Final Project Report

An Empirical Assessment of the Role of Attitudes and Identification in Safety Research

Prepared for **Teaching Old Models New Tricks (TOMNET) Transportation Center**

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16. Abstract Research in highway safety has struggled to deal adequately with two issues: the role that attitudes may play on risk perception and resulting crash and injury-severity likelihoods; and the issue of identification in safety modeling caused by self-selective sampling of safety data (the fact that riskier drivers are likely to be over-represented in crash data bases). This study addresses these two points by first collecting data that focused on highway safety perceptions and using observed crash data from the state of Florida. Statistical model estimation results that address the question of how vehicle usage has changed post-pandemic indicate that safer drivers have reduced their vehicle usage significantly more than riskier drivers. With a greater proportion of vehicle miles travelled now being riskier drivers, this has likely resulted in fundamental shift in injury severity probabilities in observed crashes, which is confirmed using Florida crash data from 2019 (pre-pandemic) and 2020 (pandemic) where a statistically significant shift was found in the factors that determined injury severities in highway the two years. The results indicate that the role of safety attitudes and perceptions are important considerations in the analysis of highway crash data and must be considered in highway-safety practice. The results also indicate the need to focus attention on identification in highway-safety practice because observed statistical estimates may not be entirely due to the effect of specific explanatory variables but may be in part due the change in the mix of risky and safe drivers, a possibility that has important policy implications.			
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EXECUTIVE SUMMARY

Research in highway safety has struggled to deal adequately with two issues: the role that attitudes may play on risk perception and resulting crash and injury-severity likelihoods; and the issue of identification in safety modeling caused by self-selective sampling of safety data (the fact that riskier drivers are likely to be over-represented in crash data bases). This study address these two points by first collecting data that focused on highway safety perceptions. With these data, two statistical models were developed. The first statistical model addressed the question of how people thought highway safety has changed in the last five years and the second model analyzed their opinions on the suitability of current speed limits. Both of these statistical models found that a wide range of household characteristics determine safety perceptions and accounting for these characteristics in traditional crash data can be difficult and often impossible, suggesting the need for statistical methods that address the issue of missing perception data and the attitudes they imply, such as models that use mixing distributions to capture unobserved heterogeneity.

The study then moved on to address the issue of identification, specifically considering the possibility that COVID-19 may have fundamentally changed the mix of drivers on the road and that this may be a contributing factor in the observed rise in the proportion of more severe crashes. Model estimation results that address the question of how vehicle usage has changed post-pandemic indicate that safer drivers have reduced their vehicle usage significantly more than riskier drivers. With a greater proportion of vehicle miles travelled now being riskier drivers, this has likely resulted in fundamental shift in injury severity probabilities in observed crashes.

To explore this shift in injury severity probabilities, Florida crash data from 2019 (pre-pandemic) and 2020 (pandemic) were gathered and focus was directed toward single-vehicle crashes (where driver error is indisputable) and crashes where one or more of the following risky behaviors were identified in the crash report; driving while asleep/drowsy, driving too fast for conditions, driving with suspected alcohol consumption, driving while inattentive, and driving while not wearing a seatbelt. It was found that there was a statistically significant shift in the factors that determined injury severities in highway crashes between 2019 and 2020. This source of this shift is likely a combination of both fundamental changes in behavior (which has been the argument made in the traditional temporal instability literature) and, a shift in the proportion of vehicle miles travelled by risky and safe drivers as indicated in the study's earlier finding that riskier drivers are responsible for a greater proportion of vehicle miles traveled relative to their pre-pandemic levels.

There are two key policy recommendations from this study. The first recommendation is that the role of safety attitudes and perceptions are important considerations in the analysis of highway crash data and must be considered in highway-safety practice. Based on the findings in this report, and the findings of a growing body of recently published research, it is essential that highway safety practice incorporate unobserved heterogeneity in their safety handbooks, most importantly the Highway Safety Manual (AASHTO, 2010).The second recommendation is that more attention must be directed toward the identification problem in the analysis of highway safety data. Understanding whether the observed statistical estimates of highway safety models are due entirely to the effect of specific explanatory variables or due in some part that the mix of risky and safe drivers is changing could clearly have important policy implications.

Part I

Safety attitudes and perceptions, the impact of the COVID-19 pandemic on vehicle usage, and safety-modeling implications

1.1 Introduction

In the past decade, there have been incredible advancements in vehicle safety technologies. For example, front and side airbag systems, antilock braking systems, traction control, and electronic stability control, adaptive cruise control, lane-departure warnings, autonomous braking have become pervasive features in a significant portion of the U.S.'s vehicle fleet. From a technical perspective, the expectation would be that the introduction of these features would greatly reduce the likelihood of crashes in general and injury-causing crashes in particular. But aggregate crash data do not show this. From 2011 to 2019 fatalities on US highways rose by 19% and fatalities per mile driven rose by nearly 25%. Moreover, the recent COVID-19 pandemic/post-pandemic period has been associated with yet another surge in fatality rates. All of this gives rise to the need to better understand exactly what is happening in highway safety.

