Does longevity impact the severity of traffic crashes? A comparative study of young-older and old-older drivers

Abstract

Introduction: This article analyzes the effect of driver's age in crash severity with a particular focus on those over the age of 65. The greater frequency and longevity of older drivers around the world suggests the need to introduce a possible segmentation within this group at risk, thus eliminating the generic interval of 65 and over as applied today in road safety data and in the automobile insurance sector. *Method:* We investigate differences in the severity of traffic crashes among two subgroups of older drivers – young-older (65–75) and old-older (75+), and findings are compared with the age interval of drivers under 65. Here, we draw on data for 2016 provided by Spanish Traffic Authority. Parametric and semi-parametric regression models are applied. *Results:* We identified the factors related to the crash, vehicle, and driver that have a significant impact on the probability of the crash being slight, serious, or fatal for the different age groups. *Conclusions:* We found that crash severity and the expected costs of crashes significantly increase when the driver is over the age of 75. *Practical applications*: Our results have obvious implications for regulators responsible for road safety policies – most specifically as they consider there should be specific driver licensing requirements and driving training for elderly – and for the automobile insurance industry, which to date has not examined the impact that the longevity of drivers is likely to have on their balance sheets.

Keywords: Older drivers, groups at risk, bodily injuries damages, policy implications, automobile insurance

1. Introduction

Spain, in common with other countries, has recorded an increase in its number of older drivers due to an increase in this population cohort (INE, 2018; DGT, 2018; Polders et al., 2015), an increase that is set to become significant over coming years. Moreover, older drivers are now living and driving for longer periods given increasing levels of life expectancy for the elderly. Today, driving among the elderly is more frequent than ever, as those in this age group seek to maximize their quality of life in terms of mobility and independence (Metz, 2000; Lin, 2003; Rosenbloom, 2011). Yet, physical and cognitive abilities decline with age and the elderly require longer perception-reaction times on the road (Hwang & Hong, 2018; Makizako et al., 2018; Anstey, Horswill, Wood & Hatherly, 2012; Clarke, Ward, Bartle & Truman, 2010). Indeed, Cicchino and McCartt (2015) report that inadequate surveillance errors committed by older drivers were primarily due to their looking but not seeing, which they claim could be related to diminishing abilities to divide visual attention and to reductions in information processing speeds. Loughran and Seabury (2007) estimate that passengers riding in a car driven by an older individual are 6.73 times more likely to be killed than passengers riding in a car driven by a middle-aged driver.

Parallel to this, older drivers themselves are at greater risk of injury or death, because of their greater physical fragility due to ageing (Regev, Rolison & Moutari, 2018; Noh & Yoon, 2017; Yaw, Stamatiadis & Aultman-Hall, 2003; Mitchell, 2013). It has been shown that older traffic victims present more skeletal injuries associated with internal injuries than younger victims in whom internal injuries usually present without rib fractures (Wisch et al., 2017; Johannsen & Müller, 2013). Elderly car occupants are at less risk of being involved in crashes but, when they are, they are at a considerably greater risk of being severely injured or killed than younger car occupants (Johannsen & Müller, 2013; Alam & Spainhour, 2008; Stutts, Martell & Staplin, 2009; Baldock & McLean, 2005).

Risk factors affecting the likelihood to be involved in a road traffic crash and crash severity vary with the age of the driver. For instance, older drivers are found to be at fault in fatal traffic crashes at much higher rates than all other drivers except the youngest cohorts (Alam & Spainhour, 2008; Chin & Zhou, 2018). Lyman, McGwin and Sims

(2001) found that driving in poor light and bad weather is more difficult for elderly drivers. However, the risk of their being involved in a crash is actually higher in daylight hours, which may reflect the tendency among older drivers to avoid night driving. Drivers over 70 are also reported to present higher risk levels when driving in driveways and alleys, and when coming to intersections controlled by stop or yield signs (Stutts et al., 2009). Indeed, the relative risk of being involved in an intersection crash increases dramatically after the age of 75 (Lombardi, Horrey & Courtney, 2017; Yamani, Horrey, Liang & Fisher, 2016; Caird, Edwards, Creaser & Horrey, 2005; Clarke et al., 2010).

In this paper, we examine crash severity according to driver age with a particular focus on those over the age of 65 categorized by subgroups of drivers with similar characteristics. We seek to determine whether certain characteristics of the crash, vehicle and driver provoke a significant increase in the probability of the oldest cohort of drivers suffering a serious crash compared to that of younger cohorts. In addition, and taking into account the rising percentage of older drivers (reflecting the rising percentage of the elderly population and the absence of any upper age limit) who can expect to live longer (reflecting the higher life expectancy after 65), we investigate the need to segment the analysis for drivers over 65 by two age interval subgroups, as we seek to identify distinct patterns of behavior. Three subgroups of drivers are compared: under 65 years, between 65 and 75 years, and over 75 years.

In our analysis, we use data concerning crashes with victims that occurred in Spain in 2016. Each crash is classified in terms of a qualitative magnitude indicative of its severity. We use a three level-measure of crash severity in line with the Spanish Traffic Authority, defined according to whether victims' injuries were slight, serious, or fatal. This article examines the link between the age of drivers and the risk factors of the severity of the crashes in which they are involved. Generalized linear models (GLMs) are applied to estimate the probability of a crash being slight, serious or fatal given a set of statistically relevant factors for different age groups of drivers. We seek to identify different subgroups by age according to changes in the crash severity patterns.

Finally, the expected cost of a crash in terms of the bodily injury severity is estimated. Estimating the cost of a crash requires determining the number of people and vehicles involved in the crash, the severity of each person's injuries, and the costs of those injuries

(Ayuso, Guillen & Alcañiz, 2010; Blincoe, Miller, Zaloshnja & Lawrence, 2015). We use predicted crash severity probabilities to calculate expected crash costs. To do so, we assign an average economic cost to the severity level of each crash based on the average number of victims and the average cost per victim at that level of severity. Our approach allows us to establish a causal link between a driver's age and crash severity. In this way, we are able to assess the impact of longevity on final crash costs. We compare the results for the young-older and old-older subgroups, as well as those for under 65 aged drivers. Our results should prove useful for determining the factors associated with a higher probability of an older driver suffering a severe crash and its economic implications.

