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A comparative injury severity analysis of motorcycle at-fault crashes on rural and urban roadways in Alabama

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ABSTRACT

The research described in this paper explored the factors contributing to the injury severity resulting from the motorcycle at-fault accidents in rural and urban areas in Alabama. Given the occurrence of a motorcycle at-fault crash, random parameter logit models of injury severity (with possible outcomes of fatal, major, minor, and possible or no injury) were estimated. The estimated models identified a variety of statistically significant factors influencing the injury severities resulting from motorcycle at-fault crashes. According to these models, some variables were found to be significant only in one model (rural or urban) but not in the other one. For example, variables such as clear weather, young motorcyclists, and roadway without light were found significant only in the rural model. On the other hand, variables such as older female motorcyclists, horizontal curve and at intersection were found significant only in the urban model. In addition, some variables (such as, motorcyclists under influence of alcohol, non-usage of helmet, high speed roadways, etc.) were found significant in both models. Also, estimation findings showed that two parameters (clear weather and roadway without light) in the rural model and one parameter (on weekend) in the urban model could be modeled as random parameters indicating their varying influences on the injury severity due to unobserved effects. Based on the results obtained, this paper discusses the effects of different variables on injury severities resulting from rural and urban motorcycle at-fault crashes and their possible explanations.

1. Introduction

Motorcycle riders are more vulnerable than other motor vehicle users once involved in accidents (Shaheed et al., 2013; Rifaat et al., 2012). Motorcycles differ from other motor vehicles in their physical design (e.g., smaller size, two wheel base) and driver exposure. These factors make motorcycles highly unstable for their user while providing little protection during accidents (Fagnant and Kockelman, 2015; Daniello et al., 2010). As a result, a motorcycle is 26 times more likely to have a fatality than a passenger car (NHTSA, 2015). This fact means that even though motorcyclists are not on the road as much as passenger cars, they still have a higher fatality rate. In many instances, the motorcycle involved crashes occur because drivers of other vehicles simply do not clearly see motorcyclists on the road. However, drivers of passenger cars or trucks are not always to blame for motorcycle accidents. Sometimes motorcyclists are the ones at fault either due to speeding, intoxication, or many other factors (Schneider et al., 2012).

There has been a prevailing public perception that compared to other motorists, motorcyclists are more likely to demonstrate high risk behaviors such as speeding, drinking and riding, or riding without a helmet (Schneider et al., 2012). Such behaviors increase the risk of accident involvement and also the risk of being found at-fault in the event of an accident (Schneider et al., 2012). Furthermore, motorcyclists who are at-fault in crashes are also found to be more likely to be killed in the event of a crash (Savolainen and Mannering, 2007). In 2015, motorcycle riders involved in fatal crashes in the United States had higher percentages of alcohol impairment than any other type of motor vehicle drivers (27% for motorcycle riders, 21% for passenger car drivers, 20% for light-truck drivers, and 2% for drivers of large trucks) (NHTSA, 2017). Similarly, higher percentages of motorcycle riders involved in fatal crashes were speeding compared to other type of motor vehicle drivers (33 percent for motorcycle riders, 19 percent for passenger car drivers, 15 percent for light-truck drivers, and 7 percent for large truck drivers) (NHTSA, 2017). In addition, 40 percent of the 4976 motorcyclists killed in motor vehicle traffic crashes in 2015 were not helmeted. An observation of police reported crash data in Alabama provided by the Center for Advanced Public Safety (CAPS) revealed that, during the period from 2010 to 2014, there were 5882 motorcycle at-fault accidents in Alabama. These accidents resulted in 2082 (35.4%) fatalities and incapacitating injuries, and 2000 (34.0%) non-

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incapacitating injuries. It was also observed that fatality rates from motorcycle at-fault crashes at rural locations were more than twice that at urban locations. Although there have been significant efforts (Debnath and Haworth, 2016; Shaheed et al., 2013; Rifaat et al., 2012; Savolainen and Mannering, 2007; Quddus et al., 2002; Shankar and Mannering, 1996) to understand injury severity in motorcycle crashes, very few of them investigated the injury severity patterns and the risk factors associated with crashes in which only the motorcyclists were at-fault. Recently, Debnath and Haworth (2016) used insurance claim data to study motorcyclist at-fault crashes. However, their study had some limitations, such as they used a very small dataset with only 356 observations. In addition, their analysis did not include variables related to roadway geometry and traffic related factors, because of the absence of such information in the insurance dataset. To overcome the aforementioned limitations, in this study, we used a larger dataset of motorcycle at-fault crashes in Alabama filtered from the original police reported crash database. We explored the factors influencing injury severities resulting from motorcycle at-fault crashes in rural and urban areas in Alabama. The rural and urban crashes were analyzed separately because researchers in the past (Brenac et al., 2006; Gkritza, 2009; Li et al., 2008) found that rural and urban locations produce different effects on the risk taking behavior of the motorcyclists. For example, Brenac et al. (2006) found that a motorcyclist's speed is significantly higher for motorcycle-involved crashes in urban areas than in rural areas; Gritzka (2009) and Li et al. (2008) reported that motorcyclist's helmet use rate is lower on urban roads compared to rural roads. Therefore, greater understanding of the location specific factors associated with motorcycle at-fault crashes is required to develop effective motorcycle safety countermeasures and safety campaigns.

