	-7
Q44. Pay highly	-6	7	3	13	16	2	7	15	18	10	10	-16	22	6	4	-3	-2	-5
Q45. Pay fully	-9	10	2	10	14	4	8	14	15	9	9	-14	16	6	4	-2	-3	-4

Note. A correlation coefficient of $\rho = 0.05$ is statistically significant ($p < 0.001$). The color gradient runs from red (lowest value) to yellow (median value) to green (highest value).

would be able to drive on public roads by 2030 (median response), which is in agreement with the findings presented by Underwood (2014) and De Winter et al. (2015). However, our findings are more optimistic than Begg (2014), who found that only 10% of the respondents believed Level-4 NHTSA automation would be commonplace on UK roads by 2030. Perhaps the difference is related to the different background of the respondents in the two studies: while Begg's respondents were all London transport professionals, our respondents were not necessarily aware of the difficulties in deployment of such vehicles. However, it is also possible that the way in which the question was phrased had influenced the results. Specifically, our question was: "In which year do you think that most cars will be able to drive fully automatically in the roads in your country of residence?", and respondents had to provide a numeric response or leave the textbox blank. In Begg (2014), the exact question was: "When do you think level 4 (cars do not even have to have a driver) will be commonplace on UK roads", in which respondents could select the following options: "2030", "2040", "2050", "2060", "2079", and "never", which means that it was not possible to arrive at a number below 2030.

People were found to be most concerned about software hacking and misuse, but also about legal issues, similar to the findings by Schoettle and Sivak (2014a). We found that respondents who scored higher on neuroticism were less comfortable about data transmitting, whereas respondents scoring higher on agreeableness were more comfortable with this. Various other interpretable correlations between personal characteristics and automation preferences are provided in Table 4. Although many of these correlation coefficients are statistically significant ($p < 0.001$), they are typically small ($-0.10 < \rho < 0.10$).

Among all available correlation coefficients, the strongest ones were obtained between income, mileage, driving frequency, and current ACC use, on the one hand, and willingness to pay, on the other. Specifically, we found that people who drive more, would be willing to pay more for automated vehicles. It can be argued that people who spend more time driving are more likely to appreciate cars, and therefore are more likely to buy a new (automated) car. In addition, people who currently use ACC would be willing to pay more for automated vehicles. So, it seems that past behavior (i.e., car driving, and automation use in the form of ACC) is the best predictor of future behavior (i.e., buy a new car, and buying an automated car).

It should be noted that small correlations at the level of individual respondents are to be expected, given the fact that survey items are known to be statistically unreliable (Rushton, Brainerd, & Pressley, 1983). It may also be possible that individual differences are obscured by the fairly large cross-national differences (cf. Fig. 7). Furthermore, our sample of

Table 4
Spearman correlation matrix at the national level (N = 40 countries; correlations were multiplied by 100).