A number of previous studies segmented the analysis of road traffic crashes for different age groups of older drivers. For instance, Mitchell (2013) and Evans (2000) report that the crash involvement rate for older drivers does not begin to increase with age until after 75 or even 80. Rakotonirainy, Steinhardt, Delhomme, Darvell and Schramm (2012) examined crash patterns by dividing old drivers between three subgroups organized as follows: 60–69, 70–79, 80+. Likewise, Caird et al. (2005) and Braitman, Kirley, Ferguson & Chaudhary (2007) categorize older drivers by age as follows: young-old (65–73 years) and old-old (74+ years). However, there is clearly no single way to group individuals of older drivers by age, as much depends on the characteristics they share as individuals and the number of observations included in each study. In this article older drivers are segmented as young-older (65-75) and older-older (75+). Here, we apply generalized additive models (GAMs) to investigate pattern changes in the road crash severity likelihood at the driver's age around 75 years.

2. Methods and data

2.1 Composition of drivers and population in Spain by age intervals

Table 1 shows the evolution of the Spanish population by age interval over the last 10 years. It can be seen that ageing has increased in recent years – the elderly (>65) have gone from representing 16.5% of the population in 2007 to 18.9% in 2016. This trend is more than matched by the increase in the percentage of older drivers, rising from 10.2% in 2007 to 14.3% in 2016.

Here, an important indicator is the number of drivers with respect to the population by age group, showing just how many individuals in each interval hold a driving license. In the period 2007 to 2016, this indicator has risen from 45.6 to 58.2% for those aged 65 to 75 and from 22 to 28.6% for those aged >75. As such, we can identify two major trends: first, the percentage of older people in the total population is increasing; and second, the percentage of older people holding a driving license is also increasing. So, the percentage of elderly drivers in the drivers' population is increasing faster over the years than the percentage of elderly adults in the total population (Figure 1).

Table 1. Drivers, population and drivers with respect to population by age intervals, Spain 2007-2016 (%)

	Drivers				Population				Drivers with respect to population			
	< 65	≥65	65-75	>75	< 65	≥65	65-75	>75	< 65	≥65	65-75	>75
2007	89.76	10.24	6.96	3.28	83.53	16.47	8.33	8.14	71.03	33.92	45.62	21.96
2008	89.22	10.78	7.17	3.61	83.52	16.48	8.18	8.30	71.81	36.26	48.55	24.14
2009	88.82	11.18	7.32	3.86	83.34	16.66	8.18	8.49	71.95	37.22	49.67	25.21
2010	88.40	11.60	7.53	4.07	83.05	16.95	8.25	8.70	71.92	37.9	50.55	25.9
2011	87.89	12.11	7.77	4.35	82.77	17.23	8.32	8.91	72.58	39.31	52.23	27.27
2012	87.15	12.85	8.10	4.75	82.51	17.49	8.43	9.06	72.82	41.34	54.09	29.49
2013	86.40	13.60	8.56	5.04	82.09	17.91	8.71	9.20	73.17	43.02	55.71	31.01
2014	86.47	13.53	8.93	4.60	81.68	18.32	9.09	9.23	73.37	41.68	55.45	28.14
2015	86.07	13.93	9.22	4.71	81.40	18.60	9.29	9.30	73.74	42.53	56.31	28.77
2016	85.66	14.34	9.60	4.74	81.14	18.86	9.41	9.45	74.00	43.37	58.18	28.62

Source: DGT (2018) and INE (2018).

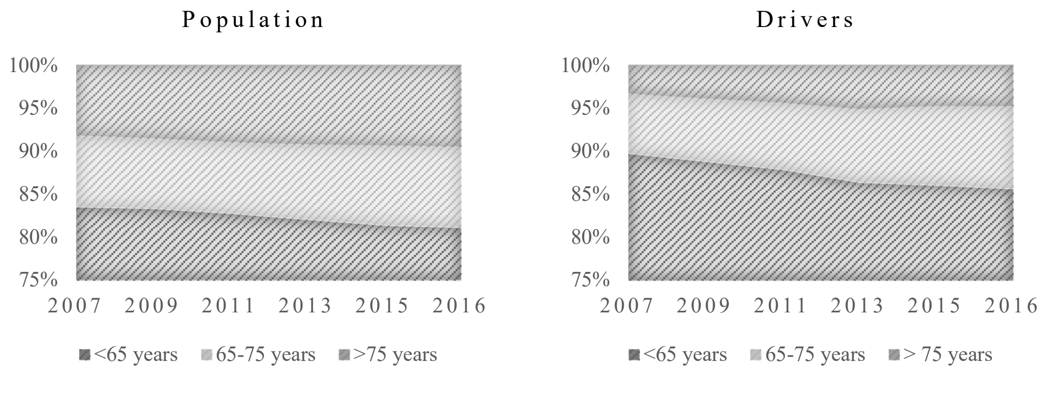


Figure 1. Percentage of population (left) and percentage of drivers (right) by age intervals in Spain (2007-2016)

2.2 Research design

Here, we draw on a dataset of motor crashes with victims in the Spanish territory. In our analysis, we use data concerning crashes with victims that occurred in Spain in 2016, as reported by the Dirección General de Tráfico (DGT), Spain's Traffic Authority. Note that in Spain the police have to file a report on all crashes with victims, which ensures an exhaustive source of individual information on such events. A total of 100,494 police-reported motor vehicle crashes with victims occurring between 1 January 2016 and 31 December 2016 are included in the dataset.[1] Our analysis focuses specifically on older drivers, defined as those over the age of 65. Here, we find that 88,286 crashes involved drivers below the age of 65 while in the remaining 12,208 crashes at least one driver was over the age of 65.

The dataset compiles information from three databases maintained by the DGT describing the characteristics of each crash, the vehicles involved, and the drivers. This information is recorded in the police report immediately following the crash. The evolution in the health of the victims is monitored by the traffic officers over the succeeding thirty-day period and the information in the police report updated accordingly. The crash database contains information about the type of crash, the type of road and the road surface conditions at the time of the crash, as well as prevailing meteorological and light conditions. The vehicle database contains information about the vehicle type and age, the number of occupants, and whether it had passed the mandatory periodical roadworthiness test and was covered by a compulsory insurance policy. Finally, the driver database contains information about driver age and sex, seat-belt and helmet use, and whether a traffic infraction was committed.

Here, we model the severity of the crash based primarily on the characteristics of the driver and the vehicle. When multiple vehicles were involved in a crash, we have various registers – one per vehicle – associated with the same crash in the dataset. To match the number of registers with the number of crashes, we randomly selected one register per crash. In this way, we end up with 68,435 registers recording information of 68,435

[1] There were, in fact, a total of 102,362 traffic crashes with victims in Spain in 2016, registered by the DGT, but we include only those for which full records exist.

different crashes, 59,622 crashes in which the drivers were below the age of 65 and 8,813 crashes in which the driver was over the age of 65.

