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Occupant injury severities in hybrid-vehicle involved crashes: A random parameters approach with heterogeneity in means and variances

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Differences in hybrid and non-hybrid vehicle design, and potential differences in driver-related behavior among owners of these vehicle types, can potentially have interesting implications for safety-related policies. To study possible differences in hybrid and non-hybrid occupant injury severities in motor vehicle crashes, this paper uses a sample of hybrid-vehicle-involved crashes and estimates a mixed logit model of the resulting injury level of the most severely injured occupant in the crash, while accounting for possible heterogeneity in the means and variances of model parameters. A total of 2015 crashes in Washington State, involving at least one hybrid vehicle in the 5-year period from January 1, 2006 to December 31, 2010 were analyzed. The data included crash information regarding occupants, vehicles, environmental conditions at the time of the crash, hybrid and non-hybrid vehicle attributes, crash-contributing circumstances for both hybrid and non-hybrid involved vehicles, collision type and crash location information relating to intersections, functional class of the highway, and highway curvature. Model estimation results show that a wide range of variables influence the most severely injured occupant, and that the number-of-occupants parameter and the intersection-location indicator parameter are random with significant heterogeneity in both means and variances. Sources of heterogeneity include the ratio of hybrid to non-hybrid vehicle counts in the crash, vehicle weight to horsepower ratio range (maximum difference in ratio) for the crash, number of adult occupants aged 41–64 years, functional class, and vehicle type interactions. The results further demonstrate the potential of models that address unobserved heterogeneity to unravel important relationships in the analysis of highway injury severities.

1. Introduction

As of 2016, over 4 million hybrid vehicles have been sold in the U.S. (Argonne National Laboratory, 2017). As the number of hybrid vehicles on the road has increased over the years, data on their crash involvement has become available in

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sufficient numbers to warrant a comprehensive statistical analysis. For the most part, the structural elements of such vehicles are similar to their conventionally-powered counterparts, so one would expect similar crash performance. However, there are at least three compelling reasons to expect the safety performance of hybrid vehicles to differ significantly from conventionally-powered vehicles as a whole. First, manufactures tend to offer hybrid drivetrains in a limited number of their vehicle models (or have dedicated models that are exclusively hybrid). The specific vehicle models that they choose to offer hybrid drivetrains may have crash worthiness characteristics that differ from the average crashworthiness characteristics of other vehicle models they offer. Second, the performance characteristics of hybrid-drive vehicles (in terms of acceleration, etc.) may differ from their conventionally-powered counter parts, and this could impact occupant safety. Third, and perhaps most importantly, hybrid vehicles attract a non-random sample of vehicle purchasers, and these drivers may have injury risks that will differ from conventionally-powered vehicle owners. For example, studies have shown that purchasers of new hybrid vehicles tend to have significantly higher levels of education, higher annual incomes, and tend to be about 4 years older relative to purchasers of conventionally-powered vehicles (Power and Associates, 2008). Because the effect of such personal attributes on risk-taking behavior are well established in the literature (see Abay and Mannering, 2016), one may also find that hybrid and non-hybrid vehicle owners have different levels of crash risks and injury outcomes.

Given the above, unobserved heterogeneity can influence interactions between hybrid and non-hybrid vehicles (and interactions between drivers and occupants in hybrid versus non-hybrid vehicles). When injury-severity models are estimated in the presence of unobserved heterogeneity, the distribution of parameter values across observations becomes an important specification issue, and not accounting for heterogeneity, in both the mean and variance of parameters can potentially result in biased parameter estimates and marginal effects. The intent of our research is to specifically examine this issue by studying injury severities in single and multi-vehicle crashes that involve at least one hybrid vehicle. This subset of crashes is distinguished by both vehicle characteristics (hybrid drivelines) and the self-selected population of drivers that chose to own hybrid vehicles.

2. Empirical elements

An abundance of recent research has emphasized the importance of accounting for unobserved heterogeneity in the analysis of vehicle crash data (Mannering et al., 2016). For the statistical modeling of crash injury-severity outcomes (such as no-injury, possible injury, evident injury, disabling injury, fatality), unobserved heterogeneity (factors that affect crash-severity but are unobserved to the analyst) can arise from a number of sources including unobserved environmental effects, interactions between the driver and vehicle, interactions between vehicles, and so on (see Mannering et al., 2016, for an extensive discussion of this topic). To account for unobserved heterogeneity in crash-injury severity models, early work by Milton et al. (2008) applied a mixed logit model to crash injury-severity analysis by studying the impact of highway geometrics on the proportions of crash frequencies by injury severity on specific sections of highway. Their analysis was conducted at the unconditional level (they did not use data gathered after a crash had occurred) and, as such, their explanatory variables included roadway attributes such as highway geometrics, traffic-volumes, and so on. While such an analysis deals with unobserved heterogeneity at the highway-section level, a more disaggregated analysis of crash-injury severities, involving the additional crash-related information available once a crash has occurred, is the more common approach (Savolainen et al., 2011). At the crash-specific scale, insight into the unobserved heterogeneity of crash-specific factors, and how this unobserved heterogeneity might influence the likelihood of specific crash-injury outcomes, can be studied in detail by allowing for the possibility of observation-specific parameter estimates. In addition, certain factors might affect both the mean and variance of these parameters, implying that not all observations are distributed alike due to crash-specific variations resulting from vehicle attributes, occupant attributes, and other crash-related attributes that may affect resulting occupant-injury severities.

Past work on the application of the mixed logit in the analysis of crash injury severities has focused on identifying random parameters (parameters that vary across observations) in injury-severity functions (Kim et al., 2010; Anastasopoulos and Mannering, 2011; Moore et al., 2011). Other studies have focused specifically on the possibility of having heterogeneity in the means and variances of parameters to better track unobserved heterogeneity (Kim et al., 2008, 2013; Venkataraman et al., 2014; Huang et al., 2016). Studies have also applied a variety of other approaches to account for unobserved heterogeneity in injury-severity analyses such as Markov switching models, copula based approaches, generalized ordered models, and latent class analyses (Xie et al., 2012; Castro et al., 2013; Cerwick et al., 2014; Xiong et al., 2014; Yasmin et al., 2014a, 2014b). As newer methods have emerged to address unobserved heterogeneity, additional insights have been made possible, particularly with regard to the variability of crash injury-severity parameters across observations due to unobserved heterogeneity and other related factors.

The use of an approach wherein a specified vector of crash-level and/or segment-level attributes can influence the mean of a parameter that varies across observations (often referred to as random parameters) has been shown to be important in many studies. However, a focus on how heterogeneity influences the variance of a random-parameter distribution (which ultimately determines parameter values for individual observations) is potentially an important concern as well. Allowing the variance in the parameter distribution to further define the dispersion of parameter values across observations provides additional flexibility in capturing the underlying unobserved heterogeneity by potentially allowing a high degree of sensitivity to crash conditions. Thus, this approach may provide additional insight into factors that can be controlled with crash