Research in highway safety, and specifically the statistical analysis of the frequency and injury severity of highway crashes, has been limited in uncovering a true understanding of what has been happening because two issues have not been adequately addressed; the role that safety perceptions and attitudes may play on resulting crash and injury-severity likelihoods, and the issue of identification in safety modeling caused by self-selective sampling inherent in commonly used safety data (mostly from the fact that drivers in observed crashes are not a random sample of the driving population, and it is thus likely that data from observed crashes over-represents risky drivers). Regarding the role of perceptions/attitudes toward safety, there is a very high likelihood that these and other factors are likely to be influential in determining the risk profile of drivers and ultimately their likelihood of a crash and the extent of the resulting injury severity. In fact, there is an abundance of research that suggests that risk-related perceptions/attitudes play a role not only in highway safety, but also in other areas of life. For example, Abay and Mannering (2016) provided empirical evidence showing that risk-taking in driving was significantly correlated with risk taking in other aspects of life. This suggests that accounting for safety-related preferences/attitudes (by viewing them as unobserved heterogeneity in model estimation if such preferences/attitudes are not directly observable) is an important consideration in safety research.

The second point, the issue of identification in safety research, is a potentially important concern that has just recently been recognized as a modeling issue (Mannering et al., 2020). The identification problem arises in safety data because crashes are only observed for a portion of the population, making drivers involved in crashes a self-selective group of riskier drivers. Thus, any change in the selectivity of people involved in crashes (changing safety features in cars, etc.) could affect the interpretation and forecasting of statistically estimated models of safety. The magnitude of this problem is not known but needs to be explored because it has important implications for safety-policy decisions. Currently, safety models deal with this issue by using mixing distributions, but this does not completely mitigate the potential effects of the selectivity problem (Mannering et al., 2020).

To expand upon this point, it is important to recognize that commonly used police-reported data are only observed for a portion of the driving population (the crash-involved portion) and that this can lead to erroneous interpretations of findings. For example, if crash injuries are found to be more severe during the COVID-19 pandemic this could lead to two distinct interpretations. The first interpretation is what almost all COVID-19 crash-related research has assumed by default.

That is that the COVID-19 pandemic has fundamentally altered driving behavior and opened up roads to be less congested, both of which have resulted in a higher proportion of severe injuries in observed crashes. But there is a second interpretation that would say that driver behavior has not changed in fundamental ways but that during the COVID-19 lock downs the characteristics of drivers that continued to drive (as opposed to those that drove less and worked remotely) were a sub-sample of riskier drivers that naturally would tend to be involved in higher injury level crashes, thus increasing the proportion of severe injuries in observed crashes. In reality, the true interpretation is likely to be some combination of these two elements, but this creates an identification problem because one cannot identify with certainty the cause of the finding that crashes have become more severe.

Given the above, the use of observed crashes, and particularly data conditioned on a crash having occurred, can be potentially problematic.[1] For sure, the possibility of such selectivity (riskier drivers being overrepresented) would make the interpretation of the parameters difficult. More importantly, for forecasting with models estimated with traditional police data, anything that would shift the self-selectivity (as the COVID-19 pandemic almost certainly did) would result in inaccurate predictions.

There are numerous econometric methods that attempt to control for self-selectivity and related considerations as documented in Mannering et al. (2020). However, the data requirements and econometric complexities required to implement these methods are formidable obstacles. As a side bar here, it should be mentioned that there is a body of literature that seeks to resolve this selectivity concern by using approaches to address the identification problem by using more

[1] There is also the issue of under-reporting of crashes, particularly less severe crashes. That is, minor crashes are less likely to be reported to police, which in turn affects what the analyst sees as observed crashes. This can create model estimation problems as discussed in Mannering and Bhat (2014).

aggregate data (Dale and Krueger, 2002). This is generally done by using control variables such as indicator variables and fixed effects, with the intent of achieving the equivalent of a randomized trial where self-selectivity and endogeneity can be strictly eliminated (Angrist and Pischke, 2009; 2015; 2017). However, the generalizability of the fixed-effects results can be questionable. In the relatively complex non-linear models of the likelihood and severity of highway crashes, which include many explanatory variables relating to roadway characteristics, traffic conditions, weather conditions, and vehicle and driver characteristics, identifying control variables and incorporating them into the model is much more difficult than the more aggregated-data methods typically applied to address this problem. Also, predictions can be quite limited with this aggregate approach because the variables used as control variables are often also of interest for predictive purposes, making the use of aggregate safety data and the associated corrective approaches of little value in safety practice.

As discussed extensively in Mannering et al. (2020), the potential bias that selectivity introduces and the effect it may have on prediction is not fully understood. But, as pointed out in Mannering (2018), the issue is likely to be very context dependent. For instance, because everyone has a chance of being involved in a crash (even the safest drivers), it may be that a crash data sample collected just so happens to include the full spectrum of individuals from the safest to the least safe. Also, when considering the injury severities in a crash, it is not clear whether the drivers observed in crashes will have more severe injuries, less severe injuries, or about the same injuries relative to drivers not observed in crashes. For example, drivers frequently appearing in crash data bases may get involved in more crashes of lower-injury severity than those less frequently involved in crashes. Also, in the case of vehicle crashes, once various driver actions are taken, the resulting injury severity is determined by physics where forces are transferred through the vehicle to its occupants (though even the physics involved in the crash are influenced by underlying risk profiles of the driver including vehicle choice and other factors). However, the endogeneity of variables in crash data due to the self-selective nature of observed crashes is likely to be a serious issue that has yet to be adequately addressed (Mannering et al., 2020).

The current research intends to gain insight into the magnitude of the self-selectivity problem by studying changes in travel behavior and crashes resulting from the COVID-19 pandemic. The idea is that the pandemic significantly affected the mix of drivers on the roads, such that the mix of risky and safe drivers changed in fundamental ways (as some drivers will stay at home and others will not) and this changing mix could at least partially explain or provide a better understanding of what has been happening in highway safety.