We categorize the severity of the crash according to the severity of the injuries suffered by the victims. A non-serious injured victim is who suffers only minor injuries that does not require hospitalization. A victim is seriously injured if he requires hospitalization for more than 24h. A crash with victims is defined as slight if all victims with personal injuries suffered only minor injuries that did not require hospitalization. A crash with victims is defined as serious if at least one of the victims had to be hospitalized for at least 24 h but did not die. Finally, a crash with victims is defined as fatal if at least one person died within 30 days of the crash and as a consequence of that crash.[2] Based on these criteria, 89% of crashes were slight, 9% were serious and 2% were fatal. In case of crashes with at least one older driver, these figures were 86.6%, 10% and 3.4%, respectively.

The variables used in the analysis are shown in Table 2. Thus, for the drivers, we specifically consider their age and gender, the type of vehicle being driven at the time of the crash and the number of occupants in the vehicle. For the crash itself, we specifically consider the police report regarding responsibility for the crash – i.e. whether, according to the criteria of the police, the crash was the fault of the older driver. Additionally, we include variables that capture the type of road and light (visibility) conditions at the time of the crash, the type of crash, and whether the occupants of the vehicles were wearing safety protection devices (i.e. seat-belts or helmets, depending on vehicle type). Finally, we include three variables capturing the number of victims as evaluated thirty days after the crash, differentiating between victims suffering slight, serious or fatal injuries, as defined above.

Table 2. Description of variables

Name	Categories	Description
Driver and vehicle		
Age		Age of driver
Gender	Female	Driver is female (category of reference)
	Male	Driver is male
Vehicle	Car	Passenger car (category of reference)
	Van	Van or mini bus
	Bicycle	Bicycle

[2] This classification is often employed in the literature (see, for example, Johannsen & Müller, 2013) and is followed by the *Dirección General de Tráfico* in Spain.

	Motorcycle	Motorcycle, moped or quad
	Heavy vehicle	Truck, tractor or other heavy vehicle
Occupants		Number of occupants in the vehicle
Crash		
Responsibility	Responsible	Driver is responsible for the crash according to police criteria (category of reference)
	Not responsible	Driver is not responsible for the crash according to police criteria
	Unknown	Responsibility of driver is unknown according to police report
Light conditions	Visibility	Good visibility (category of reference)
	No visibility	Poor visibility
Road	High speed	Highway (category of reference)
	Normal speed	Freeway, main road
	Public way	Conventional road or street
	Other	Subsidiary road, local road, cycling lane and others
Type of crash	Head-on collision	Two vehicles involved in frontal crash (category of reference)
	Pile-up	Multi-vehicle collision
	Run over	Involving pedestrians and cyclists
	Collision	Crash into an obstacle, rollover and drop
	Other	Other types of crash
Protection	No use	Driver/passengers did not wear belt and/or helmet (category of reference)
	Use	Driver/passengers wore belt and/or helmet
Victims		
Non-serious		Number of non-serious victims involved in the crash
Serious		Number of serious victims involved in the crash
Fatalities		Number of fatalities involved in the crash

2.3 Selection of subgroups of older drivers

Older drivers were defined as those over the age of 65. We seek to identify different subgroups of older drivers by age. By so doing, we seek to define homogeneous age intervals for these drivers in order to perform separate regression analyses for each age group and, thus, to identify any differences in their characteristics. The age of the older drivers is plotted against the number of victims in the crash (Figure 2). Figure 2 shows the number of victims on average with slight, serious and fatal injuries involved in the crash by the age of the driver. Plot records a change in direction of the trend between the ages of 75 and 80. But while the total number of victims with slight injuries fall with age, the numbers of victims with serious and fatal injuries increase.

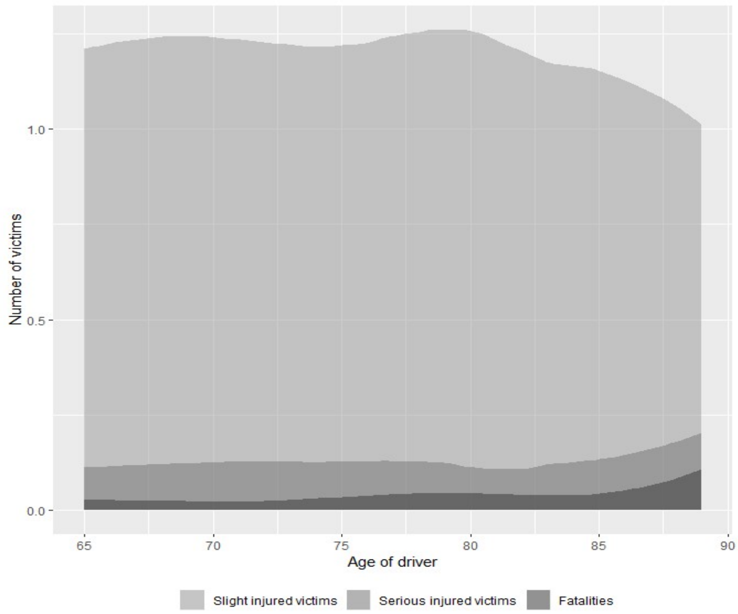


Figure 2. Average number of victims according to crash severity by age of older drivers

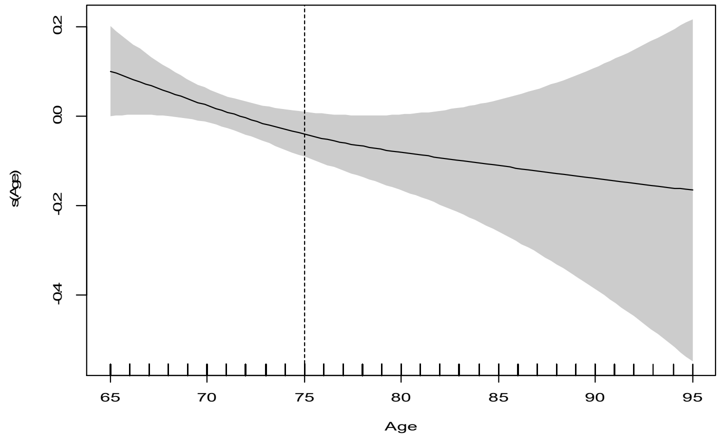
The univariate analysis reported in Figure 2 does not, however, consider potential association between the driver's age and other explanatory variables in the regression analysis, that is, the potential existence of dependence between regressors is omitted. To examine the relationship between the driver's age and the rest of the variables in Table 2, a GAM is fitted to the data. GAM regressions are similar to GLMs, the main difference being that with the former the functional form of the effect of the explanatory variable on the linear predictor is not previously fixed. This flexible modelling approach allows the linear predictor to be linearly explained by means of smooth functions of the explanatory variables and so it potentially provides a better fit than GLM models, albeit that the interpretation of results is hindered somewhat. However, GAM regressions are a powerful tool for understanding how an explanatory variable affects the linear predictor taking into account connections with the rest of the regressors (Hastie & Tibshirani, 1990).

