Factors affecting motorcyclists' injury severities: An empirical assessment using random parameters logit model with heterogeneity in means and variances

Muhammad Waseem[a], Anwaar Ahmed[b,*], Tariq Usman Saeed[c]

[a] National Institute of Transportation, School of Civil and Environmental Engineering, National University of Sciences and Technology, Islamabad, Pakistan
[b] Military College of Engineering, National University of Sciences and Technology, Risalpur, Pakistan
[c] Lyles School of Civil Engineering, Purdue University, 550 Stadium Mall Dr., W. Lafayette, IN, 47907, United States

ABSTRACT

Motorcycles constitute 61% of the total registered vehicles in Pakistan and there has been a 371% growth in motorcycles in the country from year 2005-2015. Motorcycle is an essential and popular mode of transportation in Pakistan, therefore, the present study estimated a random parameters logit model to investigate the factors influencing the motorcycle injury severity using motorcycle crash data of Rawalpindi city collected by the Provincial Emergency Response Service. No injury, minor injury, severe injury and fatal injury are used as four categories of motorcyclist injury severity levels to calibrate the model. Mainly the effects of speed limits, crash-specific factors, rider attributes, roadway characteristics, weather and socio-demographics factors are considered for motorcycle-injury severity analysis. It was revealed that probability of fatal/severe injury increases for crashes: involving middle-aged riders (25–50 years) and riders with no education, occurring on roads with posted speed limit of 70 kms per hour or higher, crashes involving a motorcycle and a heavy vehicle, involving collision of a motorcycle with a fixed object and occurring during dry weather conditions. Also, the probability of minor injury increases for crashes: occurring on divided streets and road segments with a posted speed limit of less than 50 kms per hour, involving Chinese brand motorcycles, involving registered motorcycles, and where at least one motorcycle and auto rickshaw is involved. The research findings suggest that besides measures to control/ reduce the risky motorcyclists behavior there is a need to lower speed limits on roads with a higher motorcycle proportion, separate motorcycles from heavy vehicles and removal of fixed objects from the road-side. Besides data limitations, results are expected to generate more discussion and interest in motorcycle safety in the country and can be used by the enforcement agencies to improve/ enhance the current state of motorcycle safety in the country.

1. Introduction

Globally more than 1.2 million fatalities occur due to road traffic crashes each year and almost 50% of these fatalities are among pedestrians, cyclists, and motorcyclists (WHO, 2015). Compared to other motorized road users, motorcyclists or powered-two-wheelers are usually associated with higher fatality and injury rate due to lack of protection in a crash event (Elliot et al., 2003; Yannis et al., 2005; Rifaat et al., 2012). Approximately a quarter of global road crash fatalities are among motorcyclists (WHO, 2015). Pakistan has high road crash fatality rate with approximately 25,781 fatalities annually resulting from motor vehicle crashes (WHO, 2015; Ahmed et al., 2016a).

In Pakistan, there has been a disproportionate growth in vehicle population over last one decade particularly the vulnerable means of transport (motorcycles and auto rickshaw). Motorcycles constitute 61% of total registered vehicles and there has been a 371% growth in motorcycles from the year 2005 to 2015 (PBS, 2015). Due to lack of adequate public transportation, motorcycles are an essential mode of transportation in Pakistan. Annual motorcycle production in the country has increased from eighty-nine thousand in 1998 to 1.36 million in 2016 (PAMA, 2016). Rapid motorcycle growth combined with general overall poor road safety environment has resulted in 137% increase in motorcycle crashes in last 8 years in Rawalpindi city (Rescue1122, 2016). Available data shows that in almost 55% crashes

in the country, vulnerable road users are involved (Minhas et al., 2016).

Despite alarming number of motorcycle crashes, very few studies have focused on motorcycle safety issues in Pakistan (Khan et al., 2008; Bhatti et al., 2018; Khan et al., 2012, 2015; Ahmed et al., 2016b; Minhas et al., 2016; Saeed et al., 2017). Highway driving/ riding environment in Pakistan significantly differs from developed countries in terms of motorcycle types, riding exposure, riding purpose, riding experience, vehicle mix, highway geometrics, legislation and the level of police enforcement. Road environment in Pakistan is characterized by congested lanes, traffic mix comprising slow and fast moving vehicles (trucks, buses, motorcycles, auto rickshaws and animal drawn-carts), roadside eateries and businesses, uncontrolled access to abutting properties, low enforcement level of key crash risk factors, vehicle parked on travel lanes and general disregard of traffic rules and safety. Low tendency to wear helmets, use of non-standard helmets, speeding, running a red light, underage riding and low level of police enforcement are common issues related to motorcycle safety in Pakistan (Khan et al., 2008; Bhatti et al., 2018; Ahmed et al., 2016b; Farooq, 2017; Saeed et al., 2017). In developed countries of Europe and America, motorcycles are only 2% of the registered vehicles with high engine capacities and are generally used for leisure riding (Haworth, 2012; NHTSA, 2014), while in Pakistan low engine capacity motorcycles are preferred for the daily commute to work/ business.