1.2 An Assessment of Safety Perceptions

The Leisure Activity and Social Resources Longitudinal Study was used as the basis for gathering data for the proposed study. This longitudinal study is based on a longitudinal survey whose intent is to better understand the social determinants that influence leisure activity participation as well as the effects of the COVID-19 pandemic on leisure activity. The survey is divided into sections that include respondents' activity space, social capital, mobility/accessibility, and individual and household characteristics. There are also parts on people's personality types, subjective well-being, and perspectives on the pandemic. More importantly for the current report, the survey was modified to include questions in the mobility/accessibility section about individuals' driving safety such as the number of years with a driver's license, violations, crashes, speed-limit perceptions, and perceptions of highway safety today versus 5 years ago. Table 1 provides an overview of the survey's safety-related questions (collected in the fall of 2021 and spring of 2022), and Figures 1, 2 and 3 provide illustrations of the distribution of values of some of the key responses shown in Table 1.

The exploration of safety perceptions/attitudes will be addressed by exploring two questions from this portion of the survey: 1) About how safe do you believe it is to drive today compared to 5 years ago? and 2) In general, do you believe speed limits are too low, too high or about right? Both of these questions involve an ordered response (responses that are ordered from low to high). The question “About how safe do you believe it is to drive today compared to 5 years ago?” has five ordered responses: (1) much less safe, (2) less safe, (3) about the same, (4) more safe and (5) much more safe. The question “In general, do you believe speed limits are too low, about right, too high” has 3 ordered responses: (1) too low, (2) about right, (3) too high. These type of data are best modeled statistically using ordered probability models as outline in the next section of this report.

Table 1. An overview of survey safety-related questions.

Question	Overview
Do you have a state-issued driver's license?	Yes (88%)/No (12%)
How many years have you had a driver's license?	Mean=27.87; Standard deviation=16.46
About how many miles per year do you drive?	Mean=8,275; Standard deviation=11,348
How many police-reported crashes (as a driver) have you had since you started driving?	Mean=1.09;Standard deviation=1.48
About how many moving violations (speeding tickets, etc.) have you had since you started driving?	Mean=1.96;Standard deviation=2.53
In general, do you believe speed limits are	Too low (12%)/about right (83%)/too high (5%)
About how safe do you believe it is to drive today compared to 5 years ago?	Much less safe (13%)/less safe (29%)/ about the same (44%)/more safe (12%)/ much more safe (2%).

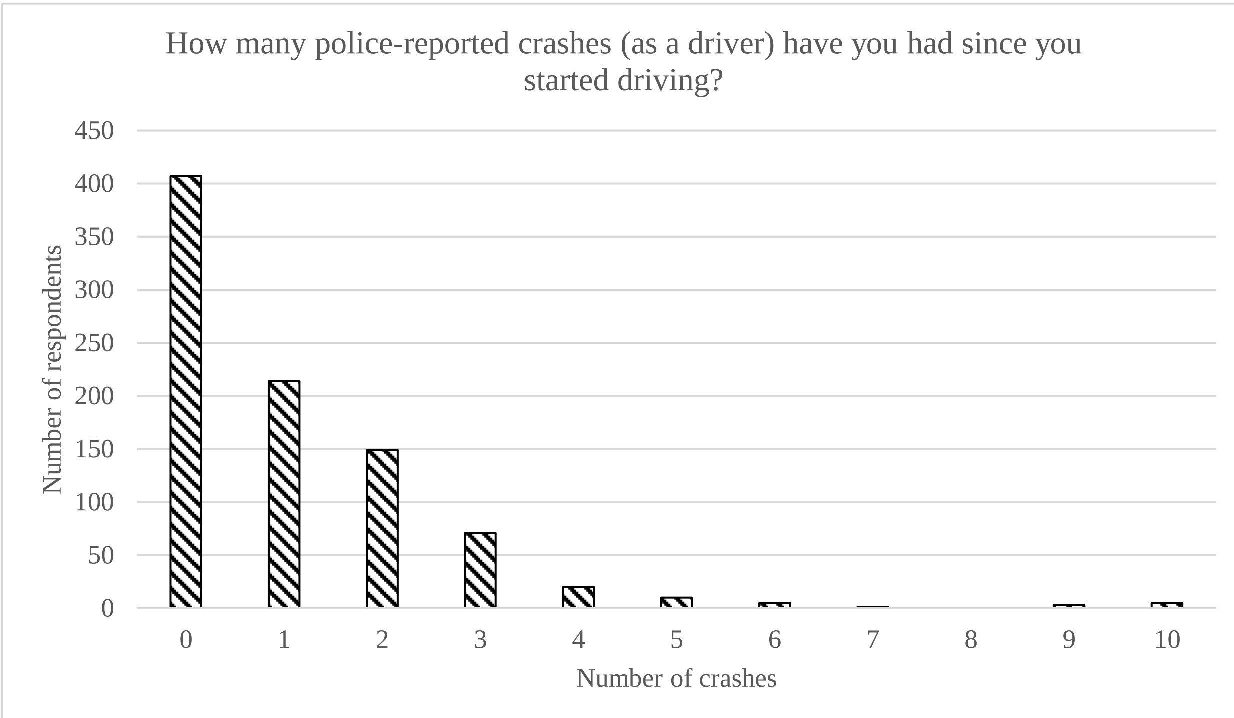

Figure 1. Distribution of crash histories in the survey sample.

