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Modelling the economic impacts of road crashes in Greece

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Abstract

This research aims to quantify the willingness-to-pay attitude of the Greek public towards mitigating road crash risk and thus crash involvement in the macroscopic scale. An online questionnaire survey was designed and distributed to participant drivers. Two scenarios of willingness-to-pay in order to reduce crash involvement probability were included: 20% and 50% reductions in probability; 238 valid responses were collected and analyzed. Ordinal and multinomial logistic regression models were used to correlate driver preferences between the two scenarios and several independent variables, in contrast with the do-nothing (0% reduction) scenario. Results indicated that most drivers are very positively predisposed towards a road crash risk reduction. The choice between low and high reductions depends on trip duration and cost increases, family situation, driving experience and annual family income. The calibrated WTP models are used in a case study to calculate the human cost (value of statistical life) in Greece during 2016.

Keywords: road crashes; human cost; stated preference; willingness to pay; ordinal logistic regression; multinomial logistic regression

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1. Introduction

Despite scientific and technical progress, road crashes remain a critical issue of land transport and modern societies overall, and their numbers have been plateauing in recent years (WHO, 2018). The respective costs for lives and property that they incur have been the subject of research in modernized countries in recent years. In comparison, little has been done to determine societal perspective on the cost of road crash prevention for Greece. Road crashes are a global public health problem and have emerged as the leading cause of death from crashes in Greece. Road safety is the subject of national, regional and local documented interventions aimed at both passive and active crash prevention (Petridou et al., 2007). A study conducted by the World Health Organization in co-operation with Harvard University and the World Bank (Murray & Lopez, 1996) showed that until 2020 road crashes will be the third most common cause of death (DALY's index). In the case of Greece, in the year 2015 there were 74 deaths per million population. This figure, although exceeding the average of 58 deaths per million inhabitants of the EU Member States, is an important indication of the effort to reduce road crashes in the last two decades. Specifically, in the decade of 2000-2010, in Greece there was a reduction in fatal road crashes by 37.1%.

This significant reduction, although satisfactory, has failed to meet the objectives of the Greek Strategic Road Safety Plan and to remove Greece from the last positions in the comparative list of the European Union. The corresponding plan for the period 2011-2020 aimed to reduce the number of road deaths by 50% (NTUA, 2011). It is worth noting that in recent years, namely 2007-2017, Greece has achieved one the highest rates of reduction of fatal road crashes at European level (Hellenic Statistical Authority, 2018), which apparently was still not enough to achieve the set target. It is therefore imperative to endeavor to determine the human costs of road crashes, and thus provide a quantitative estimate of the benefits of crash mitigation. In turn, this information can be assessed by stakeholders and the public, and can be used to promote road safety measures and interventions. This is especially true given the varying cost-effectiveness of road safety measures (Daniels et al., 2019; Høye et al., 2018) and the limited budget each road safety administrator can allocate.

In that context, the objective of this study is the estimation of the human cost of road crashes based on the Willingness-to-Pay (WTP) methodology, and the identification of driver attitudes towards the probability of being involved in a road crash, using the stated preference method. This is attained by the statistical analysis of stated preferences of participant drivers. WTP is used by the majority of countries when estimating the human cost of road crashes (Wijnen et al., 2019) by recording the preferences of participants when presented with hypothetical road safety investment scenarios. This stated choice approach is reported to be state-of-the-art when examining non-market goods (Bahamonde-Birke et al., 2015). Furthermore, this study is complemented by the estimation of the additional crash cost components in order to acquire comprehensive costs of crashes per injury severity in Greece during 2016 (the most recent year with sufficient data availability).

2. Data collection

To answer the research question of human cost estimation, an online questionnaire survey was utilized, which lasted approximately one month. Participant drivers were invited to fill simple and comprehensible questions without any researcher guidance. The questionnaire consisted of four distinct sections that each had a different purpose: (i) driving experience, (ii) road crash perception and involvement, (iii) willingness to pay investigation and (iv) demographic questions. The questionnaire was sent via personal e-mail to drivers solely, in order to ensure the exclusive participation of drivers in the survey. The questionnaire was created on Google Forms, and was thus fully GDPR-compliant. Furthermore, full anonymity was ensured in the results as no personal information was requested or given by the drivers.

