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RESEARCH ARTICLE

A Comparison of Ordered and Unordered Response Models for Analyzing Road Traffic Injury Severities in the North-Eastern Turkey

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Abstract

Road traffic injuries are estimated to be one of the major causes of death worldwide and a majority of them occur in low- and middle income countries. In that respect, further studies that address to determine risk factors that may influence road traffic injury severities in the corresponding countries may contribute the existing road safety literature. This paper determines possible risk factors influencing road traffic injury severity in north-eastern Turkey. For this purpose, a retrospective cross-sectional study is conducted analysing 11,771 traffic accidents reported by the police during the sample period of 2008-2013. As the accident severity is inherently ordered, the data are analysed using both ordered and unordered response models. The estimation results reveal that several driver (age and education level), accident (speeding violation, avoiding manoeuvre and right-of-way rule), vehicle (bus/minivan, single-unit truck/heavy truck, private and single vehicles), temporal (time of day, morning peak, evening peak), environmental (summer and cloudy or rainy weather), geometry (asphalt road and road class type), and control characteristics (presence of crosswalk and traffic lights) were found to have an impact on injury severity. This paper is most probably the first attempt to analyse possible risk factors of road traffic injury severities in Turkey using both ordered and unordered response models. The evidence of this study may be valuable for future road safety policies in emerging countries.

Keywords

injury, severity, ordered logit, partial proportional logit, heterogeneous choice model, multinomial logit, mixed logit

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1 Introduction

Road traffic injuries are predicted to become the ninth leading cause of death by 2030 and result in the deaths of 1.9 million people annually by 2020 (WHO, 2013b; 2014). According to the latest road safety report, ninety percent of road traffic deaths occur in low- and middle-income countries (WHO, 2015) that may be reflected by the rapid rate of motorization in many emerging countries without a significant improvement on road safety strategies and planning (WHO, 2013a). As an emerging country, Turkey also suffers from adverse effects of road traffic accidents. Between 2008 and 2013, almost seven millions of road traffic accidents occurred in Turkey, causing the deaths of nearly twenty-four thousands of people. In 2014, more than 3,500 people were killed and almost 285,000 people were injured due to road traffic accidents in the country (Turkish National Police, 2015). As of August 31, 2015, there were more than nineteen millions registered motor vehicles in Turkish roads (Turkish Statistical Institute, 2015), which may dramatically confirm the rapid motorization phenomenon for this emerging country.

Whilst road traffic injuries cause considerable economic and intangible losses to several parties including victims, their families and nations, it seems that they have been neglected from the global health agenda for many years. Fortunately, evidence from eighty-eight countries suggests that the number of road traffic accidents have dramatically decreased since 2007 implying that road traffic accidents can be prevented (WHO, 2013a). In this respect, road traffic accident data are adopted as one of the most important sources to determine contributing factors of road traffic injury prevention (Qin et al., 2013). Since many distinctive factors may contribute to road traffic injury severity, relative effects of these factors should be extensively examined to prevent or reduce injury severity levels (Eluru and Bhat, 2007). When remarkably higher mortality rates in middle-income countries are considered, further attempts to determine risk factors influencing injury severity in such countries may give valuable information on future road safety strategies. However, only a few previous studies (Celik and Oktay, 2014; Çelik and Senger, 2014; Karacasu et al., 2014; Kartal et al., 2011; Uçar and Tatlıdil, 2007) have addressed risk factors that may contribute to road traffic injury severity in Turkey.

This paper aims to determine potential risk factors that may contribute to road traffic injury severity in north-eastern Turkey between 2008 and 2013. Although earlier studies conducted to the Turkish sample perform different discrete choice models including a binary logistic or probit regression (Çelik and Senger, 2014; Karacasu et al., 2014; Kartal et al., 2011; Uçar and Tatlıdil, 2005), an ordered probit model (Uçar and Tatlıdil, 2007), and a multinomial logit model (Celik and Oktay, 2014), most probably no studies have accomplished to compare both ordered and unordered response models simultaneously in Turkey. Indeed, further studies that provide such a comparison are needed and valuable since alternative ordered and unordered disaggregate model experiences are also limited worldwide except for some recent research (Abay, 2013; Qin et al., 2013; Sasidharan and Menendez, 2014). Therefore, the major contribution of the current paper to the existing road safety literature is to provide a comparison of ordered and unordered response models and to determine the most parsimonious model in terms of avoiding underreporting issue and better understanding the heterogeneity of a variety of road safety characteristics. The remainder of the paper is as the following. Section 2 reviews earlier studies that address potential risk factors affecting road traffic injury severities. Section 3 introduces the data. Section 4 and Section 5 describe the data and estimation results with a discussion of the most noteworthy outcome in the light of previous research. The paper concludes with remarkable implications and recommendations for further research and road safety policies.

2 Earlier Studies

Prior experience from road safety research suggests that many characteristics may have an impact on road traffic injury severity levels. Particularly, driver characteristics have been extensively considered as an important risk factor influencing road traffic accident injury severity, while the association between drivers' or other vulnerable users' age group and injury severity was highly addressed. Other most recent studies (Chu, 2015; Curry et al., 2014; Lee and Li, 2014; Ma et al., 2015; Martensen and Dupont, 2013; Weiss et al., 2014) highlighted the association between younger drivers and an injury severity increase. Haleem and Gan (2015) found that younger and mid-age drivers were less likely to be involved in more severe injuries. A very recent study (Donmez and Liu, 2015) found that younger drivers were more likely to be involved in more severe injuries when talking to the mobile phone during driving. Nevertheless, other studies (Celik and Oktay, 2014; Kim et al., 2013; Morgan and Mannering, 2011; Yasmin et al., 2014) indicated that older drivers were at higher risk of involving a more severe injury. Driver's gender was previously underlined as a significant risk factor affecting road traffic injury severity levels. Male drivers (Behnood and Mannering, 2015; Chen et al., 2015; Kim et al., 2013; Martínez-Ruiz et al., 2014) were found to be more likely involved in road traffic accidents with a more severe injury than their female counterparts, whereas some other work (Haleem and Gan, 2015; Morgan and Mannering, 2011) showed that female drivers were at higher risk of involvement in a more severe injury. Driver's education level may be an indicator of injury severity levels. Particularly, primary educated drivers (Celik and Oktay, 2014) were found to increase fatal or severe injury, while other work (Uçar and Tatlıdil, 2007) showed the association between higher educated drivers and less severe injuries.

Accident characteristics and driver's several violations were found to be potential risk factors affecting injury severity levels. Many earlier research (Chu, 2015; Chung et al., 2014; Haleem et al., 2015; Hao and Daniel, 2014; Kim et al., 2008; Kröyer, 2015; Ma et al., 2015; Mitchell et al., 2015; Sasidharan et al., 2015) exhibited driver's violation of speed limits were extensively associated with increasing more severe injuries. The results of another earlier research (Hao et al., 2015) revealed that speed control might have a significant impact on decreasing more severe injuries. A previous research (Celik and Oktay, 2014) showed that driver's speeding violation increases the occurrence of less severe injuries. Many previous work (Kim et al., 2008; Ma et al., 2015; Uçar and Tatlıdil, 2007; Yasmin et al., 2014; Yulong and Chuanyun, 2014) found that collision type was significantly effective on injury severities. On the other hand, distracted driving (Behnood et al., 2014; Chu, 2015; Donmez and Liu, 2015) and falling asleep (Abegaz et al., 2014) were addressed as contributing risk factors for an increase on minor or severe injuries.