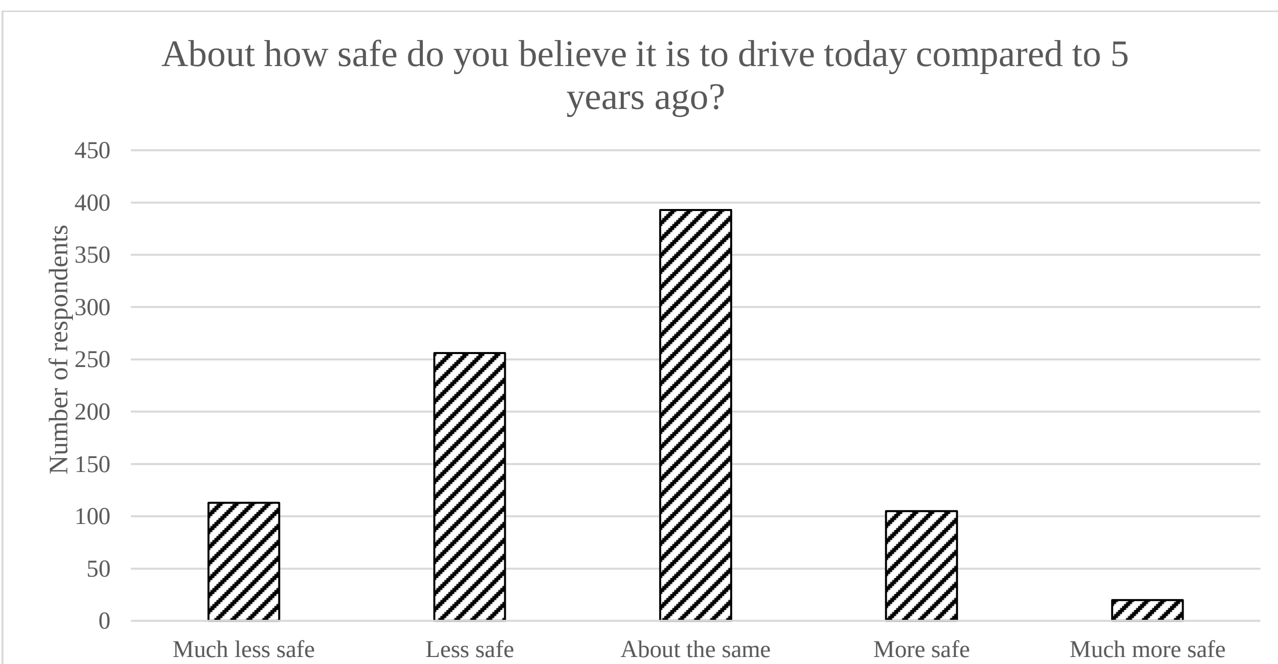

Figure 2. Current perceptions of safety relative to 5 years ago.

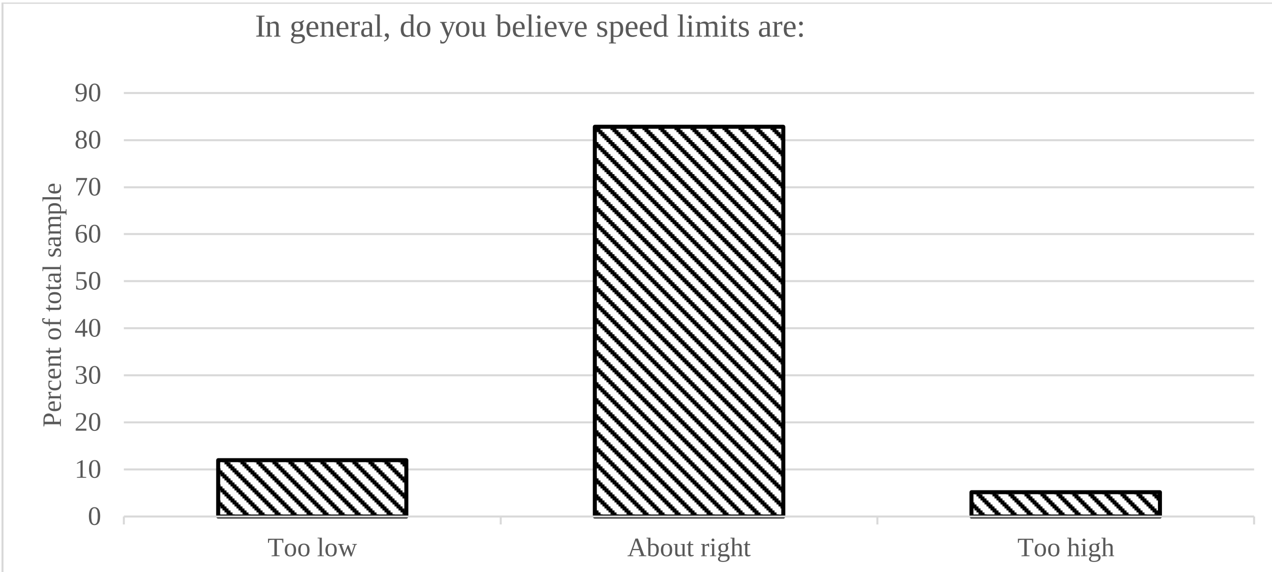

Figure 3. Perceptions relating to speed limits.