We apply a GAM logistic model in which the dependent variable is the constructed categorical variable indicating crash severity. Let y_{li} be a binary random variable indicating *slight, serious,* and *fatal* crashes (*l*=0, 1, 2) for each crash i. The regressor *Age* indicates the age of the driver and vector x_i includes the remaining characteristics of crash i included in the analysis. The GAM logistic model takes the following form:

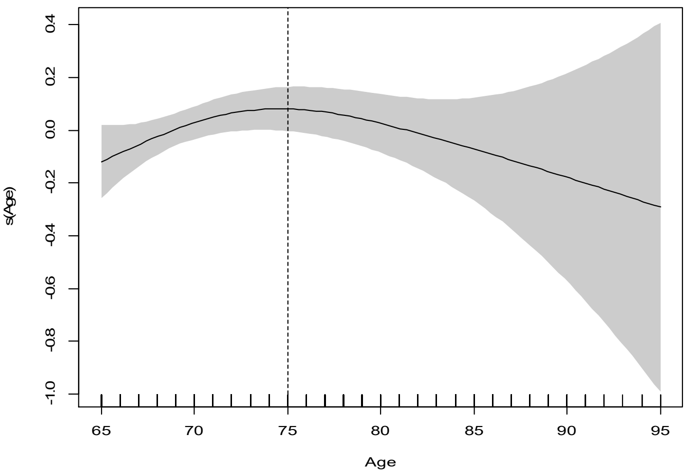
$$\log\left(\frac{P(y_{li}=1|x_i)}{1-P(y_{li}=1|x_i)}\right) = s_l(Age_i) + \beta_l' x_i, \quad l = 0, 1, 2;$$

where s_l is a non-parametric function and β_l is a vector of coefficients.

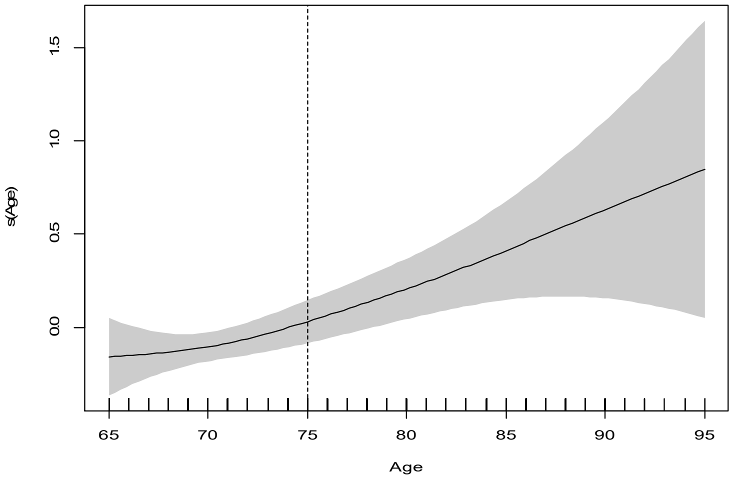
The estimated effect of the driver's age on the linear predictor is plotted in Figure 3. In the case of serious crashes, a visible change in the trend occurs at around the age of 75. In the case of slight and fatal crashes, a modest change is suggested at around the age of 75.



(a) Slight crash



(b) Serious crash



(c) Fatal crash

Figure 3. Estimated effect of driver's age in the GAM linear predictor by crash severity

Based on the outcomes reported in Figures 2 and 3, we divided the subsample of older drivers in two subgroups: drivers aged between 65 and 75 – *young-older* – and drivers aged over 75 – *old-older*. The former account for 66% of the observations (5,796 crashes); the latter for 34% (3,017 crashes). The Davies test (Davies, 2002) was computed to analyze a change in the slope in the linear predictor of logistic regression models at age of 75 years. The null hypothesis of constant regression parameter was rejected in serious crashes (p-*value*: 0.07) and fatal crashes (p-*value*: 0.01), while it was not rejected in slight crashes (p-*value*=0.89). More specific age intervals of older drivers were not attempted as the loss in reliability due to the reduction in sample size was not justified by the potential gains (as Figs. 2 and 3 indicate).

The group of drivers under 65 years was not divided in subgroups, although changes in patterns of slight and serious crashes were also appreciated around the age of 21 years (not shown). The reason of no dividing the group of drivers under 65 years in subgroups was twofold. The length of the age interval would be very short, from 18 years (legal driving age) to 21 years (observed change in pattern), and our focus for the age segmentation was on older drivers.

2.4 Estimation of a multinomial logistic regression model

We divide our dataset in subsamples according to the age of drivers involved in a crash. Three subgroups of drivers are considered: under 65 years, between 65 and 75 years, and over 75 years. By so doing, we seek to define homogeneous age intervals for these drivers in order to perform separate regression analyses for each age group and, thus, to identify any differences in their characteristics. We estimate multinomial logistic regression models (MLM) for the age intervals considering the exogenous information presented in Table 2. Crash severity is defined as a qualitative dependent variable with three categories. Thus, y_{lig} are binary random variables indicating *slight, serious,* and *fatal* injuries (*l*=0, 1, 2) in each crash *i* corresponding to each age group (g= ≤ 65, 65-75, >75). Vector x_{ig} indicates the characteristics of crash *i* based on the variables included in the analysis and for each age group and β_{lg} is a vector of coefficients. $P(y_{lig} = 1|x_{ig})$ can then be estimated from the MLM, conditional on the exogenous variables (Greene, 2018):

$$P(y_{lig} = 1|x_{ig}) = \frac{e^{\beta'_{lg}x_{ig}}}{1+\sum_{l=1}^{2} e^{\beta'_{lg}x_{ig}}}, \quad l = 1, 2; g = \leq 65, 65\text{-}75, >75$$

$$P(y_{0ig} = 1|x_{ig}) = \frac{1}{1+\sum_{l=1}^{2} e^{\beta'_{lg}x_{ig}}}, \quad g = \leq 65, 65\text{-}75, >75 \tag{1}$$

2.5 Expected economic costs of traffic crashes by age group

Finally, the estimated probabilities resulting from the MLM can be used to quantify the expected individual costs of a crash as follows:

$$E(c_{ig}) = \widehat{c_0}P(y_{0ig} = 1|x_{ig}) + \widehat{c_1}P(y_{1ig} = 1|x_{ig}) + \widehat{c_2}P(y_{2ig} = 1|x_{ig}) \tag{2}$$

where $\widehat{c_0}$, $\widehat{c_1}$ and $\widehat{c_2}$ are the estimated average costs per crash based on its severity (*slight, serious,* or *fatal*). To estimate the average costs of a crash with victims according to our three categories, we use the same criteria as used by the DGT (DGT, 2018, p. 210, Table 195). In its estimates, the DGT includes direct and indirect costs (medical aid and hospital resources, administrative costs, etc.) and the fair actuarial value society is prepared to pay to avoid the risk of fatal traffic crashes, known as the value of a statistical life.