Many research in the road safety literature considered a variety of vehicle characteristics as a contributing factor. Particularly, number of vehicles involved in the accident were found to be a significant risk factor of injury severities. Earlier studies (Celik and Oktay, 2014; Chen et al., 2015; Khorashadi et al., 2005; Wu et al., 2014) found that road traffic accidents involving single vehicle dramatically increase the probability of fatal injuries. A previous study in the Turkish sample (Uçar and Tatlıdil, 2007) found that two-vehicle involved accidents caused less severe injuries. Vehicle type and purpose of use were considered other vehicle characteristics in the existing literature. Commercial vehicles are found to have an increasing impact on less severe injuries, whereas the probability of occurring a more severe injury decreases with passenger cars (Behnood and Mannering, 2015; Celik and Oktay, 2014). At the same time, the increasing effect of motorcycles (Chiou et al., 2013; Shaheed et al., 2013; Yau et al., 2006) and buses or cars (Chiou et al., 2013; Martensen and Dupont, 2013; Yau et al., 2006) on more severe injuries were also addressed. Similarly, past research (Celik and Oktay, 2014) reported that private vehicle- and car-involved accidents were found to cause less severe injuries. Recent research (Abegaz et al., 2014) highlighted that minibus or van involved accidents were found to be more severe injuries. The estimation results of other past studies (Haleem et al., 2015; Sasidharan et al., 2015; Wu et al., 2014) put forward accidents involving heavy vehicles were more likely to increase the level of injury severity.

The significant roles of temporal and environmental characteristics were highly considered in the road safety literature. In fact, time of day, seasonal and thereby adverse weather conditions, the absence of lighting and road surface at the scene of the accident are very crucial risk factors for better understanding the causes of the injury severity levels. Such factors may especially be considered as important since consequent inclement conditions including decreasing driver's visibility, distraction, insufficient road infrastructure and possible traffic congestion are carefully examined. Evidence from earlier research (Celik and Oktay, 2014; Kim et al., 2008) revealed that road traffic accidents occurred during the evening peak were more likely to result in less severe injuries, while other studies (Abegaz et al., 2014; Chung et al., 2014; Uçar and Tatlıdil, 2007) showed the impact of driving at night on injury severities. Other past research (Chu, 2015; Khorashadi et al., 2005; Yau, 2004; Yau et al., 2006) also studied the impact of various time periods on injury severity levels. On the other hand, some earlier studies indicated that accidents occurred on either weekdays (Carson and Mannering, 2001; Rifaat et al., 2011) or weekends (Martensen and Dupont, 2013; Yau, 2004; Zhang et al., 2013) might significantly affect injury severity levels. In relation to temporal effects, riding season may also be effective on injury severities. Specifically, accidents occurred in summer months (Celik and Oktay, 2014; Shaheed et al., 2013) were found to result in less severe injuries. Moreover, adverse weather conditions (Abegaz et al., 2014; Haleem et al., 2015; Kim et al., 2008; Ma et al., 2015; Uçar and Tatlıdil, 2007; Yulong and Chuanyun, 2014) were referred to increasing injury severities, whereas the results of a recent study (Celik and Oktay, 2014) showed that clear weather led to less severe injuries. The absence of natural and street lighting at the scene of the accident may also have an impact on injury severity levels. Indeed, dark lighting condition (Clarke et al., 2006; Haleem et al., 2015; Wu et al., 2014) and absence of street light (Abegaz et al., 2014; Kim et al., 2008) were associated with injury severity levels. A number of studies (Carson and Mannering, 2001; Chu, 2015; Morgan and Mannering, 2011) found that that wet or snow/ice road surface were the increasing or decreasing causes of injury severities.

Geometry characteristics have also been emerged as a significant driver of injury severity levels. For instance, road grade (Chen et al., 2015) was highly associated with an increase on fatal injuries, while asphalt roads (Ma et al., 2015) were found as another contributing risk factor of injury severity. Moreover, traffic accidents occurred on national roads (Sasidharan et al., 2015) were found to increase the probability of more severe injuries. On the other hand, a most recent study (Behnood and Mannering, 2015) found that road construction is associated with the increase of less severe injuries. Accidents occurred in interstates (Behnood et al., 2014) were found to decrease the probability of level of injury severity. Other studies (Uçar and Tatlıdil, 2005; Yulong and Chuanyun, 2014) also highlighted the impact of road class type on injury severity. Khorashadi et al. (2005) found that accidents occurred in both rural and urban settlement were associated with a remarkable increase on injury severity level.

Control characteristics take their respectable place on decreasing more severe injury severities. Prior studies (Haleem et al., 2015; Kim et al., 2008) emphasized the availability of pedestrian walk on decreasing more severe injuries, whereas other work (Celik and Oktay, 2014) put forward that the availability of pedestrian walk might not have been preventive to decrease more severe injuries. The presence of other traffic control devices such as warning bells (Haleem and Gan, 2015) or traffic signs or lights (Celik and Oktay, 2014; Kim et al., 2008; Yulong and Chuanyun, 2014) were also found to have a decreasing effect on injury severity levels.

3 Empirical Setting

The main objective of this paper is to analyse possible risk factors affecting the severity levels of injuries resulting from traffic accidents with a comparison of both ordered and unordered response models including ordered logit (OLOGIT), generalised ordered logit (GOLOGIT), partial constrained generalised ordered logit (PCGOLOGIT), and heterogeneous choice model (HCM). See Williams (2006; 2010) and Long and Freese (2001) for a detailed conceptual framework for all these models. The data used in the present study involve road traffic accident reports which occurred in the Erzurum and Kars Provinces, the north-eastern Turkey during the sample period of 2008-2013. Each report gives information on the characteristics of the specific road traffic accident in many aspects including time and location, type of accident, current weather conditions, environmental and road characteristics at the scene of the accident, drivers and vehicles involved in the accident and other demographic, vehicle characteristics associated with the accident. Both Erzurum and Kars Provinces are located in the north-eastern Turkey with 1,652 and 741 km of network lengths, respectively (Republic of Turkey General Directorate of Highways, 2015a; Republic of Turkey General Directorate of Highways, 2015b). Between 2008 and 2013, 47,387 traffic accidents occurred in the Erzurum and Kars Provinces (Celik and Oktay, 2014; Turkish National Police, 2015; Turkish Statistical Institute, 2013) and 11,771 usable road traffic accidents were analysed in this study. Exogenous, random sampling with a uniform distribution is chosen for model-specific sub-samples to avoid biased samples (Celik and Oktay, 2014; Ulfarsson and Mannering, 2004). The injury severity level is classified into three categories (no injury, possible or evident injury and fatality), while only drivers' injuries are considered due to the nature of the data. Turkish Statistical Institute (2013) defines an accident as fatal when an injured driver dies at the scene of the traffic accident. The results of an earlier work (Yamamoto et al., 2008) reveal that fatal traffic accidents have the highest reporting rate among others, while a most recent study (Ye and Lord, 2014) recommends to use the fatal injuries as the base category to avoid underreporting issue. This study also prefers the fatal injuries as the base category in line with these recommendations.