The high percentage of motorcycle crashes in the country is a major concern for all stakeholders and demands that risk factors contributing to the motorcycle injury severity are investigated in order to develop appropriate counter measures to improve overall motorcycle safety in the country. The current study is the first of its kind to investigate injury severity of motorcycle crashes in Pakistan. Motorcycle crash data for Rawalpindi city were obtained from a provincial emergency response service (Rescue 1122) to develop a random parameters logit model to estimate significant contributory factors to injury severity of motorcycle crashes.

2. Review of past studies

In previous research endeavors, a wide range of factors were found to potentially influence the injury severity of motorcyclists. Factors found to be associated with an increase in injury severity were: no-helmet use (Shankar and Mannering, 1996; Savolainen and Mannering, 2007; Schneider and Savolainen, 2011; Shaheed et al., 2013; Shaheed and Gkritza, 2014), high travel speed (Shankar and Mannering, 1996; Savolainen and Mannering, 2007; Shaheed et al., 2013; Shaheed and Gkritza, 2014), motorcycles with larger engine capacity (Quddus et al., 2002; De Lapparent, 2006; Pai, 2009), rider age (Savolainen and Mannering, 2007; Schneider and Savolainen, 2011), motorcyclist riding without valid license (Dandona et al., 2006), collision with heavy vehicle/ roadside fixed objects (Savolainen and Mannering, 2007; Schneider and Savolainen, 2011; Shaheed and Gkritza, 2014), riding in dark condition (De Lapparent, 2006; Savolainen and Mannering, 2007; Shaheed et al., 2013; Chung et al., 2014), alcohol-impaired riding (Savolainen and Mannering, 2007; Schneider and Savolainen, 2011; Shaheed and Gkritza, 2014) and roadway functional class (Quddus et al., 2002; Savolainen and Mannering, 2007; Eustace et al., 2011).

Several modeling procedures have been applied in the past to estimate motorcyclist's injury severity. Shankar and Mannering (1996) utilized multinomial logit (MNL) model and stated that MNL is a promising approach to study factors contributing to motorcycle injury severity. Quddus et al. (2002) used ordered probit approach to investigate injury severity and motorcycle damage severity in motorcycle crashes in order to account for the ordinal nature of the severity outcomes. Savolainen and Mannering (2007) identified potential drawbacks in applying ordered probit and multinomial logit models to injury severity analysis. The ordered probit modeling approaches impose restrictions on extreme outcomes and influence outcome probabilities. On the other hand, a multinomial logit model is susceptible to violate independence

of irrelevant alternative (IIA) property. To overcome these limitations, authors estimated nested logit model to analyze injury severities in single and multi-vehicle motorcycle crashes. Rifaat et al. (2012) carried out motorcycle crash severity analysis in Calgary using an ordered logit model, a heterogeneous choice model, and a partially constrained generalized ordered logit model. These traditional crash severity models do not allow explanatory variables to vary across individual outcomes. In reality, each individual outcome responds differently to explanatory variables and thus cannot be considered fixed. Also, there are some unobserved factors affecting the severity of individual crashes for which comprehensive data collection is sometimes difficult. Ignoring these unobserved factors (referred to as unobserved heterogeneity) could lead to biased parameter estimates and erroneous inferences (Mannering et al., 2016). To address the problem of unobserved heterogeneity, studies on crash injury severity analysis in the recent past have used mixed logit model (Milton et al., 2008; Shaheed et al., 2013), latent-class models with random parameters (Xiong and Mannering, 2013), Markov switching model with random parameters (Xiong et al., 2014), latent class models (Cerwick et al., 2014; Shaheed and Gkritza, 2014), bivariate/multivariate models with random parameters (Russo et al., 2014), random parameters with heterogeneity in means (Behnood and Mannering), random parameters with heterogeneity in means and variances (Seraneeprakarn et al., 2017 and Behnood and Mannering, 2016).