1.3 Methodological Approach – Ordered Probit

Using random parameters ordered probability approach, attention is first directed toward exploring the different variables affecting drivers' perception of the safety of driving today compared to driving 5 years ago. As shown in Figure 2, these are ordered data ranging from 1 if much less safe, 2 if less safe, 3 if about the same, 4 if more safe, and 5 if much more safe. Such data are appropriately modeled using ordered probability models which have been in widespread use since the mid-1970s (Washington et al., 2020). Ordered probability models are derived by defining an unobserved variable for observation n, z_n, that is used as a basis for modeling the ordinal ranking of data. This unobserved variable is typically specified as a linear function for each observation, such that,

$$z_n = \boldsymbol{\beta}\mathbf{X}_n + \varepsilon_n, \qquad (1)$$

where $\mathbf{X}_n$ is a vector of explanatory variables that determines the discrete ordering of observation n, $\boldsymbol{\beta}$ is a vector of estimable parameters, and ε_n is a disturbance term. Using this equation, observed ordinal data, y_n, for each observation are defined as,

$$
\begin{aligned}
y_n &= 1 \quad \text{if } z_n \le \mu_0 \\
&= 2 \quad \text{if } \mu_0 < z_n \le \mu_1 \\
&= 3 \quad \text{if } \mu_1 < z_n \le \mu_2 \\
&= 4 \quad \text{if } \mu_2 < z_n \le \mu_3 \\
&= 5 \quad \text{if } z_n \ge \mu_3,
\end{aligned}
\qquad (2)
$$

where, for the case being explored herein, values of y_n would be; 1 if much less safe, 2 if less safe, 3 if about the same, 4 if more safe and much more safe. The μ are parameters that are estimated jointly with the model parameters $\boldsymbol{\beta}$. The estimation problem then becomes one of determining the probability of a specific ordered responses for each observation n. This determination is accomplished by making an assumption on the distribution of ε. If ε is assumed to be normally distributed across observations with mean = 0 and variance = 1, an ordered probit model results with the ordered selection probabilities being,

$$
\begin{aligned}
P_n(y = 1) &= \Phi(-\boldsymbol{\beta}\mathbf{X}_n) \\
P_n(y = 2) &= \Phi(\mu_1 - \boldsymbol{\beta}\mathbf{X}_n) - \Phi(-\boldsymbol{\beta}\mathbf{X}_n) \\
P_n(y = 3) &= \Phi(\mu_2 - \boldsymbol{\beta}\mathbf{X}_n) - \Phi(\mu_1 - \boldsymbol{\beta}\mathbf{X}_n) \\
P_n(y = 4) &= \Phi(\mu_3 - \boldsymbol{\beta}\mathbf{X}_n) - \Phi(\mu_2 - \boldsymbol{\beta}\mathbf{X}_n) \\
P_n(y = 5) &= 1 - \Phi(\mu_3 - \boldsymbol{\beta}\mathbf{X}_n)
\end{aligned}
\qquad (3)
$$

where $\Phi(.)$ is the cumulative normal distribution,

$$
\Phi(u) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{u} EXP\left[-\frac{1}{2}w^2\right] dw \qquad (4)
$$

Note that in Equation 2, threshold μ_0 is set equal to zero without loss of generality (this implies that one need only estimate 5 – 2 thresholds). For model estimation, Equation 3 is written,

$$P(y = i) = \Phi(\mu_i - \boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_{i+1} - \boldsymbol{\beta}\mathbf{X}), \tag{5}$$

where μ_i and μ_{i+1} represent the upper and lower thresholds for outcome i. The likelihood function (L) is (over the population of N observations),

$$L\left(y|\beta_1,\ldots,\beta_k,\mu_2,\ldots,\mu_{I-1}\right) = \prod_{n=1}^{N}\prod_{i=1}^{I}\left[\Phi\left(\mu_i - \boldsymbol{\beta}\mathbf{X}_n\right) - \Phi\left(\mu_{i+1} - \boldsymbol{\beta}\mathbf{X}_n\right)\right]^{\delta_{in}}, \tag{6}$$

where δ_{in} is equal to 1 if the observed discrete outcome for observation n is i, and zero otherwise. This equation leads to a log likelihood (LL) of

$$LL = \sum_{n=1}^{N}\sum_{i=1}^{I}\delta_{in} LN\left[\Phi\left(\mu_i - \boldsymbol{\beta}\mathbf{X}_n\right) - \Phi\left(\mu_{i+1} - \boldsymbol{\beta}\mathbf{X}_n\right)\right]. \tag{7}$$

Maximizing this log likelihood function is subject to the constraint $0 \leq \mu_1 \leq \mu_2 \leq \mu_3$.