	Traffic deaths/inhabitant	Traffic deaths/vehicle	Education	GDP/capita	GDP/capita, PPP corr.
Q7. Age	-67	-79	85	62	74
Q8. Male gender	35	50	-63	-43	-49
Q9. Age license	27	53	-40	-63	-55
Q10. How often drive	5	-33	33	20	23
Q11. Mileage	2	-42	47	44	47
Q13. Computer	46	51	-48	-50	-53
Q14. Heard of Google car	-26	-38	40	40	41
Q15. Fascinating	5	-2	4	17	11
Q16. Enjoyable manual	-11	-10	0	-8	-1
Q17. Enjoyable partial	41	34	-35	-30	-35
Q18. Enjoyable highly	32	28	-23	-12	-19
Q19. Enjoyable fully	30	25	-19	-9	-17
Q20. Education	26	37	-32	-45	-44
Q21. Income	-44	-71	66	83	81
Q22. Accidents	54	52	-43	-47	-49
Q23. Disability	36	44	-39	-51	-51
Q24. Year fully	2	-1	9	1	7
Q25. Partially easier manual	44	52	-52	-37	-43
Q26. Highly easier manual	7	30	-36	-10	-19
Q27. Fully easier manual	-14	4	-8	16	8
Q28. ACC use	32	24	-10	-17	-18
Q29. Comfortable without wheel	39	48	-50	-37	-45
Q30. Fully is silly	-10	-12	18	8	8
Q31. Advanced in 30 years	39	53	-60	-56	-64
Q32. Comfortable surrounding vehicles	26	42	-32	-35	-35
Q33. Comfortable vehicle developers	58	73	-65	-68	-73
Q34. Comfortable insurance companies	68	82	-72	-86	-87
Q35. Comfortable roadway organisations	60	78	-69	-84	-85
Q36. Comfortable tax authorities.	62	82	-77	-84	-90
Q37. Worry privacy	-19	-15	5	20	19
Q38. Worry misuse	-31	-21	18	15	15
Q39. Worry legal	20	37	-36	-21	-28
Q40. Worry safety	22	25	-20	-22	-24
Q41. Worry joy	14	23	-20	-37	-27
Q42. Pay next vehicle	-18	-38	31	59	52
Q43. Pay partial	27	12	-16	13	4
Q44. Pay highly	28	17	-17	10	2
Q45. Pay fully	33	18	-21	3	-4
Survey time	46	51	-48	-53	-50
Extraversion	-3	12	-23	-34	-28
Agreeableness	17	35	-36	-38	-39
Conscientiousness	6	17	-21	-3	-8
Neuroticism	-15	-36	44	39	43
Openness	-29	-25	22	39	36
Traffic deaths/inhabitant	100	79	-67	-63	-65
Traffic deaths/vehicle	79	100	-90	-82	-88
Education	-67	-90	100	76	86
GDP/capita	-63	-82	76	100	96
GDP/capita, PPP corr.	-65	-88	86	96	100

Note. A correlation coefficient of $\rho = 0.51$ is regarded as statistically significant ($p < 0.001$). The color gradient runs from red (lowest value) to yellow (median value) to green (highest value).

respondents consisted mostly of young people (median age = 30), resulting in attenuation of correlation coefficients due to range restriction.

For fully automated driving we observed a high spread in responses. Specifically, some people were clearly against automated driving while others would certainly enjoy it (Fig. 1). People were inclined to pay the most, on average, for fully automated driving, whereas the step from partially to highly automated driving was not considered worth extra money. However, we also found that there is a large share of people who would not like to pay anything, especially not for fully and highly automated driving (Fig. 4). In conclusion, there appears to be a market for automated driving technologies, but one has to acknowledge that a part of the population is reluctant against such technology. At the same time, there is a fair part of the population who will enjoy fully automated driving, and about 5% would be willing to pay even more than $30,000 to purchase it.

Some of our results on the foreseen behavior during automated driving mirror the findings that have been obtained in high-fidelity driving simulators and on test tracks. For example, it has been experimentally found that people are inclined to watch DVDs in a highly automated car (Carsten, Lai, Barnard, Jamson, & Merat, 2012; Llaneras, Salinger, & Green, 2013). Furthermore, over 30 driving simulator studies have measured a reduction of self-reported workload in sophisticated driving simulator studies, (see De Winter, Happee, Martens, & Stanton, 2014, for a review), which matches the results of our questions regarding task difficulty (Q25–27). Although people's responses in a survey do not necessarily match behavior in real traffic, we would like to argue that surveys are a powerful and low-cost means to obtain initial observations regarding certain hypotheses. The 'wisdom of the crowd' can be particularly valuable regarding the development of future technologies, especially in situations where the necessary technology is not yet developed, not yet feasible, or not yet safe to use in human subject experiments.