3. Data description

The study setting was Rawalpindi city, located in the northern part of Pakistan adjoining Federal capital, Islamabad. According to the 2017 national population census, the city had a population of 5.40 million and is the fourth largest city of Pakistan (PBS, 2017). Motorcycle crash data for this study were obtained from Rescue 1122 Rawalpindi office for a one-year period from July 1, 2014 to June 30, 2015. Rescue 1122, is a provincial government emergency response service providing integrated emergency services in 36 districts of Punjab province of Pakistan. Rescue 1122 maintains a record of all emergency responses including road traffic accidents. Police-reported crash data was also explored for this study that had record of 684 crashes only compared to Rescue 1122 data (record of 6104 crashes) from July 1, 2014 to June 30, 2015. Police-reported accident data in Pakistan is known to have serious underreporting issues (Ahmed et al., 2016a). Moreover, police-reported crashes included only fatal or severe injury crashes, thus missing information on no-injury and minor injury crashes, therefore data collected by Rescue 1122 were used in this study. Rescue 1122 uses a two-page crash report form to record crash details. Crash details are recorded on the crash report form at the time of response and weekly and monthly summary of crashes is forwarded by district emergency officer to the provincial office of agency. Over 8442 traffic crash report forms were obtained from Rescue 1122 Rawalpindi district office and were sorted out to extract data on crashes involving a motorcycle. A total of 6104 road crashes involved a motorcyclist. The form includes the demographic information of the victim such as age and gender, location, date and time of the crash, type of vehicle involved in the collision, victim's motorcycle details and injury sustained by motorcyclists at the crash scene. The weather data at the time of the collision were obtained from Pakistan Meteorological Department Islamabad (PMD, 2015) and geometric information of the roadway segments were obtained from Rawalpindi Development Authority (RDA). To obtain missing geometric details and to confirm the geometric details of the road segments provided by RDA, some of the road segments were visited by the research team. In the data collection form victim's actual injury (actual bodily harm) at the crash scene is recorded by the emergency response officer. Reported crash injuries are categorized as: no injury, minor injury, severe injury and fatal injury. Out of 5311 crashes having complete data and involving a motorcyclist, 179 (3.37%) crashes had no injuries, 3848 (72.45%) crashes involved

minor injuries, 1234 (23.23%) crashes involved severe injuries and 50 (0.94%) had fatal injuries (Table 1).

The dataset revealed that majority of the victims were drivers (78.35%) compared to pillion riders. Due to cultural and social constraints, female motorcycle riders are rare in Pakistan. Usually, male ride motorcycle as a driver while female ride as pillion passenger; therefore male victims are dominant (90.83%) in our dataset. Less educated riders (high school or below) were mostly involved in crashes (77.62%). Crashes during day light conditions (62.46%) were more than dark/night conditions.

It was observed that motorcycle crash frequency was substantially higher during weekdays (71.91%) and in summer months (June, July, and August) (35.91%). Crash frequency was also higher during off-peak hours (74.71%) and in dry weather conditions (62.49%). The highest number of crashes occurred on major arterials (37.64%), and on road segments with a posted speed limit of 70 kmph or higher (50.94%). Low engine capacity motorcycles (70cc) were found involved in the majority of the crashes (73%). Majority of the motorcycles used in Pakistan are either Japanese (Honda, Yamaha, Suzuki and Kawasaki) or Chinese (Hero, United, Unique, Union Star, Hi-Speed etc.) brands. A similar rate of crash involvement was observed for Japanese (37.9%) and Chinese (35.7%) brands. It was revealed that passenger car-motorcycle collisions account for the maximum number of crashes (31.48%) followed by motorcycle rickshaw-motorcycle collisions (20.22%).

4. Methodology

Following the recent work of Behnood and Mannering (2017a, 2017b) and Seraneeprakarn et al., (2017) we estimated a random parameters logit model with heterogeneity in means and variances to determine significant factors contributing to motorcycle injury severity in Pakistan. The unavailability of certain key variables in our data set that could potentially affect motorcyclist's injury severity outcome, (for instance, helmet use, driving license, motorcycle mechanical condition, road and traffic condition at the time of crash and driving behavior), may induce unobserved heterogeneity that can affect the impact of observed variables on injury severity and can lead to biased parameter estimates and erroneous inferences (Mannering et al., 2016). Unlike commonly used heterogeneity models, estimated models allows random parameters mean and variance to vary across observations, thus allowing to capture observation-specific variation in the effect of explanatory variables in a better way (Behnood and Mannering, 2017a, 2017b). Following (Milton et al., 2008) the severity function determining individual crash n belongs to injury severity i is defined as:

$$M_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{1}$$

M_{in} is a motorcyclist injury severity function determining severity for category i (no injury, minor injury, severe injury, fatality) for crash n; X_{in} is a vector of explanatory variable, βi is a vector of estimable parameter for discrete outcome i; and ε_{in} is a stochastic error term. Following Behnood and Mannering (2017a, 2017b) and Seraneeprakarn et al. (2017) unobserved heterogeneity in the means and variances of random parameters is accounted for by allowing β_i to be a vector of estimable parameters that varies across motorcycle crashes defined as:

$$\beta_i = \beta + \Theta_i Z_i + \sigma_i EXP(\omega_i W_i)_{v_i} \tag{2}$$

where β is the mean parameter estimate across all crashes, Z_i and W_i are vectors of attributes that capture heterogeneity in the mean and standard deviation (σ_i, with corresponding parameter vector ω_i) respectively, Θ_i is a corresponding vector of estimable parameters, and v_i is a disturbance term. Assuming that the error term ε_{in} is generalized extreme value distributed, resulting standard multinomial logit model probabilities that allow for parameters to vary across observations, are specified as (McFadden, 1981),

$$P_n(i) = \int_x \frac{EXP[\beta_i X_{in}]}{\sum EXP[\beta_I X_{in}]} f(\beta/\varphi) d\beta \tag{3}$$