To evaluate the effect of individual estimated parameters in ordered probability models, marginal effects are computed (see Washington et al., 2020). The marginal effects for each response category can be interpreted as change in the outcome probability of each threshold category, $P(y = j)$, given a unit change in a continuous variable, x. A positive marginal effect for a safety category indicates an increase in probability for that category, while a negative value would correspond to a decrease in probability for that category. For indicator variables, the effects are computed as the difference in the estimated probabilities with the indicator variable changing from zero to one, while all other variables are equal to their means. For continuous variables, the effects are computed from the partial derivatives:

$$
\begin{aligned}
\frac{\partial P(y=1)}{\partial \mathbf{X}} &= -\phi\left(-\boldsymbol{\beta}\mathbf{X}\right)\boldsymbol{\beta}' \\
\frac{\partial P(y=2)}{\partial \mathbf{X}} &= \left[\phi\left(\mu_0-\boldsymbol{\beta}\mathbf{X}\right)-\phi\left(\mu_1-\boldsymbol{\beta}\mathbf{X}\right)\right]\boldsymbol{\beta}' \\
\frac{\partial P(y=3)}{\partial \mathbf{X}} &= \left[\phi\left(\mu_1-\boldsymbol{\beta}\mathbf{X}\right)-\phi\left(\mu_2-\boldsymbol{\beta}\mathbf{X}\right)\right]\boldsymbol{\beta}' \\
\frac{\partial P(y=4)}{\partial \mathbf{X}} &= \left[\phi\left(\mu_2-\boldsymbol{\beta}\mathbf{X}\right)-\phi\left(\mu_3-\boldsymbol{\beta}\mathbf{X}\right)\right]\boldsymbol{\beta}' \\
\frac{\partial P(y=5)}{\partial \mathbf{X}} &= \left(-\phi\left(\mu_3-\boldsymbol{\beta}\mathbf{X}\right)\right)\boldsymbol{\beta}'
\end{aligned}
\tag{8}
$$

where $P(y=j)$ is the probability of response category j, $\phi(.)$ is the standard normal density, and all other terms are as previously defined. Marginal effects are computed for each observation and then averaged across all observations for reporting and interpretation.

To allow for random parameters in this ordered probability model, estimable parameters are written as,

$$\boldsymbol{\beta}_n = \boldsymbol{\beta} + \boldsymbol{\omega}_{\mathrm{n}} \tag{9}$$

where $\boldsymbol{\beta}_n$ is a vector of estimable parameters that potentially varies across observations n, $\boldsymbol{\beta}$ is the vector of mean parameter estimates across all observations, $\boldsymbol{\omega}_n$ is a vector of randomly distributed terms (for example a normally distributed term with mean zero and variance σ^2). Because probability estimations are computationally cumbersome much like the case for the mixed logit, a simulation-based maximum likelihood method is used for model estimation (with Halton draws again being an efficient alternative to random draws).

1.4 Safety-Perception Model Estimation Results

A random parameter ordered probability model is estimated to study the variables affecting respondent's opinion about how safe to drive today compared to five years ago. Tables 2 and 3 present estimation results and marginal effects, respectively. Starting with fixed parameters variables, results in Table 2 show that driving experience and marital status are statically significant variables in determining respondent's opinion about the safety of driving today compared to five years ago. As shown by marginal effects in Table 3, experienced drivers (who had a license for more than 20 years) and married respondents are less likely to think driving is more and much more safe and more likely to think driving is less safe and much less safe today compared to five years ago. Table 3 shows that married respondents had, on average, 0.035 and 0.041 higher probability of thinking that driving is much less safe and less safe today compared to five years ago, respectively. However, gender and number of vehicles in the household were statically significant variables with an opposite effect. Marginal effects in Table 3 indicate that male respondents and respondents who live in a two-vehicles household are more likely to think that driving is more safe, much more safe or about the same and less likely to think driving is less safe and much less safe today compared to five years ago. Tables 2 and 3 show that other indicator variables like age (55 year or greater), low income (less than $30.000), low milage (less than 8,000 per year), household size (two people), and long work commute (more than 40 minutes) are all statistically significant with the effect being to decrease the likelihood of the conception that driving is more and much more safe or about the same and increase the likelihoods of the conception that driving is less or much less safe today compared to five years ago.

Table 2. Random parameters ordered probit model estimation of respondent's opinion about how safe to drive today compared to 5 years ago (much less safe, less safe, about the same, and more and much more safe).

Variable description	**Estimated parameter**	**t-Statistic**
Fixed parameters		
Constant	1.65	14.26
Experience driver indicator (1 if driver has had a driver's license for more than 20 years, 0 otherwise)	-0.27	-2.7
Two vehicles indicator (1 if the respondent's household has two vehicles, 0 otherwise)	0.18	2.16
Male indicator (1 if respondent is male, 0 otherwise)	0.23	2.99
Marital status indicator (1 if the respondent is married, 0 otherwise)	-0.20	-2.19
Age indicator (1 if respondent is 55 years old or greater, 0 otherwise)	-0.22	-2.33
Low-income indicator (1 if the respondent-household's total annual income is less than $35,000, 0 otherwise)	-0.15	-1.68
Low-milage indicator (1 if the respondent drives less than 8000 mile per year, 0 otherwise)	-0.20	-2.62
Household size indicator (1 if two people live in the respondent's household, 0 otherwise)	-0.16	-1.92
Long commute indicator (1 if the respondent's round-trip commute to work takes more than 40 minutes, 0 otherwise)	-0.24	-1.96
***Random parameters* (*Normally distributed*)**		
Ride hailing indicator (1 if the respondent uses ride hailing services at least once a week, 0 otherwise) (Standard deviation of parameter distribution)	0.30 (0.98)	1.51 (4.51)
Children in the household indicator (1 if the respondent's household has at least one person under 15 years old, 0 otherwise) (Standard deviation of parameter distribution)	0.31 (0.79)	1.48 (3.82)
Crash indicator (1 if the respondent has been in at least one police-reported crash as a driver, 0 otherwise) (Standard deviation of parameter distribution)	0.001 (0.42)	0.02 (8.16)
Threshold, μ_1	1.04	18.07
Threshold, μ_2	2.49	31.68
Number of observations	887	
Log-likelihood (constant only)	-1076.70	
Log-likelihood at convergence	-1072.80	

Table 3. Marginal effects of the random parameters ordered probit model estimation of respondents' opinion about how safe to drive today compared to 5 years ago.