In order to reduce uncertainty, the questionnaire consisted of multiple choice questions. The first section contains general questions concerning the driving behavior and aiding in the determination of the preferences of the sample. The second part is designed to familiarize the drivers with the probability of getting involved in a road crash and asks them to estimate the annual slightly injured people, the seriously injured people as well as the casualties by road crashes in Greece. This section had the additional aim to impart to the participants discrepancies between their estimates and the actual probability involvement, which are expected but nonetheless undeniable.

In the third part of the questionnaire, participant drivers were asked to state their preference related to the annual amount that they are willing to invest, in order to reduce the probability of getting involved in a road crash. At the same time, concerning the above-mentioned probability, they choose the level of reduction by selecting the transporting intervention and the additional cost and duration of the hypothetical trip. It should be noted that this part of the questionnaire consisted of hypothetical scenarios that had the purpose of expressing willingness to pay for the reduction of crash involvement probability under a diverse range of situations. These situations included singular or simultaneous increases in trip costs and trip duration, extending to more extreme cases such as the tripling of either time or duration. Furthermore, the questions involved providing reductions of crash involvement probability both to the participant themselves and to their close relatives. This consisted an attempt to remove any driver overconfidence to their skills and capture the true willingness to invest in road safety interventions. Lastly, the fourth section of the questionnaire aimed to define the socio-economic demographics and background of the drivers in order to verify the diversity of the selected sample.

To participate in the survey, respondents were required to have a valid driver license and thus be over 18 years old. Overall, a total of 251 questionnaires were gathered. After a quality check, 238 of them were considered valid and reliable. Figures 1 illustrates a sample of participant demographic information which discloses satisfactory spread across observations.

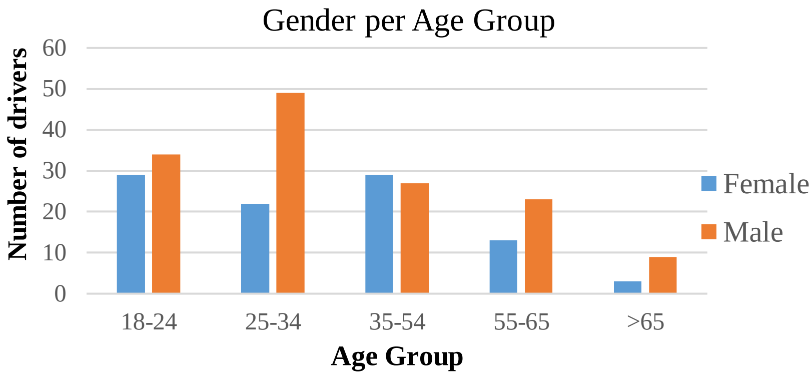

Figure 1. Gender distribution per age group of participant drivers

3. Methodology

As previously stated, two modelling approaches were employed in this paper: (i) ordinal logistic regression and (ii) multinomial logistic regression. These models have been used in the literature and are covered extensively in the respective research, therefore here an outline is provided only. Following Washington et al. (2011), a brief description is provided as follows. Based on the proportional odds assumption (the assumption that the logarithms of odds follow an arithmetic series), the ordinal logistic regression for the occurrence probability of an event p can be expressed as the link of the logarithm of the odds with a linear utility function:

$$y_i^* = logit(p) = \ln\left(\frac{p}{1-p}\right) = b_o + \sum b_i x_i \qquad (1)$$

In this case, the actual dependent variable y_i^* is unobserved and therefore standard regression techniques cannot be performed. Instead, the observed variable y_i is included in the data, as the ordered variable described previously. The typical relationship between the observed and the actual dependent variable is formalized as follows:

$$y = \begin{cases} 0, & if\ y^* \leq \beta_{01} \\ 1, & if\ \beta_{01} \leq y^* \leq \beta_{02} \\ & \dots \\ n, & if\ \beta_{0n} \leq y^* \end{cases} \qquad (2)$$