Where $P_n(i)$ is the probability of crash severity outcome i for a certain crash n and I is a set of possible injury severity categories. Where $f(\beta/\varphi)$ is the density function of β with φ referring to a vector of parameters of the density function. The density function $f(\beta/\varphi)$ is utilized to determine β, which can account for the unobserved heterogeneity (Milton et al., 2008). The probabilities are estimated by drawing values of β from density function ($f(\beta/\varphi)$) for given values of φ. Simulated maximum likelihood approach is employed to estimate mixed logit model using Halton draws (Train, 2009). Previous studies have shown that Halton draws are more effective than random draws. We used 500 Halton draws for our model estimation which are sufficient for accurate parameter estimation as per prior studies (Train, 1999; Bhat, 2003; Milton et al., 2008; Anastasopoulos and Mannering, 2009; Savolainen, 2016). In our model estimation normal distribution provided the best statistical fit for functional form of parameter density function which is consistent with past literature (Shaheed et al., 2013; Behnood and Mannering, 2016).

5. Results and discussion

Table 2 presents the results of fitted random parameters logit model with heterogeneity in mean and variance for motorcycle injury severity. Average marginal effects based on population of observations are also presented in Table 2. Marginal effects describe the effect of a unit change in the independent variable on the injury severity outcome probabilities. In case of indicator variables, marginal effect give the effect of independent variable moving from zero to one on the injury severity outcome probabilities (Washington et al., 2011). The parameters included in the final model (Table 2) were tested and found statistically significantly at a 0.05 level of significance or higher. Overall twenty-two variables were found statistically significant in the estimated random parameters logit model. All the variables included in the final model (Table 2) have plausible sign and model has a reasonable fit with a McFadden Pseudo R-squared value of 0.494. One parameter "the engine capacity of the motorcycle (CC)" was found to be random, having varying influence on motorcycle injury severity. The engine capacity of the motorcycle (CC) also produces significant heterogeneity in mean and variance. Normal distribution provided the best statistical fit for all the statistically significant random parameters[1]. Table 3 reports Akaike information criterion (AIC) and Bayesian information criterion (BIC) for the two competing models (one with heterogeneity in mean and variance and the second with no heterogeneity in mean and variance). Though the two models have approximately the same AIC and BIC values, however the model that accounts for heterogeneity in mean and variance is chosen as the final model. This is done given the context of motorcycle data from the study area, the sources of heterogeneity in means and variances are captured through the chosen model.

A discussion on significant parameters is provided in the ensuing paragraphs.

5.1. Heterogeneity in means and variances

Model was checked for heterogeneity in the means and variances for all the variables with statistically significant random parameters (Table 2). Only one variable "engine capacity of the motorcycle (CC)"

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[1] There is no theoretical evidence that favors one distribution over the other. Final selection of the random parameter should be based on the statistical fit of the model. In the current study four distributions were checked for the random parameters and the normal distribution had better log likelihood at convergence (-3726.430) compared to triangular (-3730.412), uniform (-3730.922) and log normal (-3752.522).

Table 1
Summary Statistics of Key Variables.

Variables	Percentage
Crash Severity	
No injury/Minor injury/Severe injury/Fatal	3.37/72.45/23.23/0.94
Month of the Year	
Jan/Feb/Mar/Apr/May/Jun/Jul/Aug/Sep/Oct/Nov/Dec	7.72/6.89/6.83/8.36/8.98/9.94/9.62/8.28/8.06/9.68/8/7.63
Day of the Week	13.29/14.61/14.65/13.37/15.99/14.12/13.97
Mon/Tue/Wed/Thu/Fri/Sat/Sun	13.29/14.61/14.65/13.37/15.99/14.12/13.97
Weekday/Weekend	71.91/28.09
Weather Conditions	
Sunny Dry/Cloudy/Rainy	62.49/16.79/20.71
Season of the Year	
Winter (December to February)/ spring (March to May)/summer (June to August)/ autumn (September to November)	24.18/17.68/35.91/22.24
Time of the Day	
12am-3am/3am-6am/6am-9am/9am-12pm/12pm-3 pm/3 pm-6 pm/6 pm-9pm/ 9pm-12am	4.91/1.86/9.64/16.46/17.72/19.19/18/12.22
Peak (7am to 10am, 4 pm to 7 pm)/off-peak hours	25.29/74.71
Roadway Type	
Major Arterial /Minor Arterial /Collector /Local	37.64/28.32/28.83/5.22
Posted Speed Limits	
≥70 kmph / ≥50 kmph and < 70 kmph / below 50kmph	50.94/43.85/5.22
Rider Details	
Driver/Pillion Rider	78.35/ 21.65
Age: ≤ 20 yrs, 20-30 yrs, ≥ 30 yrs, 30-40 yrs, 40-50 yrs, 25-50 yrs, over 50 yrs	27.90/40.58/31.52/16.80/8.62/48.08/6.1
Gender: Male/Female	90.83/9.17
Education	
Illiterate/Middle School/ High School/College or Higher Education	13.09/24.8/45.4/16.76
Motorcycle Registration Status	
Registered/unregistered or unknown	72.6/27.4
Brand	
Japanese (Honda, Yamaha, Suzuki, Kawasaki) /Chinese (Hero, Unique, United, Union Star, Hi Speed.)/ Others Unknown	37.9/35.7/26.4
Engine capacity (cc) : 70cc /Above 70cc/Unknown	73.06/14.71/12.24
Crash Characteristics	
Single vehicle /Multi-vehicle Crash	43.14/56.86
Heavy Vehicle/Passenger Car /Bike & Rickshaw/Cloth Stuck in Wheel/ Roadside fixed Object/Animal/ Pedestrian	5.16/31.48/20.22/2.81/5.03/0.75/3.56
Pillion Rider: Present/Not Present	36.41/63.59

