Accident Analysis and Prevention 89 (2016) 142–150

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Copula-based regression modeling of bivariate severity of temporary disability and permanent motor injuries

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ARTICLE INFO

Article history:
Received 4 May 2015
Received in revised form 11 January 2016
Accepted 16 January 2016

Keywords:
Bodily injuries
Multiple severities
Frank copula
Vuong test

ABSTRACT

The analysis of factors influencing the severity of the personal injuries suffered by victims of motor accidents is an issue of major interest. Yet, most of the extant literature has tended to address this question by focusing on either the severity of temporary disability or the severity of permanent injury. In this paper, a bivariate copula-based regression model for temporary disability and permanent injury severities is introduced for the joint analysis of the relationship with the set of factors that might influence both categories of injury. Using a motor insurance database with 21,361 observations, the copula-based regression model is shown to give a better performance than that of a model based on the assumption of independence. The inclusion of the dependence structure in the analysis has a higher impact on the variance estimates of the injury severities than it does on the point estimates. By taking into account the dependence between temporary and permanent severities a more extensive factor analysis can be conducted. We illustrate that the conditional distribution functions of injury severities may be estimated, thus, providing decision makers with valuable information.

1. Introduction

Personal injuries arising from traffic accidents can be classified into two categories: temporary disabilities and permanent injuries. The former can be defined as an impairment of an individual's mental or physical faculties that might impede the victim from functioning normally for as long as they remain under treatment (or until their injuries have stabilized); the latter is understood to be a physical or mental injury that will impose certain restrictions on the employment and/or other activities of a traffic victim for the rest of their life. In this study we examine the bidimensional composition of personal injuries in order to shed some light on the interaction of these two categories.

A possible approach to the evaluation of the severity of a temporary disability is to measure the time it takes for a traffic victim to recover fully or for their injuries to stabilize. In this article, the period of recuperation is calculated as the number of working days lost because of the accident including the number of days the victim is hospitalized. This definition is provided by Spain's insurance legal system and is based on the number of days of medical leave taken, which can be evaluated for both working and non-working groups (including the unemployed, the young and the elderly).

Any evaluation of permanent injuries arising from an accident is made once the victim's condition has stabilized (i.e., it is assumed their injuries will not be subject to any further evolution according to medical criteria). At this stage the permanent impairment resulting from the injuries is evaluated. Most EU member states operate systems for bodily injury assessment to quantify the amount of compensation to be paid out for permanent injuries following a motor accident. In countries such as Italy, France, Belgium and Spain these systems comprise medical scales for evaluating the severity of permanent injuries. In 2003, however, an attempt at homogenizing medical evaluation practices in the EU was made with proposals for a European disability rating scale (EP, 2003).

In the case of Spain a system of bodily injury scores is used in appraising the permanent injury severity of non-fatal victims of traffic accidents and is used in this article for this same purpose (see Ayuso and Santolino, 2007, for a review of the system). The scoring system involves applying a single numerical value that ranges from zero, for a victim without any permanent injury, to one hundred and indicates the percentage of difficulty the victim faces in performing activities of daily living. Although not expressly created to evaluate the injuries of motor victims, international medical scoring systems are widely used in assessing the severity of a patient's illness. They include the Injury Severity Score (ISS), which is based on the

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http://dx.doi.org/10.1016/j.aap.2016.01.008
0001-4575/

Abbreviated Injury Scale (AIS) and is probably the most frequently used system for assessing trauma severity around the world (Baker et al., 1974), and the International Classification of Disease (ICD)-based Injury Severity Score (ICISS) (for a comparison, see Osler et al., 1996).

The analysis of the factors influencing the severity of injury of traffic victims has been extensively covered in the specialized literature. A variety of statistical models have been applied in investigating the effects of road conditions, driver attributes and vehicle characteristics on severity of injury. This variety reflects the need to model different qualitative or quantitative outcome variables when measuring temporary disabilities or permanent injuries.

Most of this literature has examined the relationship between a set of factors and a specific outcome variable of the severity of temporary disability, on the one hand, or permanent injury, on the other. To the best of our knowledge, little attention has been paid to personal injury severity as a whole; that is, the simultaneous consideration of temporary disability severity and permanent injury severity. A prior intuition suggests that these two categories of severity are not independent and that we can expect to observe a positive correlation between them. However, what we seek to determine is whether the expected dependence between the two categories affects the analysis of factors influencing the severity of personal injury.