As traffic injury severity levels have an inherently-ordered nature (Qin et al., 2013), the use of one of the alternative ordered response models may be considered as the most reasonable approach (Islam and Mannering, 2006). Indeed, many previous studies (Hao and Kamga, 2015; Jiang et al., 2013; Lee and Li, 2014; Quddus et al., 2010; Uçar and Tatlıdil, 2007; Yamamoto et al., 2008; Yamamoto and Shankar, 2004) successfully performed several alternative ordered response models to analyse risk factors that may contribute to road traffic injury severity. Nevertheless, in many cases, unordered alternative response models (Celik and Oktay, 2014; Haleem and Gan, 2013; Khorashadi et al., 2005; Kim et al., 2013; Manner and Wünsch-Ziegler, 2013; Moore et al., 2011; Shaheed et al., 2013; Wu et al., 2014) have been also extensively used for analysing traffic injury severities as the ordered models may be insufficient to have the flexibility on the control the category probabilities (Washington et al., 2010) and unordered response models provide a more flexible functional approach (Malyshkina and Mannering, 2008). This paper performs both ordered and unordered response models to determine risk factors that may influence road traffic injury severity levels in Turkey. Table 1 summarizes descriptive statistics of possible risk factors that may contribute to the injury severity levels in traffic accidents.

4 Results

Following past research (Celik and Oktay, 2014; Long and Freese, 2006; Quddus et al., 2010; Yau, 2004; Yau et al., 2006), a chi-square test of independence[1] was initially performed to check the basic relationship between injury severities and selected independent variables. According to the underlying test, driver's gender and day of the week variables are not included in the final ordered and unordered models being fitted. Other risk factors are strongly associated with the road accident injury severity. All fitted models were found as statistically significant. Following an earlier table design (Quddus et al., 2010), Table 2 presents the estimated coefficients and other statistics for fitted OLOGIT, GOLOGIT, PPO and HCM models. As the OLOGIT model violates the parallel lines assumption (χ^2 = 135.94, p < .01) proposed by Brant (1990), alternative ordered response models were estimated where all these models do not violate this assumption. The estimation results of OLOGIT model were only presented for a comparison with other three models. All alternative ordered response models were fitted by two user-written programs in Stata (Williams, 2006; 2010).

A test by Small and Hsiao (1985) provides to check whether the MNL model violates the IIA assumption or not[2]. Results indicated the fitted MNL model does not violate the IIA assumption at the relevant confidence levels ($\chi^2 = -154.677$ and $\chi^2 = 147.062$ for non-injury and injury severity levels, respectively). Hausman and McFadden (1984) suggest that the chi-square test statistic may occasionally be negative due to lack of positive semi-definiteness in finite sample applications.

The estimation of the MXL model was performed using a maximum simulated likelihood approach. The MXL model was estimated using 200 and 500 Halton draws (Anastasopoulos and Mannering, 2011; Bhat, 2003; Gkritza and Mannering, 2008; Haan and Uhlendorff, 2006; Shaheed et al., 2013; Train, 2000) as recommended by the existing literature. Since the estimation results of both MXL models are very similar, only the results of the MXL model with 500 draws are presented in Table 3. This implies that both MXL models are sensitive and efficient enough. Random parameters in both MXL models confirm that both models are able to explain unobserved heterogeneity of risk factors that may influence road traffic accident injury severity. In line with some previous research (Haleem and Gan, 2013; Manner and Wünsch-Ziegler, 2013; Milton et al., 2008; Moore et al., 2011; Train, 2009), it is considered that the random coefficients are normally distributed and all parameters are randomized initially for the MXL model. When their standard deviations are statistically significant, they are evaluated as random parameters in a stepwise fashion. All discrete choice models were fitted using the Stata 13. Specifically, the MXL model was fitted by a user-written program in Stata (Hole, 2007).

Table 3 presents both the MNL and MXL estimation results. In addition, no serious multicollinearity problem was found used in the fitted models. According to the chi-square test, several variables such as driver's gender and day of the week were omitted from the models since they are irrelevant to the dependent variable. After all specification tests proposed by Washington et al. (2010), all fitted ordered and unordered response models were found to be statistically sound. HCM and MXL models were the best fitted models among others for ordered and unordered response models, respectively with respect to AIC and McFadden rho-square values. Therefore, the interpretation of the results were mostly performed using the average pseudo-elasticity values[3] in Table 4.

1 For brevity, the results of this test is not presented in the text.

2 For brevity, the results of this test is not presented in the text.

3 The average direct pseudo-elasticity results are not presented in Table 4, because the relevant user-written Stata module does not give pseudo-elasticity values.

Table 1 Descriptive statistics of independent variables[4]

