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Unobserved heterogeneity and the statistical analysis of highway accident data

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ABSTRACT

Highway accidents are complex events that involve a variety of human responses to external stimuli, as well as complex interactions between the vehicle, roadway features/condition, traffic-related factors, and environmental conditions. In addition, there are complexities involved in energy dissipation (once an accident has occurred) that relate to vehicle design, impact angles, the physiological characteristics of involved humans, and other factors. With such a complex process, it is impossible to have access to all of the data that could potentially determine the likelihood of a highway accident or its resulting injury severity. The absence of such important data can potentially present serious specification problems for traditional statistical analyses that can lead to biased and inconsistent parameter estimates, erroneous inferences and erroneous accident predictions. This paper presents a detailed discussion of this problem (typically referred to as unobserved heterogeneity) in the context of accident data and analysis. Various statistical approaches available to address this unobserved heterogeneity are presented along with their strengths and weaknesses. The paper concludes with a summary of the fundamental issues and directions for future methodological work that addresses unobserved heterogeneity.

1. Introduction

Accidents, and specifically highway-vehicle accidents, cost the lives of roughly one and a quarter million people worldwide every year. In addition, highway-traffic injuries are globally the leading cause of death among people 15 to 29 years old with over 300,000 deaths (World Health Organization, 2015). From a policy and engineering perspective, perhaps the most challenging element of these numbers is their persistence and the inability of advanced vehicle safety features, advances in highway design, and various safety-countermeasure policies to drastically lower these numbers.

Without doubt, efforts to improve highway safety are complicated by the behavior of individual vehicle operators which can vary widely across the population and can be inherently difficult to predict and/or modify. This is in contrast to other transportation modes (such as air and water transport) where fewer operators mean the human element can be more

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tightly controlled through licensing standards and other safety protocols. On highways, individual vehicle operators have a wide range of physical and mental abilities, different perceptions of risk, different reactions to external stimuli, and their operating abilities may be further complicated by varying degrees of self-inflicted impaired driving (alcohol and drug consumption). Engineering a safe transportation system with this level of behavioral variance is virtually impossible. This safety problem is one of the leading factors in the current move toward autonomous (connected and automated) vehicles that can remove the human element, potentially leading to huge advances in safety by making safety largely a function of engineered systems (hardware and software) where variance in performance, and ultimately safety, can be more tightly controlled and predicted.

Even after the introduction of autonomous vehicles in mainstream traffic, which unquestionably has the potential to substantially reduce variation in human elements, there will still remain variations in the effects of many other factors that influence the likelihood and resulting injury severity of highway accidents. For example, on any highway in the world, one will find considerable variation in vehicle attributes including mass, occupant protection, safety features, vehicle accident-energy dissipation features, and so on. In addition, there are variations in roadway characteristics such as pavement friction, proximity and types of objects just off the roadway, median design, guardrail design, and other infrastructure-related elements. Finally, there are variations in environmental conditions such as lighting, temperature, and precipitation, all of which will affect both the likelihood and resulting injury-severity of accidents. The entire process is further complicated by the variance in individual vehicle operators' physiologies and responses to vehicle characteristics, roadway characteristics and environmental conditions.

Existing data bases, which typically extract data from police accident reports, local weather stations, and state highway-asset-management databases, contain a wealth of information, especially after an accident has occurred, when injury-severity levels, safety-feature deployment, and many other factors are reported. However, these conventional databases only cover a small fraction of the large number of elements that define human behavior, vehicle and roadway characteristics, traffic characteristics, and environmental conditions that determine the likelihood of an accident and its resulting injury severity. Many other elements remain unobserved to the analyst. For example, weather and lighting conditions change continually over time as do the driver reactions to these conditions. In conventional databases, analysts will not have access to these data. Once an accident has occurred, the characteristics of energy dissipation through the vehicle structure and the resulting effect on individuals, which may vary widely based on which of the vehicle safety features deployed as well as bone mass, overall health, physical dimensions, and so on, will be largely unknown to the analyst.[1]

In light of the inherent deficiencies of current data sources (and likely deficiencies in future data sources), statistical and econometric methods have been developed to address this issue as unobserved heterogeneity (variations in the effect of variables across the sample population that are unknown to the analyst). The intent of these "heterogeneity" models is to allow analysts to make more accurate inferences by explicitly accounting for observation-specific variations in the effects of influential factors (which we will refer to in this paper as unobserved heterogeneity).

Our paper begins with a quick review of the statistical consequences of ignoring unobserved heterogeneity in highway accident data (Section 2). The paper then moves on to a presentation and discussion of various statistical/econometric methods (heterogeneity models) that have been applied in the accident analysis literature to date, including random parameter models (Section 3), latent class models (Section 4), joint latent-class/random-parameters models (Section 5), Markov-switching models (Section 6), unobserved heterogeneity in multivariate models (Section 7), and omitted variable and transferability issues relating to unobserved heterogeneity (Section 8). The paper concludes with a summary and insights for future work (Section 9).

2. The need to account for unobserved heterogeneity

The statistical analysis of accident data typically addresses the likelihood of an accident and its resulting injury severity (see Lord and Mannering, 2010, Savolainen et al., 2011, Mannering and Bhat, 2014 for reviews of studies that have addressed the likelihood and severity of an accident). The likelihood of an accident is often analyzed by considering the number of observed accidents occurring on a defined spatial entity over a specified time period; for example, the number of accidents per month occurring over a specified highway segment (of known distance) or at a highway intersection. Once an accident is observed, the injury severities of involved individuals are often modeled as discrete outcomes (for example, no injury, possible injury, evident injury, disabling injury, fatality).

With commonly collected data, some of the many factors affecting the likelihood of an accident and the resulting injury severity are not likely to be available to the analyst. These factors (which constitute unobserved heterogeneity) can introduce variation in the impact of the effect of observed variables on accident likelihood and injury severity. For example, consider gender as an observed human element that affects injury-severity outcomes. While there are clearly physiological differences between men and women (justifying the use of an indicator variable such as 1 for male and 0 otherwise), there is also great variation across people of the same gender, including differences in height, weight, bone density and other factors

[1] New data sources, such as those from naturalistic driving where many vehicle and human functions are monitored continuously, will help provide additional influential data but will still not approach the detail of data needed to fully model the likelihood and severity of accidents.