1.1. A two-dimensional modeling approach

In this paper, a bivariate copula-based regression model for temporary disability and permanent injury severities is introduced for the joint analysis of the relationship with the set of factors that might influence both categories of injury. Using this model, we aim to achieve a better factor analysis of personal injury severity by taking into account the dependence between permanent and temporary severities. In particular, such a model allows us to estimate the joint distribution function and hence to know the marginal and the conditional distribution functions. Here, we follow the methodology proposed by Krämer et al. (2013) to conduct a copula-based regression.

The dataset was previously used in a marginal regression analysis of personal injuries in Santolino et al. (2012) and Boucher and Santolino (2010). In the first article, a generalized Tobit regression model was applied in analyzing the factors that influence both the likelihood of being admitted to hospital after a motor collision and the length of hospital stay in the event of admission. In the second article, also in the univariate setting but in relation to permanent severity, the effects of a victim's characteristics, the road user type and recovery duration in relation to permanent injury severity were examined using different discrete regression models. In the Boucher and Santolino's study temporary disabilities were included via regressors to explain the permanent injury severity. Their results showed that the length of the recovery period, including time spent in and out of hospital, affected the expected permanent injury severity score.

The bidimensional design proposed in this study to take into consideration multivariate dependence is a more flexible modeling approach than the inclusion of temporary disabilities via regressors in the modeling of permanent disability. First, a deeper understanding of the underlying interdependence between injury variables can be achieved. The two dependent variables are regressed on two sets of explanatory variables. So, the effect of regressors and the mutual dependence between the two injury variables are jointly analyzed. When the temporary disability is included as an exogenous variable, the effect of the remaining regressors on the temporary disability is not directly shaped. In this latter case, no conclusion can be drawn with regard to the way in which the explanatory factors influence the severity of the personal injuries as a whole, i.e. what the joint effect of the explanatory factors is on temporary disabilities and permanent injuries, taking into account the dependence between the respective severities of personal damage. Second, under our bidimensional approach, the joint distribution of the two injury variables and the marginal distributions are known (or estimated), so the conditional probability distribution of the permanent injury severity given a temporary disability can be fully computed. This is useful when the temporary disability of the victim is unknown (e.g. at the moment just after the collision). In our approach the marginal distribution of the permanent injury severity can still be estimated. If this information is included as a regressor, an unknown temporary disability severity cannot be confused with the case in which the regressor is equal to zero (i.e. the victim did not sustain temporary disabilities). Third, the use of other statistical measures of association different from the linear correlation, such as rank correlations, is appropriate for the dependence specification in our bidimensional modeling approach.

1.2. Literature review

Different approaches are to be found in the literature to the univariate analysis of temporary disability severity, depending on the outcome variable used to measure this disability. The most common approach is to consider length of hospitalization as an outcome variable (Guria, 1990; Gardner et al., 2007; Peek-Asa et al., 2011) and to examine its relationship with injury and victim characteristics. However, this approach may underestimate the total financial cost of a traffic injury. Non-serious injuries do not generally require hospitalization, but they may be associated with substantial work disability, the case, for example, of whiplash injuries (Buitenhuis et al., 2009). Ebel et al. (2004) studied the number of work days lost as a result of motor vehicle crashes and the factors that influenced a victim's return to work. Berecki-Gisolf et al. (2013) described the distribution and determinants of work disability outcomes for traffic injury victims including injuries not sufficiently severe to require hospitalization.

A number of univariate analyses of permanent injury severity should be mentioned. In a seminal paper, O'Donnell and Connor (1996) used ordered multiple choice models to predict the severity of motor vehicle accident injuries. More recently, the studies of Savolainen et al. (2011) and Mannering and Bhat (2014) have provided a thorough review of statistical analyses of the severity of permanent injuries. Among others, Kockelman and Kweon (2002), Delen et al. (2006), Tay and Rifaat (2007), Yasmin and Eluru (2013) and Ye and Lord (2014) have examined the question in relation to a number of areas of traffic safety. Other authors have analyzed the impact of road traffic injuries on disability rates and long-term care (Alemany et al., 2013; Chen et al., 2013; Dhondt et al., 2013, Ameratunga et al., 2004).

In a bivariate setting, Rana et al. (2010) consider a copula based regression approach in their joint modeling of collision type and injury severity. Yasmin et al. (2014) extended the Rana's model framework allowing more flexible dependence structures between variables. A copula based model is also used by Eluru et al. (2010) to account for the injury severity dependence of multiple vehicle occupants. Finally, Wang et al. (2015) suggest a copula based model to estimate the injury severity and the vehicle damage. The marginal distributions considered in these studies are mainly the logit and probit.

The article is organized as follows. Section 2 describes the methodology; Section 3 presents the data and variables; Section 4 summarizes the results; and, finally, Section 5 concludes.