Multinomial logistic regression for N possible outcomes can be described as an array of N-1 independent binary regressions of the odds of an outcome compared to the previous one. The respective error terms are assumed to follow the Gumbel distribution. The generalized expression of selecting a single outcome from a total N possible outcomes is as follows for every n in N:

$$\hat{P} = \frac{e^{b_o + b_i x_i}}{\sum_n (e^{b_o + b_i x_i})} \qquad (3)$$

4. Modelling Results

4.1. Ordinal logistic regression

Questionnaire data were initially analyzed and an ordinal logistic regression approach was fitted. For this model, the dependent variable was defined as “What is the maximum amount (€/year) of your household income that you are willing to invest in order to reduce the probability of getting involved in a fatal road crash by 50%”. This is essentially the core question that is employed in the current study in order to capture the Willingness-to-pay of participants. Accordingly, the final independent variables included in the model were the number of past involvements in injury crashes, annual household income and weekly kilometers traveled. It is worth noting that a collinearity check between the independent variables has been conducted in order to avoid multicollinearity phenomena. Several trials were made to obtain the optimal model based on goodness-of-fit, both overall and based on variable significance. Results appear on Table 1. The final model had a Nagelkerke R^2 of 0.305, which is considered adequate for logistic regression models.

Table 1. Ordinal logistic regression model results

Parameter	Variable – Relevant Question	Coefficient	Std. Error	Significance	Odds Ratio
Constant P_{1-2}		-5.308	0.838	0.000	–
Constant P_{2-3}		-3.776	0.794	0.000	–
Constant P_{3-4}		-2.180	0.766	0.004	–
NC0	Answers: 0, 1, >1 to the question “As a driver, how many road crashes have you involved in?”	-2.499	0.696	0.000	0.08
NC1		-2.086	0.733	0.004	0.12
NC2 (reference cat.)		–	–	–	–
FI1	Answers: <10,000€, 10,000-25,000€, 25,000-50,000€ and >50,000€ to the question “What was your annual household income last year?”	-1.566	0.522	0.003	0.21
FI2		0.772	0.487	0.113	-
FI3		-1.433	0.466	0.002	0.24
FI4 (reference cat.)		–	–	–	–
KD1	Answers: <10, 10-40 and 40-100 >100 to the question “Approximately how many kilometers do you drive per week?”	0.988	0.457	0.031	2.69
KD2		0.901	0.400	0.024	2.46
KD3		1.185	0.367	0.001	3.27
KD4 (reference cat.)		–	–	–	–

Acronyms: NC – Number of Crashes | FI – Family Income | KD – Kilometers driven (per week)

Based on these results, a series of deductions can be made. Drivers who have not been involved in an crash with injuries have 0.08 times the probability (or an equivalent 92% reduced probability) to choose to invest 200-500€ instead of <200€ to the scenario of “What is the maximum amount (€/year) of your household income that you are willing to invest in order to reduce the probability of getting involved in a fatal road crash by 50%” compared with those who have been involved in >1 crashes with injuries. The respective probability of drivers who have not been involved in a crash with injuries is 0.12 times the initial probability (or an equivalent 88% reduced probability). Therefore it can be inferred that drivers are willing to offer higher investments the more times they were involved in injury crashes.

Similarly, drivers who have <10,000€ annual household income have 0.21 times the probability (or an equivalent of 79% reduced probability) to choose 200-500€ instead of <200€ to the previous question compared with those who have >50,000€ annual household income. The respective probability of drivers who have 25,000-50,000€ annual household income is 0.24 times the probability (or an equivalent 76% reduced probability). It is worth noting that the middle category, namely drivers who have 10,000-25,000€ annual household income, was not found to differ significantly from the more affluent drivers. Therefore the deduction can be summarized as the identification of certain income categories that are more willing to invest in road safety than others. This finding could be due to fear of unaffordable medical costs in the lower income categories and increased exposure (perhaps due to entertainment or business trips) in the higher income categories. Furthermore, results show that drivers that drive the largest distances are less likely to invest in road safety improvements, as opposed to all three lower categories. This could be attributed to the confidence brought by increased driving experience, as these drivers feel they would not be involved in a crash and thus find no need to finance crash mitigation measures.

4.2. Multinomial logistic regression

For calibration of the multinomial logistic regression, rather than investment amounts, the dependent variable was designated as the choice of the driver among (i) no change, (ii) 20% reduction of the probability of getting involved in a fatal road crash and (iii) 50% reduction of the previous probability (henceforth mentioned as 20% and 50% reduction, respectively).

