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# Examining pedestrian-injury severity using alternative disaggregate models

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ABSTRACT

This paper investigates the injury severity of pedestrians considering detailed road user characteristics and alternative model specification using a high-quality Danish road accident data. Such detailed and alternative modeling approach helps to assess the sensitivity of empirical inferences to the choice of these models.

The empirical analysis revealed that detailed road user characteristics such as crime history of drivers and momentary activities of road users at the time of the accident provide an interesting insight in injury severity analysis. Likewise, the alternative analytical specification of the models reveals that some of the conventionally employed fixed-parameters injury severity models could underestimate the effect of some important behavioral attributes of the accidents. For instance, the standard ordered logit model underestimated the marginal effects of some of the variables considered, and forced some important variable effects to be statistically insignificant, while they remain significant predictors in the other relatively flexible models.



## 1. Introduction

Walking is an integral part of human activity which provides important economic and health benefits. It is environmentally friendly, accessible, cost-effective, and accrues significant health benefits. For instance, according to NZTA (2010) the total health benefit of walking was estimated to be $2.6 per each kilometer walked (see also, Rahul & Verma, 2012). However, pedestrians are markedly vulnerable to traffic injury. According to WHO (2009a), vulnerable road users (including pedestrians, cyclists and drivers of motorized two-wheelers) account for 46% of global traffic deaths. Similarly, in Denmark, pedestrians' death account for 18% of all road fatalities in the year 2009 (ITF, 2011).[1] Thus, though walking offers immense strategic benefits, it involves a significant trade-off as pedestrians bear the highest burden of traffic injury. Hence, policy makers that advocate pedestrianization or economists who are keen at investigating the economic appraisal of non-motorized mobility need to explore the ultimate causes of the vulnerability of pedestrians to traffic injury. Likewise, safety planners and public officials involved in cost–benefit analysis of road investment projects crucially need accurate estimate on the effect of the multifaceted attributes of road accidents. Intuitively, all these require exploring the leading causes of road accidents, which involves two-step approaches aimed at exploring the ultimate causes of traffic accidents, and investigating the injury severity sustained by road users. Generally, such an investigation also helps public safety officials design economically efficient safety measures and mobility management strategies that reduce the frequency and severity of traffic accidents.

As part of the efforts to explore the leading causes for the vulnerability of pedestrians to traffic injury, previous studies have investigated the effects of different attributes of road accidents on the injury severity level sustained by pedestrians (see Ballesteros, Dischinger, & Langenberg, 2004; Eluru, Bhat, & Hensher, 2008; Kim, Ulfarsson, Shankar, & Kim, 2008; Kim, Ulfarsson, Shankar, & Mannering, 2010; Lee & Abdel-Aty, 2005; Sze & Wong, 2007; Zajac & Ivan, 2003).[2] Generally, the existing safety research commonly argues that human behavior plays a vital role in road

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[1] Worldwide, traffic accidents are the leading causes of death for individuals aged 15–29 years (WHO, 2009a). In Denmark, traffic accidents are the leading causes of 'unintentional injury-caused death' for individuals aged 15–19 years (EuroSafe, 2012). Indisputably, this yields incredible economic and social burden to the overall national economy. For instance, the economic burden of traffic accidents is estimated to be 3% of the country's gross domestic product for most of European countries (WHO, 2009b).

[2] While the earlier findings from these studies have been generally consistent to a large extent, contradicting evidences have been documented with regards to the effect of the gender of pedestrians. Some studies argue that men pedestrians are more susceptible to serious or fatal injuries (Eluru et al., 2008), probably due to their risky walking or crossing behavior (Holland & Hill, 2007). Contrary to this finding, others (Lee & Abdel-Aty, 2005; Sze & Wong, 2007) conclude that women pedestrians are more likely to sustain more fatal injuries, potentially due to men's relative physiological strength compared to women.

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accidents and their injury severity outcomes. More specifically, some earlier studies argue that driving behavior, particularly aggressive driving, is the leading cause of traffic accidents (see AAA Foundation for Traffic Safety, 2009; Evans, 1993). Thus, educational campaigns and legal enforcement measures that focus on affecting drivers' driving behavior could enhance the 'crash-avoidance' strategies and post-crash evasive measures of drivers. However, though there has been some earlier research on pedestrians' injury severity, the post-crash data used in most of the previous studies do not capture all important aspects of driving, walking and crossing behavior of road users at the time of the crash, due to the limited information available in the usual post-crash accident registers. Econometrically, omitting a relevant explanatory variable, driving (or walking) behavior, which is expected to be potentially correlated with some of the usually controlled road user attributes, can lead to inconsistency of all estimates of the model. From a policy design perspective, omitting a relevant explanatory variable is a grave problem as it could misguide intervention strategies.

