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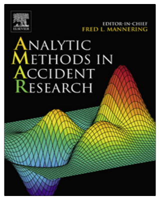

Temporal instability and the analysis of highway accident data

Fred Mannering

College of Engineering, Civil and Environmental Engineering, University of South Florida, 4202 E. Fowler Avenue, ENC 3506, Tampa, FL 33620, United States

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ABSTRACT

Virtually every statistical analysis of highway safety data is predicated on the assumption that the estimated model parameters are temporally stable. That is, the assumption that the effect of the determinants of accident likelihoods and resulting accident-injury severities do not change over time. This paper draws from research previously conducted in fields such as psychology, neuroscience, economics, and cognitive science to build a case for why we would not necessarily expect the effects of explanatory variables to be stable over time. The review of this literature suggests that temporal instability is likely to exist for a number of fundamental behavioral reasons, and this temporal instability is supported by the findings of several recent accident-data analyses. The paper goes on to discuss the implications of this temporal instability for contemporary accident-data modeling methods (unobserved heterogeneity, data driven, traditional, and causal inference methods) and concludes with a discussion of how temporal instability might be addressed and how its likely presence can be accounted for to better interpret accident data-analysis findings.

1. Introduction

Worldwide, the analysis of highway accident data has formed the basis for the development and implementation of a wide variety of safety policies. Without doubt, many of these policies have made highway travel substantially safer but, worldwide, with more than 1.2 million fatalities annually in highway-related accidents and an estimated 50 million more people injured, highway safety remains a tragic human health issue (World Health Organization, 2015).

While the highway safety field continues to address a wide variety of topics in an effort to reduce the carnage on world highways, in the past few decades researchers and safety analysts have struggled to explain two longer-term phenomena; the general downward trend in fatalities per distance driven over time in most industrialized countries, and the fact that fatalities per distance driven tend to decline in economic downturns and increase in economic upturns. The general downward trend has often been attributed to improved vehicle-safety technologies, improved highway design, improved impaired driver enforcement, and driver/public education programs, etc. And, the effect of an adverse economy on fatalities per mile driven has been attributed to factors such as changes in discretionary driving patterns, changes in values of time, changes in the distances risky versus safe drivers drive, and so on.

However, there is potentially an additional element at play in these trends. That is, human behavior may be fundamentally changing gradually over time – a change that may be in response to short-term macroeconomic conditions and other time-varying influences. In fact, as will be shown, there is a vast body of literature from psychology, neuroscience, economics, cognitive science and other fields that suggests that this temporal element, typically overlooked in accident data analysis, could play a key role in explaining accident trends. This has potentially profound implications for traditional statistical analyses that use data to estimate parameters (which are typically assumed to be fixed over time) for various

E-mail address: flm@usf.edu

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explanatory variables to determine the effect that these variables have on the likelihood and resulting injury severities of accidents. But what if the statistically estimated parameter values are changing in some fundamental way over time? The intent of this paper is to explore this possibility and discuss its potential implications for safety research.

2. Overview of accident-data analysis and the temporal element

Over the years, researchers have applied a vast array of statistical methods to analyze accident-related data in an effort to save lives, and to reduce injury severities and property damage resulting from motor-vehicle accidents. Studies that have focused on the statistical analysis of accident data have traditionally addressed one or more of three general objectives: 1) data analysis with the sole intent of quantifying the effect of statistically significant determinants (explanatory variables) on the likelihood and severity of accidents; 2) data analysis with the intent of using the resulting parameter estimates of the statistical model to forecast future accident likelihoods and severities; and 3) analysis of before and after data to evaluate the effectiveness of a specific safety countermeasure or a change in a specific factor that may influence likelihood and severity of accidents. For all three of these objectives, researchers have most often implicitly made the assumption that the effects of the statistically identified determinants are constant over time (temporally stable). For forecasting (objective 2 above) and before-and-after analysis (objective 3 above), the passage of time makes it obvious why temporal considerations are important. However, the temporal issue may even arise in what we might classify as "cross-sectional" data analysis that seeks to identify statistically significant determinants (objective 1 above). That is, because vehicle accidents are relatively rare events, they are typically aggregated over time (weeks, months or years) by analysts to provide a sufficient number of observations for statistical analysis.[1] Thus, the passage of time between accident observations implies temporal stability is being assumed and this assumption has potentially profound implications on virtually all statistical analyses of accident data.

