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Accident severity levels and traffic signs interactions in state roads: a seemingly unrelated regression model in unbalanced panel data approach

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ABSTRACT

This study intended to investigate the interactions between accident severity levels and traffic signs in state roads located in Croatia, and explore the correlation within accident severity levels and heterogeneity attributed to unobserved factors. The data from 410 state roads between 2012 and 2016 were collected from Traffic Accident Database System maintained by the Republic of Croatia Ministry of the Interior. To address the correlation and heterogeneity, a seemingly unrelated regression (SUR) model in unbalanced panel data approach was proposed, in which the seemingly unrelated model addressed the correlation of residuals, while the panel data model accommodated the heterogeneity due to unobserved factors. By comparing the pooled, fixed-effects and random-effects SUR models, the random-effects SUR model showed priority to the other two. Results revealed that (1) low visibility and the number of invalid traffic signs per km increased the accident rate of material damage, death or injured; (2) average speed limit exhibited a high accident rate of death or injured; (3) the number of mandatory signs was more likely to reduce the accident rate of material damage, while the number of warning signs was significant for accident rate of death or injured.

1. Introduction

With the development of economy and society, a variety of roadside signs, e.g. advertising signs, neon lights, and gaudy billboards are emerging and dominating the visual landscape in many urban and suburban areas, which makes the roadside environment changeable and complicated. Although there are some studies focusing on the impact of such development, limited studies have investigated the relationship between the signs and traffic safety in Croatia. Among these, traffic signs, primary means of communication between the road authorities and traffic participants, play an important role as a principal causative factor by affecting drivers' reaction time and road safety.

Currently a number of studies concentrate on the traffic sign detection, e.g. the color, the size, and lettering of road signs (Villalón-Sepúlveda et al., 2017; Vilchez, 2017), and although there are some studies (Carson and Mannering, 2001; Porter et al., 2007; Wu and Wang, 2013) attempting to establish the relationship between accidents and traffic signs, merely one type of specific traffic signs, e.g. warning signs, speed-limit signs, was investigated, which might not completely reflect the effectiveness of traffic signs and safety problem due to different categories of traffic signs.

During the last decade a variety of different approaches and perspectives (Lord and Mannering, 2010; Savolainen et al., 2011; Mannering and Bhat, 2014) have been presented in safety evaluation, involving accident frequency, accident severity or both as the function of influencing factors. However, different severity levels might be related, as possible correlations among different severity levels may exist. If dependent variables are co-dependent, and independent variables include endogenous and exogenous ones, a simultaneous equation model (SEM) is appropriate, whereas the variables are simply correlated in their regression error terms, a seemingly unrelated regression (SUR) approach becomes more reasonable (Wang and Kockelman, 2007; Washington et al., 2010). The seemingly unrelated regression estimation approach proposed by Zellner (1962) employs the correlation between disturbances in different equations to improve the efficiency of joint estimation (You and Zhou, 2014).

Moreover, various studies have indicated that heterogeneity issue can be addressed through finite mixture regression models (Park and Lord, 2007), and random parameter model (Anastasopoulos and Mannering, 2009; El-Basyouny and Sayed, 2009), in which the heterogeneity from the data or locations caused by unobserved factors was accommodated, and the estimation results and the statistical inferences

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were improved (Kim et al., 2010; Anastasopoulos and Mannering, 2011; Anastasopoulos et al., 2012; Abay, 2013; Aziz et al., 2013; Mannering et al., 2016; Anastasopoulos, 2016; Zeng et al., 2017; Fountas and Anastasopoulos, 2017). One way to deal with the heterogeneity issue is to adopt panel data, permitting more efficient estimation of parameters (You and Zhou, 2014), which has attracted considerable research interest in transportation safety.

To take advantage of the SUR approach and panel data modeling, a panel data SUR model was proposed combining the SUR approach with panel data modeling, and some scholars (Avery, 1977; Biørn, 2004; You and Zhou, 2014) have subsequently studied the statistical inference and applications of the panel data SUR model. Thus, the purpose of this study is to apply panel data SUR model to analyze different severity levels as functions of a series of traffic signs, in which the correlations between disturbances in different equations can be addressed, as well as the heterogeneity issue among different roadways.