Obviously, investigating the vulnerability (or injury severity) of pedestrians and the economic appraisal of pedestrianization heavily relies on an appropriate and more encompassing modeling approach. Some of the restricted econometric injury severity models commonly employed in the safety research could misguide educational campaigns and legal enforcement strategies that address specific safety measure. In terms of modeling the injury severity of traffic accidents, both ordered response and unordered response modeling frameworks have been employed in the earlier safety research. As injury severity levels seem inherently ordered, the ordered response framework can be considered as relatively effective in representing the data generation process, though these models impose some inconvenient restrictions on the data. Similarly, though unordered response models (multinomial, nested and mixed logit) do not capture the ordinal nature of the response outcomes, they allow for flexible variable effects across the successive injury severity levels. This implies that the choice of injury severity modeling approaches involves potential trade-off. Thus, investigating the empirical implications of these modeling approaches, and exploring the sensitivity of the empirical findings to the choice of these models are interesting questions that deserve thoughtful attention. This enables economists and transportation safety policy makers design economically efficient, optimal, coherent and convivial countermeasures that improve the safety of road users.

This paper investigates the injury severity of pedestrians considering detailed road user characteristics and alternative model specification using a high-quality Danish road accident data. It considers exogenous proxies for driving behavior and controls for momentary activities of road users at the time of accidents. This helps to identify road users' activities that are risky to pedestrians, so that alternative policy measures and mobility management strategies can be implemented. Considering some psychological researches on personality and driving behavior, crime history of drivers in the past three years before the accident is captured as a proxy for driving behavior (aggressive driving) at the time of the accident. More succinctly, this research effort adds to the existing safety literature in at least two key directions. First, it extends the research on pedestrian-injury severity considering a more encompassing specification, with exogenous proxies for driving behavior and detailed information on momentary activities of road users at the time of the crash. Second, it employs alternative model specification to investigate the sensitivity of the empirical results to the choice of the *state of the art* injury severity models commonly used in the existing safety literature.

The remaining sections of this paper are organized as follows: Section 2 reviews the two commonly employed injury severity modeling strategies in the existing safety research. Section 3 presents the details of the data, sample description and the variables considered in the empirical analysis. Section 4 presents the econometric approach and estimation strategies. Section 5 presents the estimation results, while Section 6 discusses the empirical findings and Section 7 summarizes the key findings.

## 2. Review of the existing injury severity modeling practices

In view of the fact that the overall safety and economic implication of injury severity analysis heavily relies on the choice of econometric modeling approaches, this section highlights the commonly used modeling frameworks employed in the earlier safety research. As mentioned in Section 1, there are two widely employed injury severity modeling approaches in the safety research. These models have their own working assumptions and restrictions, which could plausibly yield far-reaching implication on the overall empirical inferences from these models.

### 2.1. Ordered response framework

From data generation point of view, injury severity outcomes seem inherently ordered. With ordered outcomes, adjacent alternatives are expected to share some common trend depending on their proximity to each other, the closer they are, the larger trend they share (Train, 2009). This potentially implies that adjacent response outcomes could also share some unobservable effects. In view of this fact, some of the standard unordered response models which are built on the assumption that unobserved effects are independent across alternatives, could provide inconsistent estimates when applied to ordered response outcomes. This suggests that considering a modeling framework that accounts for the ordinal nature of response outcomes is crucial when modeling the injury severity of traffic accidents. The aforementioned inherent feature of injury severity data has paved substantial advantage to ordered response models, so that extensive use of this framework to analyze the injury severity of traffic accidents (see, for example, Abdel-Aty, 2003; Christoforou, Cohen, & Karlaftis, 2010; Eluru & Bhat, 2007; Eluru et al., 2008; Kockelman & Kweon, 2002; Pai & Saleh, 2007; Paleti, Eluru, & Bhat, 2010; Quddus, Wang, & Ison, 2010; Srinivasan, 2002; Wang & Abdel-Aty, 2008; Wang & Kockelman, 2005; Zhu & Srinivasan, 2011).[3]

However, there are at least three potentially binding shortcomings associated with the standard ordered response models used in the existing safety research. The first and most grave problem is the monotonicity restriction that the standard ordered response models impose on the data, which guides the way independent variables of the model affect successive probability outcomes (see, for example, Savolainen, Mannering, Lord, & Quddus, 2011; Washington, Karlaftis, & Mannering, 2011). This restriction mainly emanates from the proportionality (parallel-lines) assumption and linearity of the single index of these models. Evidently, this restriction could affect the final empirical inferences and policy implications drawn from the analysis as some variables do not seem to satisfy this assumption empirically.[4] A prominent observation of the fact comes from Boes and

[3] See Table A.2 in the Appendix for a detailed survey of these studies along with the specific analytical framework employed and the key findings from each study.

[4] For example, deployment of air bag decreases the probability of fatal injury while it concurrently decreases the probability of no injury due to the possible scratches from the air bag (Savolainen et al., 2011).