3. Results

3.1 Descriptive statistics

Descriptive statistics of the variables differentiated by crash severity and age are shown in Table 3. Percentage values are shown for the categorical variables and means and standard deviations for the numerical variables. The highest percentage of fatal crashes is recorded among old-older drivers (4.4%) compared to young-older drivers (2.8%) and drivers below the age of 65 (1.8%). The percentage of severe crashes involving older drivers is similar for both groups (young-older and old-older) at 10%; however, this value falls to 8.6% when we only consider drivers below the age of 65.

Table 3. Descriptive statistics by crash severity and driver age group

		Under 65 years (N=59,622)			65-75 years (N=5,796)			Over 75 years (N=3,017)		
		Slight (N=53,448)	Serious (N=5,108)	Fatal (N=1,066)	Slight (N=5,056)	Serious (N=580)	Fatal (N=160)	Slight (N=2,581)	Serious (N=302)	Fatal (N=134)
Categorical variables (Relative frequency in %)										
Gender										
	Female	28.53	18.74	13.70	15.90	13.45	8.13	9.07	7.95	8.21
	Male	71.47	81.26	86.30	84.10	86.55	91.87	90.93	92.05	91.79
Vehicle										
	Car	59.67	47.98	53.19	76.62	64.31	66.88	82.8	72.51	76.12
	Van	5.95	5.05	6.66	6.13	5.86	9.37	6.82	4.64	5.97
	Bicycle	3.63	5.80	2.16	4.53	8.62	6.88	2.40	5.30	5.97
	Motorcycle	25.56	33.32	22.98	10.46	16.55	7.50	6.62	12.58	9.70
	Heavy vehicle	5.19	7.85	15.01	2.26	4.66	9.37	1.36	4.97	2.24
Responsibility										
	Responsible	43.01	53.07	55.44	46.44	52.93	57.50	55.33	59.93	59.70
	Not responsible	28.81	26.92	27.67	26.31	23.97	20.63	17.01	21.85	14.93
	Unknown	28.18	20.01	16.89	27.25	23.10	21.88	27.66	18.21	25.37
Light conditions										
	Visibility	87.74	82.54	71.01	91.42	90.34	86.25	91.28	90.07	87.31
	No visibility	12.26	17.46	28.99	8.58	9.66	13.75	8.72	9.93	12.69
Road										
	High speed	17.52	14.12	19.70	15.80	12.24	23.12	13.45	9.93	10.45
	Normal speed	26.92	43.03	54.69	35.31	49.31	57.50	42.31	57.29	67.16
	Public way	49.83	35.12	19.04	42.94	29.83	11.25	38.74	25.50	14.93
	Other	5.73	7.73	6.57	5.95	8.62	8.13	5.50	7.28	7.46

Type of crash										
	Head-on	53.83	39.47	33.21	64.1	61.55	45.00	62.41	54.64	59.7
	Pile-up	2.86	1.33	1.31	4.75	1.04	3.13	3.76	2.98	0.00
	Run over	9.88	17.15	20.54	9.57	12.76	11.25	11.39	15.89	11.94
	Collision	20.55	30.17	32.65	12.38	16.72	26.25	12.44	17.22	17.16
	Other	12.88	11.88	12.29	9.20	7.93	14.38	10.00	9.27	11.19
Protection										
	No use	4.57	8.22	15.38	3.22	6.21	15.00	3.99	9.6	17.91
	Use	95.43	91.78	84.62	96.78	93.79	85.00	96.01	90.4	82.09
		Numerical variables (Mean and standard deviation in brackets)								
Occupants		1.34 (0.97)	1.44 (2.56)	1.52 (1.76)	1.38 (0.84)	1.58 (4.61)	1.54 (0.90)	1.35 (0.65)	1.36 (0.62)	1.44 (0.65)
Victims										
	Slight	1.40 (0.85)	0.43 (0.98)	0.53 (2.02)	1.49 (1.00)	0.49 (1.30)	0.52 (1.34)	1.50 (0.90)	0.50 (0.89)	0.71 (1.29)
	Serious		1.11 (0.40)	0.32 (1.05)		1.17 (0.48)	0.52 (0.99)		1.14 (0.41)	0.25 (0.72)
	Fatal			1.10 (0.53)			1.06 (0.27)			1.14 (0.43)

A number of interesting patterns emerge from Table 3. In the case of driver gender, the lowest (highest) relative frequency is observed for slight crashes in all age intervals when the driver is male (female). As such, in relative terms, the frequency of serious and fatal crashes increases in male drivers. The severity of the crash also increases in percentage terms for all age groups when visibility was poor at the time of the crash and when safety protection systems were not being using by the vehicle's occupants. Serious and fatal crashes occur more frequently on roads designated as being of normal speed than on road types. When non-motorized road users are involved in a collision, serious and fatal crashes are more frequent in relative terms than slight crashes. In contrast, when other vehicles were involved in the collision, slight crashes are more frequent than serious or fatal crashes.

3.2 Multinomial logistic regression models

Table 4 shows the estimated coefficients for the MLMs of crash severity fitted for the three age intervals. The reference category is 'slight crash'. The first set of parameters corresponds to the numerator of the probability that a crash with victims will be serious, while the second set corresponds to the numerator of the probability that a crash with victims will be fatal. A positive significant parameter indicates that the presence of the variable increases the probability of a crash being serious – or fatal – with respect to its being slight. This means that the presence of the corresponding factor increases the expected severity of the crash outcome. Conversely, a negative significant parameter reduces the odds of a serious – fatal – crash and increases the odds of a slight crash, thus diminishing its severity.