produced random parameter with heterogeneity in the mean and variance. The mean of the engine capacity of the motorcycle increased if the pillion rider was a female. Hence for the engine capacity indicator for motorcyclist with female pillion rider there is an increased likelihood of severe injuries. This finding is intuitive in the context of Pakistan, where females ride motorcycle as pillion passengers with an unbalanced sitting posture (both legs on one side) and are more exposed to injuries in a crash event. Regarding heterogeneity in the variance of random-parameter of "engine capacity of the motorcycle (cc)", crashes involving motorcycles with a pillion rider were found to have a lower variance.

5.2. Rider attributes

Crashes involving victims with no education are more likely to result in a fatal outcome. Table 2 shows that probability of sustaining severe, minor and no injury decreases by 0.0011, 0.0044 and 0.0002 respectively for rider with no education, while the probability of sustaining fatal injury increases by 0.0057. Our results are consistent with past findings (Borrell et al., 2005; Heydari et al., 2012; Sehat et al., 2012). With the increase in the education level, the motorcyclists tend to be more cautious about the safety. Educated road users often wear helmets and follow traffic regulations, therefore are less involved in severe traffic crashes (Kulanthayan et al., 2000; Houston and Richardson, 2008; Hung et al., 2008). Turning to the rider age, a number of different indicator variables were tried to explore the impact of age on crash injury severity. It was found that riders aged 25–50 years are more likely to be involved in severe injury crashes. The average marginal effects (Table 2) show that the probability of no injury, minor injury, and fatality decreases by 0.0007, 0.0142 and 0.0002

respectively while the probability of severe injury increases by 0.0151 for the riders between the age of 25–50 years. This is consistent with past findings. Riders aged 26–39 years are prone to medium risk injuries (Mannering and Grodsky, 1995). Talving et al., (2010) found higher crash injury severity for riders aged 19–55 years, compared to younger drivers. Higher injury severity for riders aged 25–50 years might be attributed to higher exposure to risk during morning and evening rush hours primarily being the working class. Pillion rider indicator was found significant in the minor injury outcome. It was observed that crashes involving motorcycles with pillion rider increase the likelihood of minor injuries and decrease the probability of severe and fatal injuries. The average marginal effects indicate that the probability of minor injury increases by 0.0283 and decreases for severe and fatal injury by 0.0226 and 0.0013 respectively. This may be attributed to reduced motorbike speed due to increase in motorcycle mass with a pillion rider. This may also be attributed to increased vigilance and reduced risky behavior in the presence of pillion rider. This finding is consistent with past studies where it was revealed that the presence of pillion rider can lower the probability of fatalities (Cooper et al., 2005; Jou et al., 2012).

5.3. Crash characteristics

Motorcycle-rickshaw (motorcycle pulling an attached two-wheeled passenger area) indicator was found to be a significant fixed parameter in the fatal crash function. Table 2 shows that probability of sustaining minor and severe injury increases by 0.0007 and 0.0001 respectively for motorcycle-rickshaw crashes, while the probability of sustaining fatal injury decreases by 0.0009. It was found that the collision of a motorcycle with a motorcycle-rickshaw is less likely to cause a fatal

Table 2

Estimation Results of Random Parameters logit Model with Heterogeneity in Mean and Variance.