Respondents from more developed countries (in terms of lower accident rates, higher education, and higher income) were more worried about data transmitting, with correlations up to $\rho = -0.80$ and $\rho = -0.90$. We could speculate about two possible mechanisms that can explain such strong correlations: a real and imagined threat. According to the real-threat mechanism, high-income countries have more sophisticated computer infrastructure for data misuse. The Snowden affair (Richelson, 2013), some Google cases (Hong, 2013; Segall, 2010), and Facebook cases (Debatin, Lovejoy, Horn, & Hughes, 2009; Weinstein, 2013) are examples of widely publicized cases in the high-income countries. That is, citizens of high-income countries may realistically believe that the threat of data misuse exists and is harmful for them. However, the strong negative correlation between income and worry about data transmitting could also be caused by an imagined, or luxury, problem. According to Maslow's hierarchy of needs (Maslow, 1943), people in low-income countries are mostly concerned with basic physiological and safety needs, and have other things on their mind than 'higher-level' factors as privacy. People in low-income countries may consider data sharing not as a threat for their well-being, but rather as something that could actually help them to improve the safety and efficiency of road traffic. It is striking that various seemingly unrelated variables, such as educational performance and road traffic accidents per vehicle, share very strong correlations at the country level (up to $\rho = -0.90$). These strong correlations suggest that one should consider the developmental status of a country in its entirety when making inferences about cross-national effects. In other words, correlation does not imply causation. Other limitations of cross-national correlations include our relatively small sample size (only 40 countries with at least 25 of respondents per country) and possible non-independence of data points (e.g., adjacent countries may be similar

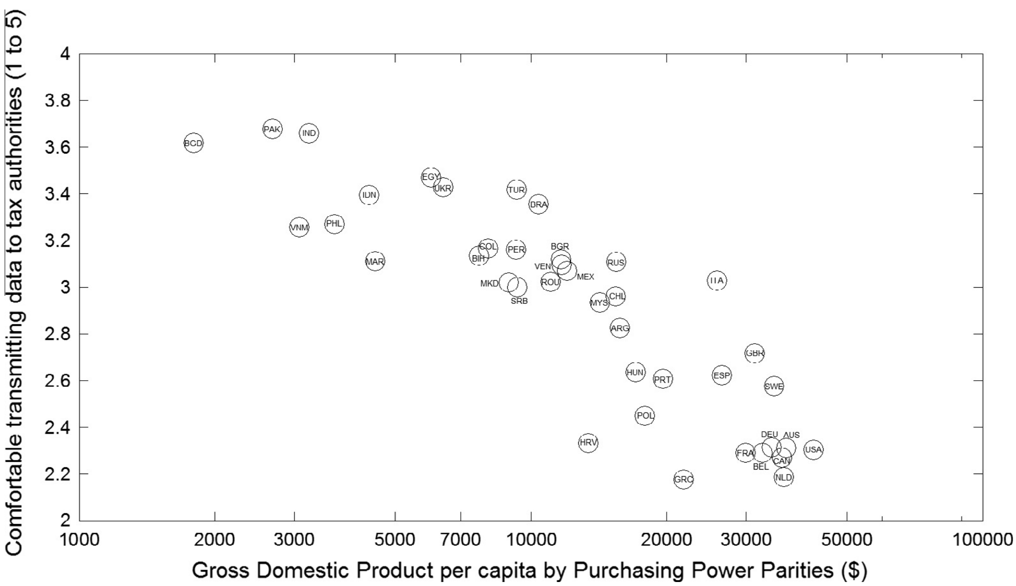

Fig. 7. National average in comfort in transmitting data to tax authorities (Q36) vs. gross domestic product (GDP) per purchasing power parities (PPP).

and dependent on each other), according to which the notion of statistical significance can be misleading (Pollet, Tybur, Frankenhuis, & Rickard, 2014). On the other hand, the very low-income countries (e.g., in Africa) were not available in our analysis. It is possible that, in case these countries were included, our observed effects would have been even stronger.

In conclusion, our survey showed that 69% of people believe that fully automated driving will reach a 50% market share between now and 2050 (cf. Fig. 6). On the other hand, a number of concerns were revealed, mainly regarding software hacking/misuse, safety, legal, and data transmitting issues of automated driving. The public opinion appears to be diverse, with a portion of respondents embracing the idea of fully automated driving and another large portion of people not willing to pay for it and thinking it will not provide an enjoyable experience. Respondents from high-income countries are particularly uncomfortable with the idea that their vehicle shares data to insurance companies, tax authorities, or roadway organizations. We expect that our results are relevant for all stakeholders involved with the development of automated driving technology.

Acknowledgment

The research presented in this paper is being conducted in the project HFAuto – Human Factors of Automated Driving (PITN-GA-2013-605817).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.trf.2015.04.014.

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