Variables	Fatality	Injury	No injury	Total
Driver characteristics				
Driver's age				
<25	5 (0.3%)	543 (36.5%)	941 (63.2%)	1489 (12.7%)
25–64[a]	71 (0.8%)	2790 (29.3%)	6658 (69.9%)	9519 (80.9%)
>65	5 (0.7%)	561 (73.5%)	197 (25.8%)	763 (6.4%)
Driver's gender				
Male[a]	80 (0.7%)	3759 (33.1%)	7503 (66.2%)	11342 (96.4%)
Female	1 (0.2%)	135 (31.5%)	293 (68.3%)	429 (3.6%)
Driver's education level				
Primary education	40 (1.1%)	1370 (36.2%)	2376 (62.8%)	3786 (32.2%)
Secondary education	31 (0.6%)	1708 (31.0%)	3769 (68.4%)	5508 (46.8%)
Higher education[a]	10 (0.4%)	816 (32.9%)	1651 (66.7%)	2477 (21.0%)
Accident characteristics				
Speeding violation	37 (0.8%)	1920 (39.5%)	2909 (59.7%)	4866 (41.3%)
Avoidance manoeuvre	13 (0.6%)	371 (16.2%)	1911 (83.2%)	2295 (19.5%)
Rear-end collision	5 (0.4%)	233 (20.8%)	884 (78.8%)	1122 (9.5%)
Violating right-of-way rule	8 (0.6%)	684 (47.4%)	750 (52.0%)	1442 (12.3%)
Other violations[a]	18 (0.9%)	686 (33.5%)	1342 (65.6%)	2046 (17.4%)
Vehicle characteristics				
Vehicle type				
Car[a]	25 (0.4%)	2323 (34.2%)	4442 (65.4%)	6790 (57.7%)
Bus/minivan	11 (1.4%)	251 (31.6%)	531 (67.0%)	793 (6.7%)
Single-unit truck/heavy truck	35 (0.9%)	1132 (30.4%)	2554 (68.6%)	3721 (31.6%)
Other type of vehicles	10 (2.1%)	188 (40.3%)	269 (57.6%)	467 (4.0%)
Number of vehicles involved				
Single vehicle	55 (1.1%)	2037 (39.0%)	3129 (59.9%)	5221 (44.3%)
Multi vehicle[a]	26 (0.4%)	1857 (28.4%)	4667 (71.2%)	6550 (55.7%)
Purpose of use				
Private vehicle	31 (0.3%)	2956 (31.2%)	6486 (68.5%)	9473 (80.5%)
Commercial vehicle[a]	50 (2.2%)	938 (40.8%)	1310 (57.0%)	2298 (19.5%)
Temporal characteristics				
Time of day				
Morning peak	11 (1.4%)	291 (38.0%)	465 (60.6%)	767 (6.5%)
Mid-day	12 (1.5%)	305 (37.5%)	495 (61.0%)	812 (6.9%)
Evening peak	25 (0.4%)	1772 (31.0%)	3923 (68.6%)	5720 (48.6%)
Evening	9 (0.6%)	508 (32.3%)	1054 (67.1%)	1571 (13.4%)
Night[a]	24 (0.8%)	1018 (35.1%)	1859 (64.1%)	2901 (24.6%)
Day of the week				
Weekday[a]	57 (0.7%)	2812 (52.6%)	5753 (66.7%)	8622 (73.2%)
Weekend	24 (0.8%)	1082 (34.4%)	2043 (64.8%)	3149 (26.8%)
Environmental characteristics				
Season				
Winter	15 (0.4%)	741 (21.9%)	2631 (77.7%)	3387 (28.8%)
Spring	16 (0.6%)	852 (29.7%)	1997 (69.7%)	2865 (24.3%)
Summer	32 (1.1%)	1130 (39.1%)	1727 (59.8%)	2889 (24.5%)
Autumn[a]	18 (0.7%)	1171 (44.5%)	1441 (54.8%)	2630 (22.4%)
Weather condition				
Clear[a]	52 (0.7%)	2805 (34.8%)	5191 (64.5%)	8048 (68.4%)
Cloudy/rainy	21 (0.8%)	833 (33.2%)	1657 (66.0%)	2511 (21.3%)
Snowy/stormy/foggy	8 (0.7%)	256 (21.1%)	948 (78.2%)	1212 (10.3%)
Natural lighting				
Daylight	48 (0.6%)	2611 (33.2%)	5216 (66.2%)	7875 (66.9%)
Dawn/dark[a]	33 (0.9%)	1283 (32.9%)	2580 (66.2%)	3896 (33.1%)
Road surface				
Dry/dusty	59 (0.8%)	2796 (37.3%)	4648 (61.9%)	7503 (63.8%)
Wet/muddy/oil on the pavement	13 (0.6%)	725 (34.1%)	1386 (65.3%)	2124 (18.0%)
Snowed/iced[a]	9 (0.4%)	373 (17.4%)	1762 (82.2%)	2144 (18.2%)
Geographic characteristics				
Asphalt road				
Yes	80 (0.7%)	3679 (33.0%)	7376 (66.2%)	11135 (94.6%)
No[a]	1 (0.2%)	215 (33.8%)	420 (66.0%)	636 (5.4%)
Road class type				
Local city street	8 (0.1%)	2347 (34.1%)	4524 (65.8%)	6879 (58.4%)
State route/highway/provincial road	69 (1.8%)	1322 (33.9%)	2514 (64.3%)	3905 (33.2%)
Public vehicular area/private property[a]	4 (0.4%)	225 (22.8%)	758 (76.8%)	987 (8.4%)
Control characteristics				
Pedestrian crosswalk				
Present	54 (0.7%)	2656 (34.7%)	4947 (64.6%)	7657 (65.0%)
Not present[a]	27 (0.7%)	1238 (30.1%)	2849 (69.2%)	4114 (35.0%)
Traffic lights				
Present	6 (0.2%)	1039 (34.5%)	1971 (65.3%)	3016 (25.6%)
Not present[a]	75 (0.9%)	2855 (32.6%)	5825 (66.5%)	8755 (74.4%)
Other traffic control device				
Present	70 (1.3%)	2088 (38.2%)	3305 (60.5%)	5463 (46.4%)
Not present[a]	11 (0.2%)	1806 (28.6%)	4491 (71.2%)	6308 (53.6%)

[a] indicates reference category

4 Adapted from Çelik and Oktay (2014). However, the referent categories differ from the corresponding study.

Table 2 Estimation results for OGOLOGIT, GOLOGIT, PPL and HCM models

Road traffic accident injury severity		OLOGIT	GOLOGIT		PPO			HCM
		Coefficient	Threshold 1 and 2	Threshold 2 and 3	Coefficient not varying	Threshold 1 and 2	Threshold 2 and 3	Coefficient
Factors affecting the ordinal categorical choice	Driver characteristics							
	Driver's age							
	<25	0.3967*	0.4066*	–0.0565	0.4018*	—	—	0.3595*
	>65	2.2163*	2.3281*	–1.5475**	2.3055*	—	—	1.8410*
	Driver's education level							
	Primary education	0.3268*	0.3168*	0.5352	0.3238*	—	—	0.2643*
	Secondary education	–0.2152*	–0.2162*	–0.5555	–0.2210*	—	—	–0.2014*
	Accident characteristics							
	Speed violation	0.2515*	0.2667*	–0.4328	—	0.2673*	–0.5452**	0.2673*
	Avoiding manoeuvre	–0.8002*	–0.7993*	–0.1291	–0.7928*	—	—	–0.7930*
	Rear-end collision	–0.2563*	–0.2511*	–0.0909	–0.2491**	—	—	–0.2401*
	Violating right-of-way rule	0.9273*	0.9560*	0.2960	—	0.9595*	0.0018	0.7817*
	Vehicle characteristics							
	Vehicle type							
	Bus/minivan	–0.1287	–0.1428	1.0860*	—	–0.1506	1.1287*	–0.2824**
	Single unit truck/heavy truck	–0.1815*	–0.1942*	0.6172**	—	–0.1972*	0.7363*	–0.2275*
	Other type of vehicles	–0.0162	–0.0433	0.6325	—	–0.0453	0.7922**	–0.0874
	Number of vehicles involved in the accident							
	Single vehicle	0.6493*	0.6511*	0.8928**	0.6559*	—	—	0.5292*
	Purpose of use							
	Private vehicle	–0.7171*	–0.7040*	–0.9918*	–0.7126*	—	—	–0.6288*
	Temporal characteristics							
	Time of day							
	Morning peak	0.0072	–0.0118	0.4906	—	–0.0160	0.7112**	–0.0527
	Mid-day	0.2048***	0.1852	0.6504	–0.1966***	—	—	0.1299
	Evening peak	–0.3517*	–0.3522*	–0.4394	–0.3531*	—	—	–0.3478*
	Evening	–0.1645**	–0.1622***	–0.2636	–0.1659**	—	—	–0.1581**
	Environmental characteristics							
	Season							
	Winter	–0.6670*	–0.6838*	0.1247	–0.6697*	—	—	–0.5367*
	Spring	–0.5567*	–0.5742*	0.0667	–0.5609*	—	—	–0.4746*
	Summer	–0.1866*	–0.2066*	0.5367***	–0.1911*	—	—	–0.1804*
	Weather condition							
	Cloudy/rainy	0.2034*	0.1968*	0.6646***	0.2044*			0.1925*
	Snowy/stormy/foggy	0.1808***	0.1832***	0.7141	0.1898***			0.1182
	Natural lighting							
	Daylight	0.2979*	0.3099*	–0.1134	0.3020*	—	—	0.3171*
	Road surface							
	Dry/dusty	0.8349*	0.8336*	1.3933**	0.8413*	—	—	0.7383*
	Wet/muddy/oil on the pavement	0.7016*	0.7052*	0.8812	0.7053*	—	—	0.6358*
	Geometry characteristics							
	Asphalt road							
	Yes	–0.2258*	–0.2512**	1.4456	–0.2309*	—	—	–0.1644***
	Road class type							
	Local city Street	0.6803*	0.7189*	–1.6658**	—	0.7206*	–1.7378*	0.6501*
	State route/highway/provincial road	0.6183*	0.6137*	0.4500	0.6158*	—	—	0.5054*
	Control characteristics							
	Pedestrian crosswalk							
	Present	0.2794*	0.2601*	0.5506**	0.2668*	—	—	0.1630*
	Traffic lights							
	Present	–0.3649*	–0.3430*	–1.3073*	—	–0.3410*	–1.7311*	–0.1232**
	Other traffic control device							
	Present	0.5493*	0.5475*	0.7655**	0.5499*	—	—	0.3758*
	Constant	—	–1.7666*	–8.3643*	–5.6199*	—	—	—
Factor affecting the error variance	Accident characteristics							
	Speed violation	—	—	—	—	—	—	–0.1357*
	Violating right-of-way rule	—	—	—	—	—	—	–0.0017
	Vehicle characteristics							
	Vehicle type							
	Bus/minivan	—	—	—	—	—	—	0.2560*
	Single unit truck/heavy truck	—	—	—	—	—	—	0.1368*
	Other type of vehicles	—	—	—	—	—	—	0.1583***
	Temporal characteristics							0.0213
	Time of day							
	Morning peak	—	—	—	—	—	—	0.2720*
	Geometry characteristics							
	Road class type							
	Local city Street	—	—	—	—	—	—	–0.1677*
	Control characteristics							
	Traffic lights							
	Present	—	—	—	—	—	—	–0.3055*