But how reasonable is the assumption of temporal stability of statistically estimated model parameters? To begin to address this question, it is important to first recognize the two general approaches to the statistical analysis of accident data that dominate the literature, because these approaches may have different implications in terms of temporal stability.[2] The first approach focuses on the likelihood of an accident in general, or the likelihood of an accident of a specified injury severity. Again, because accidents are rare events, these models typically address the frequency of accidents on a roadway entity over some time period (for a review of these models, see Lord and Mannering (2010)) and, because the focus is on the likelihood of an accident, the detailed accident information available after an accident has occurred is not used in model estimation. The second approach, in contrast, focuses on the injury severity of specific accidents and can potentially make full use of the highly detailed data (such as detailed information on vehicle and occupant characteristics) available after an accident has occurred (for a review of these models, see Savolainen et al. (2011)).

However, there is an abundance of relatively recent research that suggests the influence of factors affecting both the likelihood and resulting severity of highway accidents may not be stable over time. With regard to the aggregation of data over a specified time period (months or years) to gather a sufficient number of accident observations to conduct a statistical analysis, there is a growing body of empirical evidence that suggests at least some temporal instability. For example, Malyshkina et al. (2009) and Malyshkina and Mannering (2009) estimated Markov switching models (with estimated accident models alternating between two states over time) which provides some statistical support for temporal instability (even over the short time periods they consider), because ignoring the transition between states (over time) would cause a bias in parameter estimation. Malyshkina and Mannering (2010) and Xiong et al. (2014) found similar statistical support for Markov switching in injury-severity models using the detailed data available conditioned on an accident having occurred. Other studies have looked at temporal instability of such injury-severity models over longer time periods and found that model parameter estimates were not temporally stable.[3] For example, using detailed accident-injury severity data annually from 2004 to 2012, Behnood and Mannering (2015) found that the effect that roadway characteristics, vehicle characteristics, and driver characters have on resulting driver-injury severities varied significantly from one year to the next. Subsequent work from these authors (Behnood and Mannering, 2016), showed similar temporal instability with regard to pedestrian injuries resulting from vehicle accidents in Chicago.[4,5] These general findings are also supported by the work of Venkataraman et al. (2016) who found temporal instability in California accident data.

[1] There is also potentially a spatial consideration here as well because in traditional analysis, analysts tend to aggregate accumulated accidents over space. There would thus be an implicit assumption that the effects of explanatory variables are spatially stable. See Mannering and Bhat (2014) for a discussion of spatial considerations and a review of the literature on this topic.

[2] There are also some studies that look at accident data in aggregate form, such as the number of fatalities per year in a state/province or country. These studies usually apply some form of time-series modeling that is typically predicated on the assumption of temporal stability. These models are not addressed explicitly in this paper, but a later footnote provides additional insight into the effect that possible temporal instability would have on these models.

[3] Other fields of transportation, such as travel-activity modeling and tradition travel-demand modeling have also demonstrated temporal instability (Mannering et al., 1994; Rossi and Bhat, 2014).

[4] Temporal instability has also been observed in the demand for safety features on vehicles. For example, Mannering and Winston (1995) looked at the adoption of driver-side airbags in new vehicles in the early 1990s. They found that consumers' willingness to pay for a driver-side airbag in a new vehicle increased over time from $331 in 1990 to $512 dollars in 1993. They also found that media exposure (average number of hours spent watching television per day) and social networks (number of friends owning cars with driver-side airbags) were significant factors affecting willingness to pay.

[5] A notable exception to other findings of temporal instability is the work of Malyshkina and Mannering (2008). They found temporal stability in accident-injury parameter estimates for accidents occurring on rural interstates in Indiana between the years 2004 and 2006 data, even when speed limits were increased in 2005 (they did, however, find instability in other roadway classifications such as rural multilane highway). While their approach was less sophisticated in that it did not explicitly account for unobserved heterogeneity as the more recent approaches did (more on this below), their findings may suggest that temporal instability may also vary by highway functional class.