In order to be able to realistically capture the variables of travel trip and travel cost, which are normally linear, several different scenarios are presented in the questionnaire. This is a usual practice followed by researchers in order to confine the answers of participants in order to make them easier to handle and analyze. Initially, a baseline hypothetical trip with a duration of 3 hours and incurring a cost of 60€ was considered. Afterwards, 10 different scenarios were created in total, with smaller, modest or larger variations in time and cost (increases of 10 – 30 – 60 minutes and 10 – 30 – 60 €, respectively). These increases, which are perceived as negative by participant drivers, were the price to pay for gaining the 20% and 50% reductions of getting involved in a fatal road crash.

As previously, a collinearity check between the independent variables has been conducted to exclude correlated combinations of variables. The final model included a large amount of dependent variables, namely time and cost of trips, past and estimated crash involvement probability, categorical driver age and gender, vehicle types, trip purpose, weekly hours of driving and income levels. These were complemented by the given answer to the question of "What is the maximum amount (€/year) of your household income that you are willing to invest in order to reduce by 50%, your close relatives' probability of involvement in a road crash with severe injuries?" This time, the do-nothing scenario (i) was selected as the reference category and the calibration of the multinomial logistic regression required the transformation of the questionnaire data to long format.

Multinomial logistic model results appear on Table 2 for the 20% and 50% reductions. The variables included on Table 2 (and the respective reference categories, where necessary), are:

- Time: variable of trip time
- Cost: variable of trip cost
- Age1 (ref), Age2, Age3, Age4, Age5: variables for driver ages of 18-24, 25-34, 35-54, 55-65 and >65
- Gen1 (ref), Gen2: variables representing the men and women drivers respectively
- P1 (ref), P2, P3, P4, P5: variables representing the estimated probabilities 0-10%, 11-20%, 21-30%, 31-40%, >40% of getting involved in a road crash with slight injuries
- Veh1 (ref), Veh2, Veh3: variables representing the answers "Car", "Power-Two-Wheeler" and "Other vehicle" respectively, to the question "Which vehicle do you normally use for your daily transportation?" (more than one choice is possible)
- Purp1 (ref), Purp2, Purp3, Purp4, Purp5: variables representing the answers "Going to Work", "Entertainment", "Education", "Social responsibilities" and "Other Reasons" respectively, to the question "What is your main transportation purpose inside town?"
- CID1, CID2: variables representing the answers 0, ≥1 to the question "In how many road crashes with casualties (injuries or fatalities) have you been involved in as a driver?"
- WFC1 (ref), WFA2, WFA3: variables representing the answers "No, not at all worried", "Yes, somewhat worried" and "Yes, very worried", respectively, to the question "Are you worried for the probability of getting involved in a road crash with casualties?"
- HD1 (ref), HD2, HD3, HD4: variables representing the answers <1, 1-4, 4-10 and >10 respectively, to the question "Approximately how many hours do you drive per week?"
- Inv1 (ref), Inv2, Inv3, Inv4: variables representing the answers <200€, 200€-500€, 500-1000€ και >1000€ respectively, to the question "What is the maximum amount (in €/year) of your household income that you are willing to invest in order to reduce by 50%, your close relatives' probability of involvement in a road accident with severe injuries?"

The final model had a McFadden R^2 of 0.225, which is considered decent for non-linear regression models like the one employed here (its usual range is 0.2 – 0.4, with higher values indicating good model fit). Regarding model results, it can be seen that time and cost have statistically significant negative coefficients (indicatively, for 20% reduction, -0.088 [OR= 0.916] for trip cost and -0.038 [OR= 0.963] for time).