Statistics	Cut point 1	1.7701*	—	—	—	—	—	1.5149*
	Cut point 2	6.5393*	—	—	—	—	—	5.8047*
	Number of observations	11,771	11,771		11,771			11,771
	p-value	<0.0001	<0.0001		<0.0001			<0.0001
	Log-likelihood at convergence	–6,729.43	–6,638.44		–6,654.61			–6,675.29
	McFadden pseudo-rho-square	0.1506	0.1621		0.1601			0.1575
	AIC	13,526.86	13,408.88		13,393.21			13,434.57
	BIC	13,777.55	13,895.53		13,702.90			13,744.26

* significant at 99%; ** significant at 95%; *** significant at 90%

Table 3 Estimation results for MNL and MXL models

Independent variable	MNL		MXL	
	Coefficient	*t*-statistic	Coefficient	*t*-statistic
Driver characteristics: driver's age, >65 [NI]	–3.0124*	–5.66	–2.4646	–4.61
Driver characteristics: driver's education level, primary education [NI]	–0.7230***	–1.90	–0.1440	–0.47
Driver characteristics: driver's education level, primary education [I]	–0.4151	–1.09	1.5150 (0.1955)*	7.75
Driver characteristics: driver's education level, secondary education [NI]	0.6293	1.53	1.6646*	4.66
Driver characteristics: driver's education level, secondary education [I]	0.4151	1.01	3.0537 (0.2680)*	11.40
Accident characteristics: speeding violation [NI]	0.3295	1.01	0.7424**	2.51
Accident characteristics: speeding violation [I]	0.6095***	1.86	0.8060*	2.66
Accident characteristics: avoidance manoeuvre [NI]	0.2084	0.53	0.9391**	2.59
Accident characteristics: avoidance manoeuvre [I]	–0.6071	–1.53	–0.6399	–1.69
Accident characteristics: violating right-of-way rule [I]	0.2642	0.54	0.8812***	1.93
Vehicle characteristics: vehicle type, bus/minivan [NI]	–1.0167**	–2.58	–0.3698	–0.94
Vehicle characteristics: vehicle type, bus/minivan [I]	–1.1822*	–2.99	–0.7128***	–1.75
Vehicle characteristics: vehicle type, single-unit truck/heavy truck [NI]	–0.4967***	–1.70	0.0875	0.31
Vehicle characteristics: vehicle type, single-unit truck/heavy truck [I]	–0.7017**	–2.41	–0.3028	–1.07
Vehicle characteristics: number of vehicles involved in the accident, single vehicle [NI]	–1.1192*	–3.16	–0.5294***	–1.75
Vehicle characteristics: purpose of use, private vehicle [NI]	1.3733*	5.17	2.1593*	8.33
Vehicle characteristics: purpose of use, private vehicle [I]	0.6877**	2.59	0.7653*	2.87
Temporal characteristics: time of day, evening peak [NI]	0.5484	1.19	1.0173**	2.30
Temporal characteristics: time of day, evening [NI]	0.3469	0.76	0.7753***	1.76
Environmental characteristics: season, winter [NI]	0.1510	0.37	1.4955*	3.87
Environmental characteristics: season, spring [NI]	0.1959	0.54	0.9150*	2.73
Environmental characteristics: season, summer [I]	–0.7203**	–2.28	–0.4279	–1.49
Environmental characteristics: weather condition, cloudy/rainy [NI]	–0.7524**	–2.17	–0.0276	–0.08
Environmental characteristics: weather condition, snowy/stormy/foggy [NI]	–0.9184	–1.39	0.9588***	1.92
Environmental characteristics: road surface, dry/dusty [NI]	–1.4919**	–2.33	1.1405*	3.01
Environmental characteristics: road surface, dry/dusty [I]	–0.6613	–1.03	1.6049*	4.15
Environmental characteristics: road surface, wet/muddy/oil on the pavement [NI]	–0.7631	–1.20	1.1618**	2.48
Environmental characteristics: road surface, wet/muddy/oil on the pavement [I]	–0.0563	–0.09	1.6538*	3.48
Geometry characteristics: road class type, local city street [NI]	1.0829***	1.71	2.3804*	5.25
Geometry characteristics: road class type, local city street [I]	1.8208*	2.87	2.8358*	6.16
Geometry characteristics: road class type, state route/highway/provincial road [NI]	–1.1092***	–1.94	0.2418	0.70
Control characteristics: pedestrian crosswalk, present [NI]	–1.0822*	–3.63	–0.5275**	–1.99
Control characteristics: pedestrian crosswalk, present [I]	–0.8338*	–2.79	–0.3197	–1.19
Control characteristics: traffic lights, present [NI]	1.7549*	3.94	1.7792*	3.90
Control characteristics: traffic lights, present [I]	–0.8338*	–2.79	1.4371*	3.12
Control characteristics: other traffic control device, present [NI]	–1.4285*	–1.19	–1.2775*	–4.32
Control characteristics: other traffic control device, present [I]	1.4306*	3.13	–0.5011***	–1.67
Constant [NI]	8.7019*	6.05	—	—
Constant [I]	6.9318*	4.81	—	—
Number of observations	11,771		11,771	
p-value	<0.0001		<0.0001	
Log likelihood at convergence	–6,660.13		–6.625.18	
McFadden pseudo-rho-square	0.1638		0.1594	
AIC	13,382.37		13,448.26	
BIC	13,869.01		13,990.47	

[I], injury; [NI], no injury. The fatal injury is the base case with coefficients restricted at zero.