2. Literature review

There have been a variety of studies about the relationship between accidents and traffic signs during the last thirty years, but they are investigated from different perspectives. Initially Loo (1979) discussed the role of primary personality factors in the perception of traffic signs, driver violations and accidents. The findings indicated that the fast decision-time component of personality factors carried the relationships with accidents and the ability to perceive embedded traffic signs in the verbal message and symbolic message types. As for the warning signs, Jørgensen and Wentzel-Larsen (1999) optimized the use of warning signs in traffic. It was concluded that warning signs would increase safety and have a greater positive impact on total driving costs than on accident costs. Similarly, Carson and Mannering (2001) investigated the effect of ice warning signs on ice accident frequencies and severities. It was found that an ice warning sign would be one way of understanding the impact of warning signs, and ice-warning signs were more likely to be placed at locations with high numbers of ice-related accidents. From the freeway point of view Wu and Wang (2013) explored the impact of speed-limit signs on freeway work zones. The speed-limit model was established by considering the relevant factors of driver's field of vision and transportation distance of visual cognition. The results showed the proposed speed-limit model within warning area played an important role for freeway traffic safety, while Xuan and Kanafani (2014) evaluated the effectiveness of accident information on freeway changeable message signs (CMS) by comparing different aggregate analysis methodologies. The findings showed that CMS accident messages had no significant effect on driver diversion but visible congestion is an important factor. On the other side, if too many signs are installed, the effect may be opposite. Strawderman et al. (2015) investigated the effect of signs on driver behavior and accident frequency in school zones. It was found that sign saturation had a significant effect on vehicle speed, compliance and accident frequency. All of the literatures abovementioned have not indeed built up the actual relationship between and traffic signs except the latest study by Babić et al. (2014, 2017). They analyzed traffic signs in terms of traffic safety in Croatia, and found out that improper installation and maintenance of traffic signs can affect the traffic safety, which is the base of this study.

So far there have been different applications of SUR model in different areas (Zellner, 1962; Moon and Perron, 2006; Zhou and Kockelman, 2009; You and Zhou, 2014; Kim et al., 2015), but the application in transportation safety area is very limited. Initially, Porter et al. (2007) investigated relationships between speed behavior, roadway and roadside geometrics and traffic control in work zones using seemingly unrelated regression (SUR) model. The SUR model accounted for contemporaneous correlation of the disturbance terms in 85th percentile passenger car speed and standard deviation of passenger car speed. Then Prozzi and Hong (2008) examined the performance of a transportation infrastructure through seemingly unrelated regression models. The results demonstrated international roughness index and rut depth were associated with different mechanisms, and model estimation was efficient when accounting for the correlation among the models.

Subsequently, SUR model was extended to various forms by integrating different models from cross-sectional to panel data model. Wang and Kockelman (2007) firstly proposed a spatially and temporally auto-correlated seemingly unrelated regression model and exampled the accident rates in China. The results showed that investment in transportation infrastructure was estimated to have statistically significant effects on reducing severe accident rates, and the incorporation of spatial and temporal effects improved the model. Then Zhou and Kockelman (2009) predicted the distribution of households and employment with seemingly unrelated regression model with two spatial processes. The results demonstrated that SUR estimation of land-use intensities from parcel-level data with two types of spatial dependence was feasible and meaningful. Later Kim et al. (2015) evaluated the impact of a household head's telecommuting on household travel while controlling for the interdependence within a household and across travel purposes by applying seemingly unrelated censored regression models in the Seoul Metropolitan Area. The analysis showed that when vehicle travel budgets of a given household were limited, the compensatory travel mechanism can make optimum use of limited resources, but offset the travel-substituting effect of telecommuting. From the perspective of economics, the latest study by Mao (2016) analyzed relationship between capital income, economic growth and income inequality. The seemingly unrelated regression with fixed effects panel data model and instrumental variable estimation technique were employed, which provides the foundation for this study theoretically, and the findings suggested that although capital income taxes hindered economic growth, they achieved the purpose of income redistribution.

Summarized by the abovementioned literatures, employing seemingly unrelated regression with panel data model to investigate different severity levels as functions of a series of traffic signs would be initial attempt in transportation area, which can address the correlations of severity levels and heterogeneity issue of different state roads.

3. Data description

Our dataset integrated the data of Traffic Accident Database System from 2012 to 2016 with the traffic signs maintained by the Republic of Croatia Ministry of the Interior. Four main components from the Traffic Accident Database System were included: the accident consequence, the traffic signs profiles, the accident environment, and roadway characteristics.

About 135 state roads were elaborately selected from Croatia in five years. As shown in Fig. 1, totally there were 665 state roads, but after removing some roads without data and processing, 410 valid state roads were determined for the analysis. In Croatia, the consequences of accidents are typically categorized as death, injured, or material damage. In our sample, the death cases only accounted for 2.1%. Given that the two adjacent accident categories were quite similar, merging the death and injured categories was not expected to substantially affect the inference. Consequently, the dependent variables in the proposed model were bivariate accident severity levels in which the response of interest referred to death and injured (DI), and material damage (MD) was treated as the contrast. As required by the SUR model, dependent variables should be continuous, thus accident rate (expressed as accidents per million vehicles miles travelled (MVMT)) is introduced to represent MD and DI. The way that accident rate is considered is because incorporates the effect of volume and road length, it is more adequate to measure the accident risk faced and perceived by individual drivers than accident frequency, which is highly related to the traffic volume (Schultz et al., 2008). Thus, the variables road length, traffic volume and the number of accidents cannot be included in the independent variables to avoid the estimation bias.