Variable description	Average marginal effects			
	Much less safe	**Less safe**	**About the same**	**More or much more safe**
Experience driver indicator (1 if driver has had a driver's license for more than 20 years, o otherwise)	0.045	0.057	-0.049	-0.053
Two vehicles indicator (1 if the respondent's household has two vehicles, 0 otherwise)	-0.031	-0.039	0.034	0.036
Male indicator (1 if respondent is male, 0 otherwise)	-0.039	-0.048	0.044	0.044
Marital status indicator (1 if the respondent is married, 0 otherwise)	0.035	0.041	-0.038	-0.037
Age indicator (1 if respondent is 55 years old or greater, 0 otherwise)	0.041	0.046	-0.046	-0.041
Low-income indicator (1 if the respondent-household's total annual income is less than $35,000, 0 otherwise)	0.028	0.032	-0.032	-0.028
Low-milage indicator (1 if the respondent drives less than 8000 miles per year, 0 otherwise)	0.035	0.043	-0.038	-0.039
Household size indicator (1 if two people live in the respondent's household, 0 otherwise)	0.029	0.033	-0.032	-0.030
Long commute indicator (1 if the respondent's round-trip commute to work takes more than 40 minutes, 0 otherwise)	0.047	0.047	-0.053	-0.041
Ride hailing indicator (1 if the respondent uses ride hailing services at least once a week, 0 otherwise)	-0.045	-0.070	0.044	0.070
Children in the household indicator (1 if the respondent's household has at least one person under 15 years old, 0 otherwise) (Standard deviation of parameter distribution)	-0.045	-0.070	0.045	0.071
Crash indicator (1 if the respondent has been in at least one police-reported crash as a driver, 0 otherwise)	-0.0002	-0.0003	0.0003	0.0002

The estimated model in Table 2 produced three normally distributed random parameter variables. Respondents who use ride hailing services at least once a week and respondents who live in a household with at least one person under 15 years old had relatively similar effects producing normally distributed random parameters with the means equal 0.30 and 0.31 and standard deviations equal 0.98 and 0.79, respectively (Table 2). Meaning, that the ride hailing parameter was positive for 62% of individuals and negative for 38%, and that the 15-year-old person in the household parameter was positive for about 65% and negative for about 35%. Table 3 shows that these two random parameter variables have relatively similar marginal effects increasing the probability of believing that driving is more and much more safe or about the same and decreasing the probability of believing that driving is less and much less safe today compared to five years ago. Respondents who had been in at least one police-reported crash also produced a normally distributed random parameter with the mean equal 0.001 and standard deviation equal 0.42, meaning that this parameter was positive for about 50% of individuals and negative for the other 50% (Table 2). Marginal effects in Table 3 show that drivers who have been in at least one crash were more likely to think that driving is about the same or more safe and less likely to think that driving is less safe today compared to five years ago.

It should be noted that during the estimation of this model, some variables related to respondents' opinions were omitted for two reasons. One, it is hard to see how some questions might affect respondent's opinion about safety. For example, a question asking what type of activity performed in the last three months with some choices like watching football, attending church, and playing chess is hardly relevant to what a respondent might think about the safety of driving. Two, endogeneity issues might arise when using some variables, which could lead to inaccurate or biased inferences. For example, when a question asks about opinion about speed limits whether they are too low, about the same, or too high becomes a variable, which might not be a perfect indicator in the model as respondent's opinion about speed limits might be endogenous with the opinion about driving safety (see Washington et al., 2020).

1.5 Speed-Limit Perception Model Estimation Results

To explore safety-related perceptions further, a random parameters ordered probit model was also developed for the question: Do you believe speed limits are; too low, about right, too high. The percentage responses to this question are too low (12%), about right (83%), and too high (5%), please see Figure 3 for an illustration of the responses. For statistical modeling in this case there are just three responses: 1 = too low, 2 = about right , and 3 = too high.

Random parameters ordered probability model estimation results, using 884 valid observations, are provided in Table 4, and associated marginal effects are provided in Table 5. The estimation results show that only one of the explanatory variables produced a statistically significant random parameter, the graduate level education indicator (1 if the respondent's education level is graduate or post-graduate degree, 0 otherwise), with a mean of 0.08 and a standard deviation of 0.54. While this mean and standard deviation suggest that the effect of this variable is positive (meaning they are more likely to believe the speed limits are too high) for about 56% of the sample and negative for 44% (meaning they are less likely to believe the speed limits are too high), the net effect indicated in Table 5 shows that the average effect of this variable is that respondents with a graduate degree are less likely to think speed limits are too low (0.014 lower probability) and more likely to think they are about right or too high (both with 0.007 higher probabilities). The estimation results for the experienced driver indicator (1 if driver has had a driver's license for more than 20 years, 0 otherwise), older age indicator (1 if respondent is 55

Table 4. Random parameters ordered probit model estimation of respondent's opinion about roadway speed limits, in general (too low, about right, or too high).