When drivers aged over 65 are involved in a crash, the effect of gender on crash severity is not as explicit as it is in the case of drivers aged below 65. Among the latter, the likelihood of serious and fatal crashes increases when drivers are male. In the case of young-older male drivers, the likelihood of fatal crashes increases, but the coefficient associated with serious crashes is not significant at the 10% level. As for old-older drivers, gender has no explanatory capacity of crash severity.

If we consider the type of vehicle driven by young-older and old-older drivers, the likelihood of their being involved in a severe crash increases if they are riding a bicycle compared to driving a passenger car. In the case of fatal crashes, the coefficient associated with cyclists is not significant at the 10% level. Unlike the older subjects, the likelihood of fatal crashes decreases when cyclists are aged below 65. The likelihood of serious and fatal crashes falls in all age groups when responsibility for the crash remains undetermined by the police, but the coefficient is not significant for fatal crashes involving old-older drivers.

Table 4. Multinomial logistic regression models for the severity of crashes with victims

		Under 65 years		65-75 years		Over 75 years	
		Serious crash	Fatal crash	Serious crash	Fatal crash	Serious crash	Fatal crash
	Intercept	-2.4[a]	-3.11[a]	-1.84[a]	-2.14[a]	-1.91[a]	-1.41[b]
Gender	Female (Ref.)	-	-	-	-	-	-
	Male	0.37[a]	0.70[a]	0.04	0.63[b]	0.01	-0.02
Vehicle	Car (Ref.)	-	-	-	-	-	-
	Van	-0.05	0.08	0.01	0.35	-0.40	-0.33
	Bicycle	0.51[a]	-0.81[a]	0.78[a]	0.31	0.80[b]	0.36
	Moped	0.67[a]	0.36[a]	0.81[a]	-0.09	0.92[a]	0.66[b]
	Heavy vehicle	0.47[a]	0.79[a]	0.68[a]	0.75[b]	1.04[a]	-0.55
Occupants		0.05[a]	0.05[a]	0.07[c]	0.06	0.10	0.22[c]
Responsibility	Responsible (Ref.)	-	-	-	-	-	-
	Not responsible	-0.15[a]	-0.05	-0.27[b]	-0.31	0.15	-0.18
	Unknown	-0.52[a]	-0.63[a]	-0.34[a]	-0.38[c]	-0.50[a]	-0.20
Light conditions	Visibility (Ref.)	-	-	-	-	-	-
	No visibility	0.21[a]	0.52[a]	0.08	0.10	0.06	0.26

Road	High speed (Ref.)	-	-	-	-	-	-
	Normal speed	0.51[a]	0.42[a]	0.35[b]	-0.16	0.50[b]	0.54[c]
	Public way	-0.55[a]	-1.63[a]	-0.54[a]	-2.16[a]	-0.52[b]	-1.30[a]
	Other	0.38[a]	-0.14	0.35[c]	-0.55	0.38	0.07
Crash	Head-on collision (Ref.)	-	-	-	-	-	-
	Pile-up	-0.49[a]	-0.64[b]	-1.45[a]	-0.38	-0.16	-18.66[a]
	Run over	1.14[a]	1.75[a]	0.71[a]	1.35[a]	0.95[a]	0.90[a]
	Collision	0.27[a]	0.35[a]	-0.02	0.71[a]	0.17	-0.10
	Other	0.01	0.05	-0.32[c]	0.55[b]	-0.01	-0.17
Protection	No use (Ref.)	-	-	-	-	-	-
	Use	-0.63[a]	-1.63[a]	-0.5[b]	-1.68[a]	-0.73[a]	-2.02[a]

The chi-squared test for the significance of the model as a whole rejects the null hypothesis (p-value<0.01).
[a] p-value<0.01; [b] p-value<0.05; [c] p-value<0.10

Poor visibility at the time of the crash increases the likelihood of crash severity in the case of drivers below the age of 65. However, conditions of visibility have no explanatory capacity in the case of crashes involving older drivers. This may be attributable to the fact that older drivers drive more frequently in daylight hours. Compared to head-on collisions, in all age groups, the likelihood of slight crashes increases when the collision is multiple (pile-up) and decreases when pedestrians or cyclists are involved. Finally, the use of a seat-belt/helmet decreases the likelihood of serious and fatal crashes in all the age groups considered.

3.3 Expected economic costs of traffic crashes by age group

Older drivers are more vulnerable to suffering personal injuries in the event of a crash. Table 5 (column 4) records the average number of victims by the severity of the crash for drivers both below and above the age of 65 and then separately for the two subgroups of older drivers. The definitions of the severity of bodily injuries are the same as those used for crashes, but here are applied to the individuals involved. Thus, the crash is categorized as having been *slight* when the victims only suffer slight bodily injuries, as *serious* when at least one victim presents serious bodily injuries (though, note, the crash, may also involve victims with slight bodily injuries), and as *fatal* when at least one person dies as a result of the injuries received in the crash (though, again note, it may also involve victims with slight and/or serious injuries). The estimated average cost per victim corresponding to each level of severity (column 5) was obtained from the DGT (see section 2.5).

The average cost of a crash with victims corresponding to each level of crash severity (based on the cost per victim and the average number of victims, as shown in columns 4 and 5, respectively) is calculated in column 6. Finally, the weighted average cost of a crash by level of severity is shown in column 7, based on the average number of victims (column 3) and the estimated average cost of a crash (column 6). As can be seen, the weighted average cost of a crash involving no drivers over the age of 65 is €59,360; however, this cost rises 53.0% when at least one driver is aged over 65 (€90,823). If we distinguish these older drivers by age interval, the expected cost is notably higher for crashes with at least one old-older driver (€110,263), representing an outlay that is 85.8% higher than the cost of an crashes involving drivers below the age of 65, while for young-older drivers it is approximately 40% higher (€80,704).