* significant at 99%; ** significant at 95%; *** significant at 90%; standard errors are in parentheses.

4.1 Driver factors

As shown in Table 4, driver's age and education level were found as the significant risk factors influencing road traffic accident severity. Results reveal that drivers aged 65 and elder are approximately ten times more likely to have possible/evident injury for both HCM and MNL models. Furthermore, the probability of fatal injury increases by almost 15% and 14% when older drivers are involved for MNL and HCM models, respectively. On the other hand, the probability of possible/evident injury severity slightly increases by almost 4% for younger driver-involved accidents for both HCM and PPO models, while this probability also increases by 5% for fatal injury severity. These results are consistent with many earlier studies addressing the age group as a significant risk factor (Celik and Oktay, 2014; Chiou et al., 2013; Islam and Mannering, 2006).

Driver's education level was found as another significant risk factor affecting injury severity levels. The most noteworthy result is that both primary and secondary education variables were found as the only random parameters to explain unobserved heterogeneity in the MXL model, where these variables increase the probability of possible/evident injuries. Moreover, the probability of fatal injuries increases by almost 20% when driver is primary-educated for the MNL model. In contrast, secondary-educated drivers are almost eleven percent less likely to have a fatal injury accident for both HCM and PPO models. The probability of possible/evident injury consistently increases by 7% for all fitted models when primary-educated drivers are involved. These results are in line with recent studies focusing on Turkish samples (Celik and Oktay, 2014; Karacasu et al., 2014).

4.2 Accident type factors

Accident characteristics may give valuable information about injury severity levels. Interestingly, speed violation was not found an increasing factor of fatal injury where the probability of fatal injuries decreases by approximately 20% for HCM and PPO models. As expected, possible/evident injuries are increased by almost 8% for GOLOGIT, PPO and HCM models when speeding limit is violated. Avoiding manoeuvre was another significant accident type factor affecting injury severity. The probability of non-injury severity increases by almost 5% when manoeuvre is avoided in a road traffic accident. On the other hand, results reveal that avoiding manoeuvre does not cause more serious injuries, as the probability of possible/evident and fatal injury decreases by almost 12% and 18% for the HCM model, respectively. On the contrary, violating right-of-way rule increases the probability of both possible/evident and fatal injury by almost 8% for the HCM model. The corresponding results of accident characteristics show consistency with some earlier evidence (Kim et al., 2008; Ma et al., 2015; Uçar and Tatlıdil, 2007; Yasmin et al., 2014; Yulong and Chuanyun, 2014).

4.3 Vehicle factors

The estimation results indicate that accidents involving bus or minivan are about eleven percent more likely to result in fatal injuries for the HCM model. Other models also confirm that the probability of fatal injuries increases when bus or minivan is involved. Similarly, single-unit or heavy truck-involved accidents are more likely to be fatal. The probability of fatal injuries increases by almost 23% for the PPO model when single-unit or heavy truck is involved. Other type of vehicles also slight increase the fatality by almost 3% for the PPO model. Another noteworthy outcome is related to single-vehicle accidents in line with other research (Celik and Oktay, 2014; Martensen and Dupont, 2013). The probability of more serious injuries increases when a single vehicle is involved in the accident. Particularly, the probability of possible/evident injury increases by almost 20% for all models, while the probability of fatal injury increases by 41% for the MNL model. In contrast, private vehicle-involved accidents are more likely to cause less serious injuries. For instance, the probability of fatal injury decreases by almost 94% when the private vehicle is involved for the MNL model. The probability of possible/evident injury severity decreases by about 41% for the HCM model in private vehicle-involved accidents. This result shows consistency with earlier work (Celik and Oktay, 2014; Yau, 2004; Yau et al., 2006).

4.4 Temporal factors

Time of day was found an important significant risk factor that may have an impact on injury severity levels. Road traffic accidents occurred during the morning peak are almost ten percent more likely to be result in fatal injury for the HCM model. Fortunately, the probability of fatal injuries decreases by almost 20% for the accidents occurred during the evening peak for the HCM model. In the evening, accidents are slightly more likely to result in fatal injury. This outcome is consistent with recent studies (Yau et al., 2006; Zhang et al., 2013).

4.5 Environmental factors

As expected, seasonal effects were found as one of the statistically significant environmental factors affecting road traffic accidents in the north-eastern Turkey. Less serious injuries are more likely to occur in winter, where the probability of fatal or possible/evident injuries decrease by almost 19% and 14% for the PPO and the MNL models. The results seem to be similar for traffic accidents in the spring, since the occurrence of fatal injuries decreases. However, the GOLOGIT and the MNL results confirm that the probability of fatal injuries increases by almost 14% in the summer. This result shows consistent with other recent work (Celik and Oktay, 2014; Shaheed et al., 2013) Weather condition was found another environmental risk factor of injury severity. Results reveal that cloudy or rainy weather increases the probability of fatal accidents by almost 15% for the MNL model.