Variable	Parameter estimate	t-Stat.	Marginal Effects			
			No Injury	Minor Injury	Severe Injury	Fatal Injury
Constant[NI]	−2.623	−20.35				
Constant[SI]	−0.696	−4.34				
Constant[FI]	−4.723	−9.93				
Random Parameters (normally distributed)						
Engine capacity of the motorcycle (cc) [SI]	0.013	2.67	−0.0013	−0.0293	0.0308	−0.0002
Standard deviation of "Engine capacity of the motorcycle (cc)" (normally distributed) [SI]	0.031	3.35				
Heterogeneity in Mean of the Random Parameter						
Engine capacity of the motorcycle (cc): Female Pillion rider (1 if pillion rider is female; 0 otherwise) [SI]	0.008	2.87				
Heterogeneity in Variance of the Random Parameter						
Engine capacity of the motorcycle in (cc): Pillion rider (1 if Pillion rider was present on motorcycle during the crash event; 0 otherwise) [SI]	−0.248	−1.99				
Rider Attributes						
No education indicator (1 if rider has no education, 0 otherwise) [FI]	1.706	5.53	−0.0002	−0.0044	−0.0011	0.0057
25-50 years indicator (1 if age of the rider is between 25-50 years, 0 otherwise) [SI]	0.266	2.58	−0.0007	−0.0142	0.0151	−0.0002
Pillion rider indicator (1 if pillion rider was present, 0 otherwise) [MI]	0.612	5.08	−0.0044	0.0283	−0.0226	−0.0013
Crash Characteristics						
Motorcycle-Rickshaw collision indicator (1 if crash included a motorcycle and rickshaw, 0 otherwise) [FI]	−2.459	−3.35	0.0000	0.0007	0.0001	−0.0009
Passenger car indicator (1 if motorcyclist collided with a passenger car, 0 otherwise) [SI]	0.756	5.26	−0.0012	−0.0270	0.0289	−0.0007
Heavy vehicle collision indicator (1 if motorcyclist collided with bus, tractor or truck, 0 otherwise) [SI]	1.382	5.57	−0.0004	−0.0099	0.0107	−0.0003
Object collision indicator (1 if motorcyclist collided with a fixed object (pole, barrier, tree, wall), 0 otherwise) [SI]	0.787	3.35	−0.0002	−0.0048	0.0052	−0.0001
Single-vehicle motorcycle crash (1 if rider involved in a single vehicle crash; 0 otherwise) [FI]	−5.867	−2.22	0.0001	0.0014	0.0002	−0.0017
Roadway Characteristics						
Local road indicator (1 if crash occurred on local road,0 otherwise) [MI]	0.816	2.94	−0.0019	0.0059	−0.0038	−0.0001
70 kmph indicator (1 if crash occurred on a road with posted speed limit of 70 kmph or higher, 0 otherwise) [SI]	0.243	2.03	−0.0006	−0.0121	0.0128	−0.0002
Speed limit below 50 kmph indicator (1 if crash occurred on a road with posted speed limit below 50 kmphr, 0 otherwise) [NI]	1.203	3.12	0.0032	−0.0028	−0.0004	−0.0000
Median indicator (1 if crash occurred on concrete median divided road, 0 otherwise) [SI]	−0.658	−3.90	0.0026	0.0549	−0.0584	0.0009
Temporal Characteristics						
Weekday indicator (1 if crash occurred on weekdays, 0 otherwise) [FI]	1.072	2.35	−0.0003	−0.0058	−0.0014	0.0075
May indicator (1 if crash occurred in the month of May, 0 otherwise) [SI]	0.428	2.38	−0.0002	−0.0045	0.0047	−0.0001
August indicator (1 if crash occurred in the month of August, 0 otherwise) [SI]	0.440	2.61	−0.0002	−0.0045	0.0048	−0.0001
November indicator (1 if crash occurred in the month of November, 0 otherwise) [FI]	1.083	2.76	−0.0001	−0.0013	−0.0003	0.0016
6am-9am indicator (1 if crash occurred between 6am to 9am, 0 otherwise) [SI]	0.280	1.97	−0.0002	−0.0034	0.0036	−0.0001
3 pm-6 pm indicator (1 if crash occurred between 3 pm to 6 pm, 0 otherwise) [SI]	0.401	3.08	−0.0005	−0.0099	0.0105	−0.0002
Motorcycle Specific Details						
Motorcycle registration status indicator (1 if victim's motorcycle is registered,0 otherwise) [SI]	−0.444	−3.58	0.0015	0.0312	−0.0331	0.0005
Chinese brand indicator (1 if victim's motorcycle is manufactured by a Chinese company (Hero, United, Unique, Union Star etc.), 0 otherwise) [MI]	0.218	2.30	−0.0019	0.0101	−0.0076	−0.0005
Weather Condition						
Dry weather indicator (1 if crash occurred in dry weather, 0 otherwise) [NI]	−0.341	−2.20	−0.0060	0.0050	0.0009	0.0001

Parameter defined for: [NI] No Injury; [MI] Minor Injury; [SI] Severe Injury; [FI] Fatal Injury.

Table 3

Goodness-of-fit of the competing models.