Table 5. Average number of victims, average cost per victim and estimated average cost of a crash, by severity level and age group

Age Group (1)	Severity of the crash (2)	Nº (%) (3)	Average number of victims (4)	Average cost per victim* (5)	Estimated average cost of crash (6)	Weighted average cost of crash (7)
Under 65 years	Slight	53,448 (89.65)	1.4 Slightly injured	Slightly injured: €6,300	€8,797	€59,360
	Serious	5,108 (8.57)	1.11 Seriously injured 0.43 Slightly injured	Seriously injured: €226,190 Slightly injured: €6,300	€253,604	
	Fatal	1,066 (1.79)	1.10 Fatally injured 0.32 Seriously injured 0.53 Slightly injured	Fatally injured: €1,445,962 Seriously injured: €226,190 Slightly injured: €6,300	€1,663,763	
Above 65 years	Slight	7637 (86.66)	1.49 Slightly injured	Slightly injured: €6,300	€9,410	€90,823
	Serious	882 (10.01)	1.16 Seriously injured 0.50 Slightly injured	Seriously injured: €226,190 Slightly injured: €6,300	€265,222	
	Fatal	294 (3.34)	1.10 Fatally injured 0.40 Seriously injured 0.61 Slightly injured	Fatally injured: €1,445,962 Seriously injured: €226,190 Slightly injured: €6,300	€1,682,419	
65-75 years	Slight	5056 (87.23)	1.49 Slightly injured	Slightly injured: €6,300	€9,393	€80,704
	Serious	580 (10.01)	1.17 Seriously injured 0.49 Slightly injured	Seriously injured: €226,190 Slightly injured: €6,300	€267,515	
	Fatal	160 (2.76)	1.06 Fatally injured 0.52 Seriously injured 0.52 Slightly injured	Fatally injured: €1,445,962 Seriously injured: €226,190 Slightly injured: €6,300	€1,656,939	
Above 75 years	Slight	2581 (85.55)	1.5 Slightly injured	Slightly injured: €6,300	€9,444	€110,263
	Serious	302 (10.01)	1.14 Seriously injured 0.50 Slightly injured	Seriously injured: €226,190 Slightly injured: €6,300	€260,818	
	Fatal	134 (4.44)	1.14 Fatally injured 0.25 Seriously injured 0.71 Slightly injured	Fatally injured: €1,445,962 Seriously injured: €226,190 Slightly injured: €6,300	€1,712,844	

*According to the DGT (2018).

The probabilities resulting from the MLMs estimated in section 3.2 can now be used to quantify the individual expected cost of a crash in accordance with equation (2). By way of example, Table 6 shows the estimated expected cost for a crash defined according to the modal category for each independent variable, in each age interval. For the number of occupants, we use the mean. In each of the three intervals, the modal categories are head-on collisions in which the driver is male, driving a passenger car in conditions of good visibility on a conventional road or street (only in the case of old older drivers are crashes more frequent on a freeway or main road[3]) with his seat belt on and being considered at fault for the crash.

Table 6. Estimated expected cost for the crash defined according to the modal category for each regressor, by age group and severity level

	Below 65 years	65-75 years	Above 75 years
Gender	Male	Male	Male
Type of vehicle	Car	Car	Car
Occupants	1.44[a] 1.52[b]	1.58[a] 1.54[b]	1.36[a] 1.44[b]
Responsibility	Responsible	Responsible	Responsible
Light conditions	Visibility	Visibility	Visibility
Road	Public way	Public way	Normal speed way
Crash	Head-on collision	Head-on collision	Head-on collision
Protection	Use	Use	Use
Frequency	2,446 (4.10%)	422(7.28%)	278(9.21%)
Total	59,622	5,796	3,017
Estimated probability of slight crash according to the MLM	0.955	0.934	0.827
Estimated probability of serious crash according to the MLM	0.041	0.061	0.113
Estimated probability of fatal crash according to the MLM	0.004	0.005	0.060
Estimated average cost of slight crash (Table 5)	€8,797	€9,393	€9,444
Estimated average cost of serious crash (Table 5)	€253,604	€267,515	€260,818
Estimated average cost of fatal crash (Table 5)	€1,663,763	€1,656,939	€1,712,844
Estimated expected cost of crash according to equation (2)	€24,816.46	€33,144.06	€141,206.34

[a] Serious crash; [b] Fatal crash (category of reference: Slight crash)

[3] This probably reflects the fact that these drivers only use the vehicle when they have to, for example, to get to neighboring villages or when they have no ready easy access to public transport (Habib & Hui, 2017; Ichikawa, Nakahara & Takahashi, 2016; Haustein, 2011).

It can be seen that the expected cost for the most frequent crash, considering the probability that this crash will be slight, serious or fatal, increases significantly when the driver is over the age of 75 (old-older). In this case, we find that this cost is up to 5.7 times higher than that observed for drivers under the age of 65 and up to 4.3 times higher than that observed for crashes involving at least one young-older driver. The probability of one of the victims dying as a result of the crash increases among old-older drivers with a corresponding impact on the expected cost of the crash. Similarly, the probability of the crash being serious (with hospitalized victims) is greater in this last interval.

4. Discussion

Longevity is an increasingly observed phenomenon in developed economies, with people systematically surviving their life expectancy both at birth and at advanced ages (Oepen & Vaupel, 2002; Ayuso & Holzmann, 2014). Some countries have experienced a notable increase in life expectancy at the age of 65 (Spain recorded a 7% increase from 2007 to 2017). According to recent data published by the Spanish Statistical Institute (INE, 2018), at 65 men have an additional years of life expectancy of 19.12 years and women of 22.97 years. In conjunction with this increasing longevity, some countries are expecting the entry into these most advanced age ranges (65 upwards) of highly populated cohorts – the *baby boomers* born between 1950 and 1970 (Bavel & Reher, 2013). Spain is no exception here with the latest INE projections (2018) indicating that the total population aged 65 or more is set to increase from approximately 9 million today to 12.4 million in 2033 and 15 million in 2068. Moreover, good health life expectancy stands at about 10.4 years for Spanish men and women at the age of 65 (INE, 2018). These figures indicate that the elderly begin to show symptoms of physical and cognitive deterioration, and to need help from third parties, mainly after the age of 75 (Bolancé, Alemany & Guillen, 2013).

However, studies show that the ability to drive is affected by age (see Hwang & Hong, 2018; Classen, Wang, Crizzle, Winter & Lanford, 2013; Cicchino & McCartt, 2015; Stutts & Wilkins, 2003, among others). Against this demographic backdrop, it is clearly of some relevance to determine the effect longevity is likely to have on the traffic crash rate and the severity of these crashes, on the understanding that more and more people will be driving at an older age. To date, as in other countries, there is no upper age limit on driving in Spain. In fact, no specific requirements or restrictions are applied to Spanish elderly drivers, although older drivers are subject to more frequent physical-cognitive tests when renewing their license. A medical review involving a cognitive assessment test must be passed by all drivers to renew their driving license. The unrestricted driving license is valid for ten years for drivers up to the age of 65, and five years for those 65 and older. Although the driving license of elderly drivers has a shorter validity period, the reality is that we can expect a growing number of older drivers.