Table 4 Average direct pseudo-elasticities of GOLOGIT, PPO, HCM and MNL models

Independent variable	GOLOGIT	PPO	HCM	MNL
Driver characteristics: driver's age, <25 [NI]	–0.0157*	–0.0155*	–0.0158*	–0.0155*
Driver characteristics: driver's age, <25 [I]	0.0360*	0.0353*	0.0367*	0.0362*
Driver characteristics: driver's age, <25 [F]	–0.0071	0.0507*	0.0526*	–0.0141
Driver characteristics: driver's age, >65 [NI]	–0.0459*	–0.0455*	–0.0416*	–0.0454*
Driver characteristics: driver's age, >65 [I]	0.1050*	0.1037*	0.0964*	0.1050*
Driver characteristics: driver's age, >65 [F]	0.1002*	0.1492*	0.1380*	0.1499*
Driver characteristics: driver's education level, primary education [NI]	–0.0310*	–0.0317*	–0.0296*	–0.0300*
Driver characteristics: driver's education level, primary education [I]	0.0704*	0.0723*	0.0687*	0.0690*
Driver characteristics: driver's education level, primary education [F]	0.1719	0.1040*	0.0983*	0.2025***
Driver characteristics: driver's education level, secondary education [NI]	0.0308*	0.0315*	0.0328*	0.0305*
Driver characteristics: driver's education level, secondary education [I]	–0.0695*	–0.0718*	–0.0762*	–0.0697*
Driver characteristics: driver's education level, secondary education [F]	–0.2596	–0.1032*	–0.1090*	–0.2640
Accident characteristics: speeding violation [NI]	–0.0336*	–0.0336*	–0.0242*	–0.0346*
Accident characteristics: speeding violation [I]	0.0779*	0.0785*	0.0589*	0.0812*
Accident characteristics: speeding violation [F]	–0.1786	–0.2250**	–0.1978*	–0.1708
Accident characteristics: avoidance manoeuvre [NI]	0.0474*	0.0470*	0.0539*	0.0478*
Accident characteristics: avoidance manoeuvre [I]	–0.1088*	–0.1073*	–0.1249*	–0.1112*
Accident characteristics: avoidance manoeuvre [F]	–0.0251	–0.1543*	–0.1788*	–0.0006
Accident characteristics: violating right-of-way rule [NI]	–0.0356*	–0.0358*	–0.0333*	–0.0355*
Accident characteristics: violating right-of-way rule [I]	0.0817*	0.0822*	0.0773*	0.0824*
Accident characteristics: violating right-of-way rule [F]	0.0362	0.0002	0.0781*	0.0499
Vehicle characteristics: vehicle type, bus/minivan [F]	0.0731**	0.0759*	0.1095*	0.0717*
Vehicle characteristics: vehicle type, single-unit truck/heavy truck [NI]	0.0187*	0.0189*	0.0141*	0.0192*
Vehicle characteristics: vehicle type, single-unit truck/heavy truck [I]	–0.0438*	–0.0448*	–0.0348*	–0.0456*
Vehicle characteristics: vehicle type, single-unit truck/heavy truck [F]	0.1948**	0.2324*	0.1678**	0.1763*
Vehicle characteristics: vehicle type, other type of vehicles [F]	0.0251	0.0314**	0.0324	0.0232
Vehicle characteristics: number of vehicles involved in the accident, single vehicle [NI]	–0.0879*	–0.0885*	–0.0817*	–0.0861*
Vehicle characteristics: number of vehicles involved in the accident, single vehicle [I]	0.1999*	0.2020*	0.1896*	0.1985*
Vehicle characteristics: number of vehicles involved in the accident, single vehicle [F]	0.3954**	0.2905*	0.2714*	0.4103*
Vehicle characteristics: purpose of use, private vehicle [NI]	0.1724*	0.1744*	0.1763*	0.1670*
Vehicle characteristics: purpose of use, private vehicle [I]	–0.3922*	–0.3981*	–0.4089*	–0.3847*
Vehicle characteristics: purpose of use, private vehicle [F]	–0.7970*	–0.5726*	–0.5851*	–0.9382*
Temporal characteristics: time of day, morning peak [F]	0.0319	0.0463**	0.0989*	0.0236
Temporal characteristics: time of day, evening peak [NI]	0.0521*	0.0522*	0.0588*	0.0517*
Temporal characteristics: time of day, evening peak [I]	–0.1186*	–0.1191*	–0.1366*	–0.1193*
Temporal characteristics: time of day, evening peak [F]	–0.2132	–0.1713*	–0.1954*	–0.2149
Temporal characteristics: time of day, evening [F]	–0.0351	–0.0221*	–0.0244**	–0.0398
Environmental characteristics: season, winter [NI]	0.0599*	0.0586*	0.0538*	0.0594*
Environmental characteristics: season, winter [I]	–0.1377*	–0.1338*	–0.1248*	–0.1383*
Environmental characteristics: season, winter [F]	0.0358	–0.1924*	–0.1786*	0.0159
Environmental characteristics: season, spring [NI]	0.0425*	0.0415*	0.0402*	0.0423*
Environmental characteristics: season, spring [I]	–0.0978*	–0.0948*	–0.0933*	–0.0984*
Environmental characteristics: season, spring [F]	0.0162	–0.1363*	–0.1336*	–0.0054
Environmental characteristics: season, summer [I]	–0.0361*	–0.0326*	–0.0358*	–0.0376*
Environmental characteristics: season, summer [F]	0.1315***	–0.0468*	–0.0512*	0.1392*
Environmental characteristics: weather condition, cloudy/rainy [NI]	–0.0128*	–0.0130*	–0.0143*	–0.0124*
Environmental characteristics: weather condition, cloudy/rainy [I]	0.0287*	0.0303*	0.0332*	0.0281*
Environmental characteristics: weather condition, cloudy/rainy [F]	0.1415***	0.0435*	0.0475*	0.1481**
Environmental characteristics: natural lighting, daylight [NI]	–0.0631*	–0.0615*	–0.0739*	–0.0637*
Environmental characteristics: natural lighting, daylight [I]	0.1453*	0.1403*	0.1714*	0.1486*
Environmental characteristics: natural lighting, daylight [F]	–0.0757	0.2018*	0.2453*	–0.0876
Environmental characteristics: road surface, dry/dusty [NI]	–0.1617*	–0.1631*	–0.1639*	–0.1601*
Environmental characteristics: road surface, dry/dusty [I]	0.3672*	0.3722*	0.3802*	0.3693*
Environmental characteristics: road surface, dry/dusty [F]	0.8869*	0.5354*	0.5441*	0.7908***
Environmental characteristics: road surface, wet/muddy/oil on the pavement [NI]	–0.0387*	–0.0387*	–0.0399*	–0.0385*
Environmental characteristics: road surface, wet/muddy/oil on the pavement [I]	0.0882*	0.0883*	0.0927*	0.0891*
Environmental characteristics: road surface, wet/muddy/oil on the pavement [F]	0.1588	0.1271*	0.1327*	0.0992
Geometry characteristics: asphalt road, yes [NI]	0.0723**	0.0664**	0.0542***	0.0740*
Geometry characteristics: asphalt road, yes [I]	–0.1726**	–0.1516**	–0.1257***	–0.1772*

Geometry characteristics: asphalt road, yes [F]	1.3655	–0.2180**	–0.1799***	1.1369
Geometry characteristics: road class type, local city street [NI]	–0.1279*	–0.1281*	–0.1074*	–0.1286*
Geometry characteristics: road class type, local city street [I]	0.2983*	0.3000*	0.2540*	0.3026*
Geometry characteristics: road class type, local city street [F]	–0.9721**	–1.0139*	–0.1296*	–0.7614**
Geometry characteristics: road class type, state route/highway/provincial road [NI]	–0.0620*	–0.0622*	–0.0584*	–0.0601*
Geometry characteristics: road class type, state route/highway/provincial road [I]	0.1416*	0.1418*	0.1355*	0.1385*
Geometry characteristics: road class type, state route/highway/provincial road [F]	0.1491	0.2040*	0.1939*	0.3080
Control characteristics: pedestrian crosswalk, present [NI]	–0.0515*	–0.0528*	–0.0369*	–0.0494*
Control characteristics: pedestrian crosswalk, present [I]	0.1166*	0.1205*	0.0857*	0.1122*
Control characteristics: pedestrian crosswalk, present [F]	0.3576***	0.1733*	0.1226*	0.6546*
Control characteristics: traffic lights, present [NI]	0.0268*	0.0266*	0.0309*	0.0255*
Control characteristics: traffic lights, present [I]	–0.0598*	–0.0588*	–0.0678*	–0.0576*
Control characteristics: traffic lights, present [F]	–0.3345*	–0.4428*	–0.4907*	–0.4241*
Control characteristics: other traffic control device, present [NI]	–0.0773*	–0.0776*	–0.0607*	–0.0752*
Control characteristics: other traffic control device, present [I]	0.1759*	0.1772*	0.1409*	0.1725*
Control characteristics: other traffic control device, present [F]	0.3547**	0.2548*	0.2016*	0.5878*

[I], injury; [NI], no injury; [F], fatal injury; * significant at 99%; ** significant at 95%; *** significant at 90%.