Model statistics	Model with no heterogeneity in mean and variance	Model with heterogeneity in mean and variance
Number of parameters	27	28
Restricted Log-likelihood	−7362.609	−7362.609
Log-likelihood at convergence	−3729.526	−3726.430
Akaike information criterion (AIC)	7513.052	7508.86
Bayesian information criterion (BIC)	7690.645	7693.031
Number of Observations	5311	5311

injury which is intuitive as both colliding vehicles have low momentum. Savolainen and Mannering (2007) found similar results for collisions between two motorcycles. Passenger car collision indicator was found significant in severe injury outcome. It was found that the collision of a motorcycle with a passenger car is more likely to result in a severe injury. This is intuitive as passenger cars are more likely to operate at higher speeds; therefore, if involved in a crash with a motorcyclist can potentially lead to severe injuries. The positive

significance of heavy vehicle indicator in the severe injury outcome indicates that motorcycle-heavy vehicles (truck or bus) crashes are more likely to result in severe injuries compared to minor injuries. The results are intuitive and consistent with past findings. Savolainen and Mannering (2007) found that collision of motorbikes with tractor-trailers greatly increases the probability of severe and fatal injuries. Object collision indicator was a significant fixed parameter in severe injury outcome. It was observed that collision of a motorcyclists with a fixed

object i.e. barrier, curb-stone, pole etc. increases the probability of severe injuries. Synonymous results were obtained in past studies (Quddus et al., 2002; Savolainen and Mannering, 2007). It was also revealed that single-vehicle motorcycle crashes are less likely to result in fatal injuries and more likely to result into serious or minor injury crashes which is also intuitive.

5.4. Roadway characteristics

Crashes occurring on local roads increase the likelihood of minor injuries which is also intuitive. On local roads due to the limited number of lanes and lower operating speeds, crashes are more likely to result in minor injuries as compared to severe or fatal injuries (Shankar and Mannering, 1996; Savolainen and Mannering, 2007; Li et al., 2009; Pai, 2009). Motorcycle riding on roads with a posted speed limit of 70-kmph or higher increases the likelihood of severe injuries compared to minor injuries. It is intuitive as speeding is a major contributory factor in severe road crashes. The average marginal effects show that probability of severe injury increases by 0.0128 and minor injury decreases by 0.0121 for roads with posted speed limits of 70-kmph or higher. This is also consistent with past findings.; Shanker and Mannering (1996) and Savolainen and Mannering (2007) found that speeding increases the likelihood of severe and fatal injury crashes. Crashes on roads with a posted speed limits below 50-kmph are more likely to result in no injuries, which is also intuitive. The average marginal effects (Table 2) shows that the probability of minor injury and severe injury decreases by 0.0028 and 0.0004 respectively while the probability of no injury increases by 0.0032 for roadway segments with posted speed limits below 50-kmph. Majority of the roads with speed limits below 50-kmph in Rawalpindi city run through market places or residential streets, therefore, crashes occurring on these roads are less likely to be severe, as there are few speeding opportunities even for riders with risky-behavior. Median indicator (concrete median barrier) was found significant in the severe injury outcome. It was observed that crashes occurring on median divided roadways are less probable to result in severe injuries. This is intuitive as median barriers are primarily installed to prevent head-on-collisions and reduce crash severity (McNally and Yaksich, 1992; Donnell and Mason, 2006; Tarko et al., 2008). With the low level of police enforcement in most of the urban areas of Pakistan, many riders resort to wrong-way driving. Median divided highway help in preventing wrong-way driving, which usually results in severe crashes.

5.5. Temporal characteristics

Weekday indicator was a significant fixed parameter for fatal injury outcome. It was observed that crashes occurring on a weekday increase the likelihood of fatal injuries compared to minor injuries. It might be attributed to aggressive driving by middle and lower class riders for the daily commute. Crashes occurring during the months of May and August increase the probability of severe injuries. During August the monsoon season is at its peak in the city, thus, wet road surface may increase the likelihood of severe injury crashes. May is the last month of spring and temperature is relatively moderate. Higher injury severity may be attributed to higher speed selected by riders during relatively pleasant weather conditions. November indicator variable was found significant with positive coefficient in the fatal injury outcome. This indicates that the probability of victims involving in fatal injury crash increases during this month. Average daily temperature starts to drop in the mid of November and traditionally warm clothes are used by riders during this season that may restrict rider movements and operational capabilities. Also, smoggy conditions in the city during November can lead to poor visibility, thus resulting in more severe crashes (Singh and Suman, 2012). The next finding relates to the time of the crash, which is defined for severe injury severity level. Results revealed that injury severity of motorcycle crashes is higher if a crash occurred during the

early morning hours (6am-9am) or late afternoon/early evening time (3 pm-6 pm). It might be due to aggressive riding behavior (e.g. speeding) by riders leaving for work or schools during the early morning hours and returning back home during late afternoon hours. Also, the probability of a motorcyclist suffering a severe injury is higher during late afternoon hours (0.0105) than the early morning hours (0.0036) (Table 2). It might be due to lack of concentration/ poor observation as a result of mental and physical tiredness of riders. Also, due to day-long activity, driver's reaction times are slower and higher level injury severity may result due to traffic crashes occurring during evening hours. Lack of concentration/ poor perception-reaction time may also be one of the reasons for a higher crash frequency (19.2%) during late afternoon hours (Table 1).