The social and economic impact of traffic crashes is extremely high, which means that traffic authorities (responsible for implementing road safety policies to reduce crash rates) must undertake accurate analyses of the sociodemographic characteristics of the drivers' census. Traffic crashes have an obvious impact on a country's health services and, if we consider the mandatory nature of car insurance, they also have a significant impact on the balance sheets of insurance companies. Our results raise questions as to whether specific driver licensing requirements and driving training should be stated for elder drivers. In New South Wales (Australia), for instance, drivers 75 or older need to have a medical review every year to keep the driving license. California (United States) requires drivers over 70 to be tested every four years and can impose restrictions those who do not meet the minimum licensing standards, such as limiting driving to daytime hours or avoiding freeways (Aizenberg & McKenzie, 1997; Brar & Rickard, 2013). Another example is the new driving license system under discussion in Japan will allow drivers 75 or older to drive only vehicles with advanced safety technologies (Ryall, 2019). Additionally, automobile insurance companies need to attach more importance to the ageing factor in their definition of risk groups for pricing and reserving. The increasing number of older drivers that can be expected in some countries over the next few decades (in combination, it would seem, with a smaller number of young drivers, given the reduction in birth rates observed in the last decade) makes the issue more pressing.

In this study, we have worked with a sizeable volume of information related to traffic crashes with victims that has included data about the crash itself, the vehicles and the number of victims, as well as the severity of bodily injuries suffered, classified into three levels. We have also estimated the cost per crash taking into account the estimated probabilities for each level of crash severity as obtained from a multinomial logistic model, which identifies the influence of the regressors on severity for drivers grouped in different age intervals. The age intervals were previously defined using a generalized additive model, a flexible modeling approach that allows the linear predictor to be linearly explained by means of smooth functions of the explanatory variables. Our objective here was to define homogeneous risk groups based on age.

Our results show that the impact of the factors associated with a crash varies across the age groups defined. A number of previous studies report that men are more likely to be involved in more severe crashes (Kim, Ulfarsson, Kim & Shankar, 2013; WHO, 2002). Here, in our analysis of age intervals over 65, only in the case of young-older drivers did crash severity increase for males, although there was no significant effect of gender on older drivers. A similar effect was observed with regard to driving visibility. This factor had no significant effect on drivers over the age of 65, probably because they tend to drive more frequently in daylight hours (Stutts et al., 2009). Older drivers were less likely to suffer a head-on collision, a rollover, or a collision with an object, but in the case of young-older drivers, crashes of this type usually increased the likelihood of the crash being fatal. For the rest of crashes, especially those involving pedestrians and cyclists, the probability of the crash being serious or fatal increases both for young-older and old-older drivers (analogous to the case of younger drivers), while the likelihood of being involved in multiple crashes decreases.

Of particular relevance for the severity of the crash is the type of vehicle involved, especially in those crashes in which older drivers – above all the old-older – ride a bicycle or motorcycle. The use of these vehicles (as well as that of heavy vehicles, such as tractors) in rural areas, more prevalent today in Spain because of ageing, helps justify the results obtained and points to the need to develop future lines of research. Indeed, the severity of crashes is found to decrease when these occur in urban areas regardless of the victims' age, although the value of the parameters (statistically significant at the 1% level in all cases) points to varying degrees of impact depending on age. Being at-fault for a crash increases the probability of that crash being serious for drivers under the age of 65 and for young-older drivers, but the factor is not significant in the case of old-older drivers. Finally, wearing a seat belt/helmet decreases the likelihood of serious and fatal crashes in all the age groups considered.

In terms of the research design employed in this study, the random selection of a single vehicle per crash has allowed us to assume independence between observations. However, dependence might exist as regards the severity of injuries suffered by victims travelling in the same vehicle. We have sought to avoid this dependence by modeling the overall severity of the crash rather than the severity of injury of each victim. We are aware, however, that by selecting a single vehicle per crash we lose information about dependency in multi-vehicle crashes. This is a limitation that we hope to overcome in future research.

It should be noted that older drivers are inherently more likely to be seriously injured in crashes due to their physical fragility (Regev et al., 2018; Noh & Yoon, 2017). We show that there is positive relationship between the age of older drivers and the severity of the crash. This does not mean that older drivers are necessarily more dangerous drivers than younger drivers since they themselves were seriously injured thus can increase crash severity. Our study does not distinguish what is the part of the higher risk of severe crash attributable to the skill decline and the part associated with the higher frailty of older drivers (and likely of their passengers). Even if there were no differences in driving skill across age, one would expect the group of older drivers to have a higher rate of serious/fatal crashes due to increased frailty alone. For instance, Regev et al. (2018) suggest that the higher fatality risk incurred of older drivers due to a crash is more attributable to excess fragility than to crash seriousness. Decline in skill affects other road users, whereas, a driver's frailty is primarily limited to the frail driver. Road safety measures to reduce crash severity involving elderly drivers will be different if they are addressed to act on skill decline or driver's frailty.

A further limitation of the present study is the fact that we calculate the expected costs of a crash using the average costs for each level of crash severity, obtained from the Spanish traffic authority. Clearly, it would be better to employ the individual costs of each crash as these would be affected by the age of the victims, as well as by other factors, including employment status and personal circumstances (with or without children, etc.[4]). Finally, the study has not examined possible interactions between regressors, preferring, in this

[4] Spanish Law 35/2015, of September 22, on Reform of the system for evaluating the damages and losses suffered by victims of road crashes.

instance, to focus on the direct effects of each of the factors. We took this decision in order to facilitate the analysis of results obtained from an examination of different levels of crash severity and different age groups.

5. Conclusions

Our results would appear to be of some relevance in identifying a link between the severity of traffic crashes and driver age. Increases in life expectancy at age 65 and older, and the absence of any upper age limit on driving, mean drivers are likely to spend more years behind the wheel. It seems clear, therefore, that traffic authorities need to focus more carefully on older drivers and learn more about their driving habits. The starting point for examining the impact ageing is likely to have on road safety should be the increasingly available sources of data on older drivers. The results we report here in terms of expected costs, crash severities and their social consequences more than justify this assertion.

6. Practical applications

In fact, we would contend that our findings should be made known in debates regarding the need to reduce the number of accidents involving elderly drivers, an issue that has perhaps not attracted much attention to date because of the relatively small numbers of elderly drivers. Additionally, our results should be of use for the insurance industry in terms of segmenting drivers over the age of 65 into subgroups, in the same way as has been the custom for young people and adults. Clearly, pricing and reserving should be adapted to the industry's portfolios, the composition of which are changing with regard to their age profiles.

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