Table 2. Multinomial logistic regression model results

Parameter	**20%** Reduction in Crash Involvement probability				**50%** Reduction in Crash Involvement probability			
	Coefficient	z-value	Sig.	Odds Ratio	Coefficient	z-value	Sig.	Odds Ratio
Constant	4.971	8.961	***	–	4.917	8.961	***	–
Time	-0.038	-5.426	***	0.963	-0.034	-6.354	***	0.966
Cost	-0.088	-10.662	***	0.916	-0.061	-10.011	***	0.940
Age1 (ref. cat.)	–	–	–	–	–	–	–	–
Age2	-1.010	-3.835	***	0.364	-0.862	-3.214	**	0.422
Age3	-0.860	-2.964	**	0.423	-0.480	-1.628		0.619
Age4	0.037	0.111		1.038	0.128	0.372		1.136
Age5	1.928	1.816	.	6.872	2.186	2.060	*	8.896
Gen1 (ref. cat.)	–	–	–	–	–	–	–	–
Gen2	0.359	2.188	*	1.431	0.338	1.991	*	1.401
P1 (ref. cat.)	–	–	–	–	–	–	–	–
P2	-0.837	-3.319	***	0.433	-1.323	-5.038	***	0.266
P3	-1.011	-3.989	***	0.364	-1.179	-4.463	***	0.308
P4	-0.680	-2.263	*	0.507	-0.781	-2.570	*	0.458
P5	-0.298	-4.896	***	0.742	-2.055	-6.658	***	0.128
V1 (ref. cat.)	–	–	–	–	–	–	–	–
V2	0.189	0.766		1.201	0.501	1.793	.	1.650
V3	0.965	2.842	**	2.624	1.753	4.712	***	5.771
Purp1 (ref. cat.)	–	–	–	–	–	–	–	–
Purp2	0.313	0.998		1.367	0.772	2.440	*	2.165
Purp3	0.306	0.996		1.426	0.566	1.800	.	1.762
Purp4	-0.108	-0.291		0.897	1.302	3.645	***	3.676
Purp5	-1.468	-5.163	***	0.230	-2.163	-6.437	***	0.115
CID1	-0.116	-0.602		0.890	-0.707	-3.484	***	0.493
CID2	0.673	1.910	.	1,960	1.050	2.974	**	2.857
WFC1 (ref. cat.)	–	–	–	–	–	–	–	–
WFC2	0.344	1.882	.	1.411	0.894	4.705	***	2.456
WFC3	1.037	4.196	***	2.822	2.228	8.951	***	9.284
HD1 (ref. cat.)	–	–	–	–	–	–	–	–
HD2	-0.467	-1.241		0.627	-0.766	-2.028	*	0.465
HD3	-0.856	-2.322	*	0.425	-0.868	-2.329	*	0.420
HD4	-1.132	-2.872	**	0.322	-1.429	-3.575	***	0.239
E1 (ref. cat.)	–	–	–	–	–	–	–	–
E2	0.325	1.656	.	1.384	0.875	3.818	***	2.400
E3	0.398	1.796	.	1.489	2.011	8.263	***	7.472
E4	0.952	3.402	***	2.592	2.783	9.449	***	16.161

Significance codes: '***': 0.000 | '**': 0.001 | '*': 0.01 | '.': 0.05 | ' ': ≥ 0.1

Interpreting the results, an increase in one unit of cost leads to an 8% decrease of the probability of a driver selecting the 20% reduction. Respectively, an increase in one unit of trip time leads to a 4% decrease of the probability of a driver selecting the 20% reduction. This finding is expected. As road safety interventions increase the time and cost of trips the fraction of drivers supporting the interventions decreases; this result is a quantification of the exact relationship.

The age of the respondents significantly influences their choice regarding the reduction of the probability of getting involved in a road crash. Specifically, drivers aged 25 to 34 have 58% reduced chance of choosing 50% reduction than no change compared to the drivers aged 18 to 24. This may be due to confidence provided by driving experience, or, in reverse, by the insecurity of less experienced drivers. As age increases even more, however, driver intention to invest in road safety increases. For instance, drivers ≥65 years old are about 9 times more likely to choose 50% reduction than No change compared to the drivers aged 18 to 24. This may be due to the fact that the elderly realize much better the increased change of involvement in a crash for them and for the general population as well as their own inability to respond effectively and on time, to a possible road crash.

Females appear to be more tolerant against the increase of time and travel costs and therefore more willing to invest in transport interventions that enhance road safety levels. This observation is probably due to the fact that men already spend more time and money for their transport needs than women and as a result are less willing to invest additional time and cost for safety reasons. Men are also well-documented as more aggressive than women in the literature and more likely to be involved in crashes (e.g. Al-Balbissi, 2003). Another interesting finding is derived by the trip purpose of drivers. In particular, Greek drivers whose main purpose of transportation is "Going to work" are about 2.2 times less likely to choose 50% reduction than no change compared to drivers whose main purpose is "Shopping and Entertainment". This result may be due to the fact that travelling for work is inelastic with regard to time increases because people want to be punctual. Furthermore, work routes have typically very specific and therefore manageable features. Analytically, time and traffic conditions are similar in every travel and therefore a sense of security is created to drivers, making them less willing to reduce the risk of an crash, factors that do not apply to shopping and entertainment trips. Further similar results emerge from the examination of the rest of independent variable coefficients.