Chen and Chen (2011) showed that consideration of unobserved heterogeneity in parameter effects in the injury severity analysis can better model the complex interactions of different variables and the nature of injuries. Therefore, to capture unobserved heterogeneity in parameter effects, we used the random parameter logit model approach in this study. We estimated random parameter logit models to explicitly examine and compare the factors influencing the injury severities resulting from motorcycle at-fault accidents on rural and urban roadways in Alabama.

2. Methodology

Mannering and Bhat (2014) and Savolainen et al. (2011) have provided comprehensive reviews of crash injury severity models and methodological approaches used by researchers to explore crash risk factors and severity outcomes. The current research employed a mixed-logit model approach (Islam et al., 2016; Islam et al., 2014; Kim et al., 2013; Shaheed et al., 2013; Morgan and Mannering, 2011; Gkritza and Mannering, 2008) to capture unobserved heterogeneity that may result in the effect of explanatory variables being different from one motorcycle at-fault crashes to another. This study used four injury-severity categories: possible/no injury, minor injury, major injury and fatal injury. Given that four discrete outcomes were possible, an appropriate statistical modeling approach would be to use an ordered discrete probability model. However, the traditional ordered models may not always be appropriate for accident severity data due to some inherent limitations. Washington et al. (2011) and Yasmin and Eluru (2013) have provided detailed discussions on the limitations of traditional ordered models. One of the major limitations of the traditional ordered models is that they can restrict the influence of explanatory variables on severity outcomes (Khorashadi et al., 2005; Kim et al., 2013; Yasmin and Eluru, 2013). These models restrict variables to either increase the highest severity category and decrease the lowest, or increase the lowest severity category and decrease the highest. Although it is possible to use random parameter ordered models, the aforementioned limitation still exist (Kim et al., 2013). Therefore, the traditional simple ordered models may not always be appropriate for accident severity data. As a result, it is more appropriate to use the unordered discrete outcome model approach in injury severity analysis. Therefore, we employed the mixed logit model approach in this research.

In this study, the mixed logit approach began with a propensity function that determines injury severity,

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

where, S_{in} is a severity function that determines motorcyclist-injury severity category i in crash n, X_{in} is a vector of explanatory variables that affect motorcyclist-injury severity category i in crash n, β_i is a vector of estimable parameters for motorcyclist-injury severity category i, andε_{in} is an error term. Assuming $\varepsilon_{in}$is generalized extreme value distributed (McFadden, 1981), the probability $P_n(i)$ of the ith outcome for the nth observation in the standard multinomial logit model is specified as follows (Washington et al., 2011):

$$P_n(i) = \frac{e^{\beta_i x_{in}}}{\sum_{\forall I} e^{\beta_i x_{in}}} \tag{2}$$

The mixed logit model is a generalization of the multinomial logit model which allows the parameter vector $\beta_i$to vary across each observation. In the mixed logit model, the injury outcome-specific constant and each element of the parameter vector β_i can be either fixed or randomly distributed with fixed means. Accordingly, to allow for heterogeneity, random parameters are introduced with$f(\beta_i|\varphi)$, where φ is a vector of parameters of a chosen density function (mean and variance). If the variance in φ is determined to be significantly different from zero, there will be observation-specific variations of the effect of X on injury severity across each accident observation n, with the density function $f(\beta_i|\varphi)$ used to determine the values of β_i across accidents (Train, 2003). The probabilities in mixed-logit injury-severity analyses are specified as follows (Train, 2003; McFadden and Train, 2000):

$$P_n(i|\varphi) = \int \frac{e^{\beta_i x_{in}}}{\sum_{\forall I} e^{\beta_i x_{in}}} f(\beta_i|\varphi) d\beta_i \tag{3}$$

where, $P_n(i|\varphi)$ is the probability of injury severity i conditional on $f(\beta_i|\varphi)$.

In this study, the mixed logit models were estimated using a simulation-based maximum likelihood method. Econometric and statistical software NLOGIT 4.0 was used for model estimation. The simulation points were sampled using Halton draws (Train, 2003; Halton, 1960; Bhat, 2003). Bhat (2003) demonstrated that Halton draws of a specific number produce results as accurate as ten times that number in pure random draws. The final results in the present study are based on 500 Halton draws.

To determine if a variable could be modeled as a random parameter and then the distribution of that random parameter, a stepwise iterative process was followed. Each variable was tested in the model as either fixed or random. Statistical testing of the improvement in likelihood was used to determine the best fit. The process continued until the model was stable to changes. As a part of this study, several distributional forms (normal, lognormal, Weibull, etc) were tested as potential distribution for model parameters. The normal distribution was found to provide the best estimation results. This finding is consistent with past research (Gkritza and Mannering, 2008; Milton et al., 2008), which found that the normal distribution generally establishes the best fit for injury severity data.

Beyond inspection of the mixed logit model, the concept of direct pseudo-elasticity (Washington et al., 2011) is often used to assess the impact of indicator variables (variables taking on values of 0 or 1) on crash severity predictions. The direct pseudo-elasticity of a variable with respect to a severity category represents the percent change in the probability of that injury category when the variable is changed from 0 to 1. The direct pseudo-elasticity of the k^{th} independent variable x_{nk} with respect to the probability P_{ni} of individual n experiencing injury