According to the estimation results, fatal injuries are more likely to occur in daylight. For the HCM model, the probability of fatal injury increases by almost 25% in daylight. In addition, the probability of possible or evident injury also increases by approximately 17% when the accident occurs in daylight for the HCM model. Road surface was found to have an impact on injury severity levels. Accordingly, when the accident occurs on wet or muddy road surface or there is oil on the pavement, then the probability of fatal injury increases by almost 13%. The probability of possible or evident injury also increases by almost 9% when the road surface is wet, muddy or oily at the accident. These results are in line with earlier work (Carson and Mannering, 2001; Chu, 2015; Morgan and Mannering, 2011).

4.6 Control factors

Estimation results indicate that the presence of asphalt road and road class type were strongly associated with injury severity levels. Specifically, accidents are less likely to result in fatality on asphalt roads, where the probability of fatal injuries decreases by almost 22% and 18% for PPO and HCM models, respectively. The probability of possible/evident injury decreases by almost 18% and 17% for GOLOGIT and MNL models. Another important estimation result is the probability of fatal injury when the accident occurs on local city street. In this situation, this probability decreases by almost 101%, 97% and 76% for the PPO, GOLOGIT and MNL models, respectively. However, result put forward that the probability of possible or evident injury increases by almost 30% for GOLOGIT, PPO and MNL models. Road class type was also found statistically significant when the accident occurred on state route/highway/provincial roads. The probability of fatal injury increases by almost 20% on these type of roads. Similarly, the probability of possible or evident injuries also increases by almost 14% on state route/highway/provincial roads. These results show consistency with prior studies (Uçar and Tatlıdil, 2005; Yulong and Chuanyun, 2014).

4.7 Control factors

Control factors were found to be associated with injury severity in north-eastern Turkey during the sample period. Estimation results reveal that the presence of crosswalk is not effective on decreasing the injury severity level. Particularly, the probability of fatalities increases by almost 66% and 36% for MNL and GOLOGIT models, respectively, although the pedestrian crosswalk is present. Results also highlight the presence of pedestrian crosswalk is insufficient to improve road safety where the probability of possible or evident injury increases by almost 12% and 11% for GOLOGIT and MNL models, respectively.

Traffic lights were found to have an impact on decreasing the more severe injuries. In fact, the presence of traffic lights decreases the probability of fatal injuries by almost 49%, 44% and 42% for HCM, PPO and MNL models, respectively. Results indicate that possible or evident injuries also decrease by 7% for the HCM model when traffic lights are present. According to estimation results, other traffic control devices were insufficient to decrease more severe injuries. The probability of fatal injuries increases by 59% for the MNL model although other traffic control devices are present. The probability of possible or evident injury also increases by 18% for GOLOGIT and PPO models, respectively. All these findings show consistency with recent research (Celik and Oktay, 2014; Kim et al., 2008; Yulong and Chuanyun, 2014).

5 Discussion

Road traffic accidents are still a problematic issue for emerging countries including Turkey. This paper aims to determine risk factors that may contribute to road traffic injury severities in the north-eastern Turkey between 2008 and 2013. The data were analysed using both ordered and unordered discrete choice models in line with some most recent research (Abay, 2013; Qin et al., 2013; Sasidharan and Menendez, 2014). A comparison of ordered and unordered response models may give a valuable information about possible risk factors influencing road traffic injury severity. More specifically, the use of MXL model will provide a strong evidence to explain unobserved effects caused by underreporting of accident data. This paper is most probably the first attempt that compares both alternative ordered and unordered response models in a Turkish sample. Especially, the outcome of this paper presents the first use of some alternative models including GOLOGIT, HCM and MXL for a Turkish injury severity study. The current paper mainly differs from previous study conducted in the analogous sample (Celik and Oktay, 2014) in terms of distinctive analysis methods performed. On the other hand, the use of HCM and MXL models provide to explain the heterogeneity of some statistically significant risk factors such as driver's education level.

The results of this study reveal that several risk factors may influence the injury severity. Driver's age and education level were found to have an impact on injury severity levels. As the evidence of this study suggests, speeding violation, avoiding manoeuvre and right-of-way rule are significant indicators of injury severity levels. The underlying results may be inherently associated with the query of current education campaigns and future improvements on road traffic safety education with respect to a variety of age groups. Younger drivers should be encouraged to have a strong awareness on basic traffic regulations following successful experiences worldwide. Practically, improved road safety regulations are under consideration which ensure the periodical control of novice drivers' present and future behaviour on traffic. These regulations may be extended to encompass all age groups and educational levels. The outcome of further policies may be permanently reported to evaluate the success of each policies and provide an additional arrangement if necessary.

The estimation results indicate that bus/minivan and single-unit truck/heavy truck-involved accidents are more likely to result in fatal injuries. The significant impacts of private and single vehicles are also highlighted in this study. The appearance of heavy vehicles may be restricted on particular roads to avoid possible traffic congestions and the occurrence of future heavy vehicle-included road traffic accidents. Future road traffic strategies may also include several arrangements that increase the road safety consciousness of private and single vehicle drivers. Due to their geographic location, the impact of temporal factors should be carefully examined for both the Erzurum and Kars provinces. The results of this study indicate that fatal injuries are increased in the summer and cloudy or rainy weather. In fact, these results are not surprising since summer is the rainiest season for both provinces. The infrastructure of road network in both provinces should be significantly improved for unfavourable weather conditions with increasing further investments in the north-eastern region of Turkey. As the results of this study put forward, current traffic control devices are insufficient to decrease more severe injuries. In this sense, more advanced traffic control devices may provide to improve future road safety. Whilst Erzurum is the second largest city of the north-eastern Turkey, both provinces in this study are the emerging cities and have the potential of rapid growth in terms of road infrastructure. Along with the completion of recent ongoing road construction projects, both provinces may retrieve advanced road infrastructure in terms of sustainable transportation.

This study is limited to traffic police reports in a specific region of Turkey in a limited time period. Further studies may consider other risk factors such as insignificant variables including gender and day of week or the use of seat belt or alcohol use to successfully overcome underreporting issue. The authorized institutions such as the traffic police and gendarme should encourage the researchers to analyse further road traffic accident data in other provinces of Turkey. In this manner, further studies may enable to examine regional differences in the country. For comparative purposes, the use of other discrete models such as latent class analysis or nested models in further research may also provide more robust estimation results. The persistent use of specific models that provide evidence on the heterogeneity of driver's behaviour and other characteristics may be valuable for better understanding the effectiveness and the success of current and future road safety policies on decreasing more severe injury severities.

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