5. Crash cost calculation

The results that were obtained from the WTP model can be used to estimate the human cost of crashes. In simple terms, the total amount that people are willing to invest is given by the following relationship:

$$TI = Avg\_inc * WTP * TF \qquad (4)$$

Where:

- TI: Total amount of willing investment
- Avg_inc: Average household income
- WTP: Willingness to pay (percentage)
- TF: Total families

Therefore, the individual human cost (HC), – also known of VOSL – Value of Statistical Life – can be derived from a division:

$$HC = TI/fatalities \qquad (5)$$

Given that this study was conducted in Greece, figures from this country were used as a case study. According to the last census in 2011 of the Hellenic Statistical Authority, the number of households in Greece is 4,134,540 (Hellenic Statistical Authority, 2018). Similarly, according to Eurostat data, the average annual family income of the Greeks for the year 2017 was 8,682€ (Eurostat, 2018).

The next step is the WTP factor. After processing the respondents' answers, the percentage of family income they intend to invest in order to reduce their risk of involvement in a fatal road accident was calculated. Initially, the central (midrange) value of the answer classes to the question "What is the maximum amount (in €/year) of your household income that you are willing to invest in order to reduce the probability of getting involved in a fatal road accident by 20%" were determined. In the current study, the classes were as follows: 0-200, 200-500, 500-1,000, >1,000, therefore the central values are the numbers 100, 350, 750 and 1,000 (the last being a working assumption). The central values (x_i) of the classes are then multiplied by the frequency of the replies (n_i), resulting in a total amount of 139,700€ as shown on Table 3.

Table 3. Central classes and frequency of replies

Central value (x_i)	Frequency (n_i)	x_i*n_i
100.00 €	52	5.200 €
350.00 €	50	17.500 €
750.00 €	76	57.000 €
1,000.00 €	60	60.000 €
SUM	238	139.700 €

The obtained sum amount was divided by the size of the sample in order to calculate the amount that each driver is willing to pay, obtaining an average of 586.98€. Finally, this average value was divided by the average annual household income in order to calculate the available amount as percentage of the annual household income, obtaining the value of 6.76%.

We then consider the average annual fatalities in road crashes in Greece, from the most recent period of 2000 – 2016; the figure is 1,378 average deaths annually (Hellenic Statistical Authority, 2018). Plugging the figures in Equation (4), TI is calculated to 2,426,870,748 € and, correspondingly, using Equation (5), the human cost per road crash fatality HC, is 1,761,154 € for Greece in 2016.

6. Conclusions

From the previous analysis of the drivers towards the probability of a road crash, important characteristics of the Greek driver perception are revealed. An anonymous online questionnaire survey was conducted amongst 238 Greek drivers with satisfactory spread across age and gender characteristics regarding their willingness-to-pay in order to avoid involvement in a road crash using the stated preference method.

It is shown that Greek drivers choose to reduce the probability of getting involved in a road crash (slightly or considerably). The results of this survey have shown that the vast majority of Greek drivers choose to reduce (slightly or not) the probability of getting involved in a road crash. Drivers appeared willing to offer higher investments the more times they were involved in injury crashes. Certain income categories are more willing to invest in road safety than others. However, drivers traveling the largest distances are more reluctant to do so. Naturally, drivers are willing to adapt to new measures which will deliver positive results in addressing road safety issues, but less willing when these measures incur increased time and cost of transport on a daily basis. Additional characteristics that influence people's driving behavior and their preferences towards road safety is driver age, driver gender, purpose of transport and others. Using model results, the human cost is also determined for Greece in 2016 at about 1.76 million €.

The results of the present research provide useful and practical information in transportation planning on a statistical level. By quantifying the human cost of crashes, their economic impacts can be better understood. This means that the cost of road safety inaction is determined. Furthermore, this figure offers impetus to new road safety cost-benefit analyses, as the potential gains from casualty reduction can be factored in, thus making strategic decisions more informed.

The present research can be expanded through several future research endeavors. Regarding the ordinal and multinomial models presented here, a cluster analysis with sample profiling could follow according to the responses (for low and high WTP and risk, for instance). It is important to note that the WTP method provides higher valuations than other methods (Wijnen et al., 2019), therefore additional valuation methods can be explored as well, such as the restitution costs approach and the human capital approach, and their results can be compared.

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