5.6. Motorcycle specific details

The parameter estimate for motorcycle registration status indicator was found significant with fixed parameter in the severe injury outcome. Model estimation results show that crashes involving registered motorcycles are less likely to result into severe injuries compared to unregistered motorcycles. Average marginal effects show a decrease in the probability of severe injuries by 0.0331 and increase in the probability of minor injuries by 0.0312 for crashes involving registered motorcycles. These results are consistent with previous research findings. It is also likely that new unregistered motorcycles are operated by less skilled drivers which could be a greater threat to rider's safety (Lin et al., 2003; Sexton et al., 2004; Harrison and Christie, 2005).

The parameter estimate for engine capacity of the motorcycle was found significant random parameter with heterogeneity in mean and variance in the severe injury outcome. Model estimation results show that increased engine capacity resulted in more severe crashes. This finding is intuitive and consistent with past research (Lin et al., 2003; Sexton et al., 2004; Harrison and Christie, 2005; Quddus et al., 2002).

Motorcycle of Chinese brand (Hero, United, Union star, Hi-speed etc.) are more likely to be involved in minor injury crashes and are less likely to be involved in severe and fatal injury crashes. There is a very small share of local-brand motorcycles (8%) and majority of the motorcycles in Pakistan are either Japanese or Chinese brand. Compared to Chinese brand motorcycles, on average Japanese brand motorcycles have 68% higher price for 70cc engine capacity and 98% higher price for 100cc engine capacity motorcycles (PAMA, 2016). This price difference may be attributed to a lower manufacturing quality of the Chinese brand motorcycles. Even with the same engine capacity, it is difficult to operate a Chinese brand motorcycle at higher speed relative to Japanese-brand motorcycle mainly due to the differences in the manufacturing quality. Thus, low injury severity of Chinese brand motorcycles may be attributed to their inability to attain higher speed owing to lower manufacturing quality. In addition, this finding may also be attributed to a difference in the risk-taking behaviour of Chinese- vs. non-Chinese-brand motorcyclists.

5.7. Weather conditions

Dry weather indicator was a significant fixed parameter in no injury outcome. The negative coefficient of the parameter indicates that crashes occurring in dry weather are less likely to cause no injuries and more probable to result in injury crashes (minor, severe and fatal). This could be due to high travel speed selected by riders with a perception of safer driving conditions. Finding is consistent with past research that revealed that crashes during dry weather result into severe casualties due to risk compensating behavior of the riders (Quddus et al., 2002; Savolainen and Mannering, 2007; Shaheed et al., 2013; Shaheed and Gkritza, 2014).

6. Summary and conclusion

Motorcycle safety in Pakistan is plagued by issues such as low tendency to wear helmet, use of non-standard helmets, speeding, running a red light, underage riding and low level of police enforcement. This research focused on identifying factors affecting injury severity of motorcycle crashes in a developing country, Pakistan. A random parameters logit model with heterogeneity in means and variances was estimated using crash data obtained from a provincial emergency response unit. Mainly the effect of speed limits, rider attributes, crash-specific factors, roadway characteristics, weather and socio-demographics factors were considered for motorcycle-injury severity analysis.

Study results revealed that probability of fatal/ severe injury increases for crashes; that involve young and middle-aged riders (25–50 years), riders with no education, occurring on roads with posted speed limit of 70- kmph or higher, involving a motorcycle and a heavy vehicle, involving collision with a fixed object, occurring during dry weather conditions, in the early morning hours or late afternoon and/or early evening hours. Also, the probability of minor injury increases for crashes that occur on road segments with a posted speed limit of less than 50- kmph crashes involving a registered motorcycle, crashes involving Chinese brand bikes, crashes on divided streets, and crashes where at least one motorcycle and auto rickshaw was involved.

The research findings suggest that besides measures to control/reduce the risky behavior from motorcyclists (speeding, following too closely, running a red light, not wearing a helmet and improper lane changes etc.), there is a need to lower speed limits on roadway segments with higher motorcycle proportion, separation of motorcyclist from heavy vehicles and by removing dangerous fixed objects such as poles and trees from roadside. Also, by encouraging the use of low engine capacity bikes for daily commute can help in lowering injury severity. Educating and making the riders aware of the factors found to increase the injury severity, appropriate enforcement and regulation of the traffic laws particularly on motorcycle registration and driving licensing might be useful in minimizing the risks and reduceing the number of road crash injuries and fatalities involving motorcycles.

Although most of the results of this study are generally consistent with published literature on motorcycle crash severity, however, due to significant differences in highway driving/ riding environment in Pakistan from developed countries their implications have increased importance. Besides data limitations, this is a pioneer study on motorcycle crash injury severity in the country. Results are expected to generate more discussion and interest in motorcycle safety in the country and can be used by the City Traffic Police and highway agencies in the country to enhance road safety. Availability of quality data in the future can offer an opportunity for more in-depth assessment of motorcycle safety in Pakistan.

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