Variable description	Estimated parameters	t-Statistic
Fixed parameters		
Constant	0.93	8.88
Experience driver indicator (1 if driver has had a driver's license for more than 20 years, 0 otherwise)	0.38	3.01
Age indicator (1 if respondent is 55 years old or greater, 0 otherwise)	0.31	2.52
Low-milage indicator (1 if the respondent drives less than 8000 mile per year, 0 otherwise)	0.34	3.40
High-income indicator (1 if the respondent-household's total annual income is $100,000 or more, 0 otherwise)	-0.37	-3.01
Crash indicator (1 if the respondent has been in at least one police-reported crash as a driver, 0 otherwise)	-0.21	-1.98
Random parameters (normally distributed)		
Graduate level education indicator (1 if the respondent's education level is Graduate or post-graduate degree, 0 otherwise) (Standard deviation of parameter distribution)	0.08 (0.54)	0.64 (5.18)
Threshold, μ_1	3.07	28.55
Number of observations	884	
Log-likelihood (constant only)	-469.73	
Log-likelihood at convergence	-468.40	

Table 5. Marginal effects of the random parameters ordered probit model estimation of respondent's opinion about roadway speed limits, in general (too low, about right, or too high).

Variable description	Average marginal effects		
	Too low	About right	Too high
Experience driver indicator (1 if driver has had a driver's license for more than 20 years, 0 otherwise)	-0.072	0.043	0.029
Age indicator (1 if respondent is 55 years old or greater, 0 otherwise)	-0.051	0.024	0.027
Low-milage indicator (1 if the respondent drives less than 8000 mile per year, 0 otherwise)	-0.061	0.035	0.026
High-income indicator (1 if the respondent-household's total annual income is $100,000 or more, 0 otherwise)	0.074	-0.048	-0.026
Crash indicator (1 if the respondent has been in at least one police-reported crash as a driver, 0 otherwise)	0.035	-0.018	-0.017
Graduate level education indicator (1 if the respondent's education level is Graduate or post-graduate degree, 0 otherwise)	-0.014	0.007	0.007

years old or greater, 0 otherwise), and low-milage indicator (1 if the respondent drives less than 8000 mile per year, 0 otherwise) all indicate that these people are less likely to believe the speed limits are too low and more likely to think they are about right or too high relative to their counterparts (drivers who have been licensed 20 years or less, drivers less than 55 years old, drivers driving 8000 miles per year or more, respectively). In contrast, Table 5 shows that the high-income indicator (1 if the respondent-household's total annual income is $100,000 or more, 0 otherwise) and crash indicator (1 if the respondent has been in at least one police-reported crash as a driver, 0 otherwise) had a higher probability of thinking speed limits were too low and lower probability of thinking they were about right or too high relative to their lower-income crash-free counterparts.

The aggregate data values suggest that the majority of people (83%) think that the speed limits are about right, and the model estimation findings indicate that drivers from households with high incomes and those with past crash histories are more likely to think speed limits are too low. These findings are somewhat contradictory to those of Mannering (2009) where it was found that drivers felt safe driving well above the speed limit. Two factors could explain this. One is that speed limits have generally increased since the 2004-2005 data used in Mannering's study and the second is that people's perception of speed limits and their respect for them may have changed since the early 2000's.

1.6 COVID-19-Induced Changes in Vehicle Usage and Identification Implications

Using the same survey instrument, a question was asked as to how respondents' vehicle usage has changed since the pandemic. Specifically, since the outbreak of the COVID-19 pandemic, how has your number of miles driven changed?, with 5 responses; 1) I drive much less (drive less half of what I usually drive), 2) I drive substantially less (drive between 25% and 50% less than usual), 3) I drive less (drive between 10% and 25% less than usual), 4) I drive about the same (drive between 10% less and 10% more than usual), and 5) I drive more (drive 10% or more than usual). The intent of this question was to understand how vehicle usage has changed since the pandemic, with the idea that this could provide insights into the identification problem discussed earlier in this document. That is, is the observed pandemic/post-pandemic shift in injury severities due to fundamental changes in driver behavior or due to the fact that the driving population has become fundamentally different because the proportion of risky drivers in the overall driving population has changed (increased).

This question resulted in 747 valid responses with the distribution of responses shown in Table 6 and illustrated in Figure 4. The table and figure show that nearly 62 percent of drivers reported that they drive more than 10 percent less than they did pre-pandemic and that nearly 26 percent of respondents indicated that they now drive less than half of what they did pre-pandemic, which is an astonishing reduction in travel.

As before, a random parameters ordered probability model is estimated to study how vehicle usage has changed from pre-pandemic to post-pandemic. Table 7 and Table 8 present estimation results and marginal effects, respectively. The estimation results in this table provide strong and compelling evidence that the mix of drivers on the road has changed substantially since the pandemic with riskier drivers decreasing their vehicle use less, maintaining their vehicle use, or increasing their vehicle use and safer drivers drastically reducing their vehicle use.

To see this, first consider factors generally associated with being a safer driver; having more driving experience, being older age, having higher educational achievement, having short commutes, and having few if any previous crashes, and. The findings in Tables 7 and 8 show

Table 6. An overview of the answers for the question "Since the outbreak of the COVID-19 pandemic, how has your number of miles driven changed?"

Since the outbreak of the COVID-19 pandemic, how has your number of miles driven changed?	**Number of respondents**	**Percentage**
I drive much less (drive less half of what I usually drive)	192	25.70
I drive substantially less (drive between 25% and 50% less than usual)	133	17.80
I drive less (drive between 10% and 25% less than usual)	138	18.48
I drive about the same (drive between 10% less and 10% more than usual)	236	31.59
I drive more (drive 10% or more than usual)	48	6.43
Total	747	100

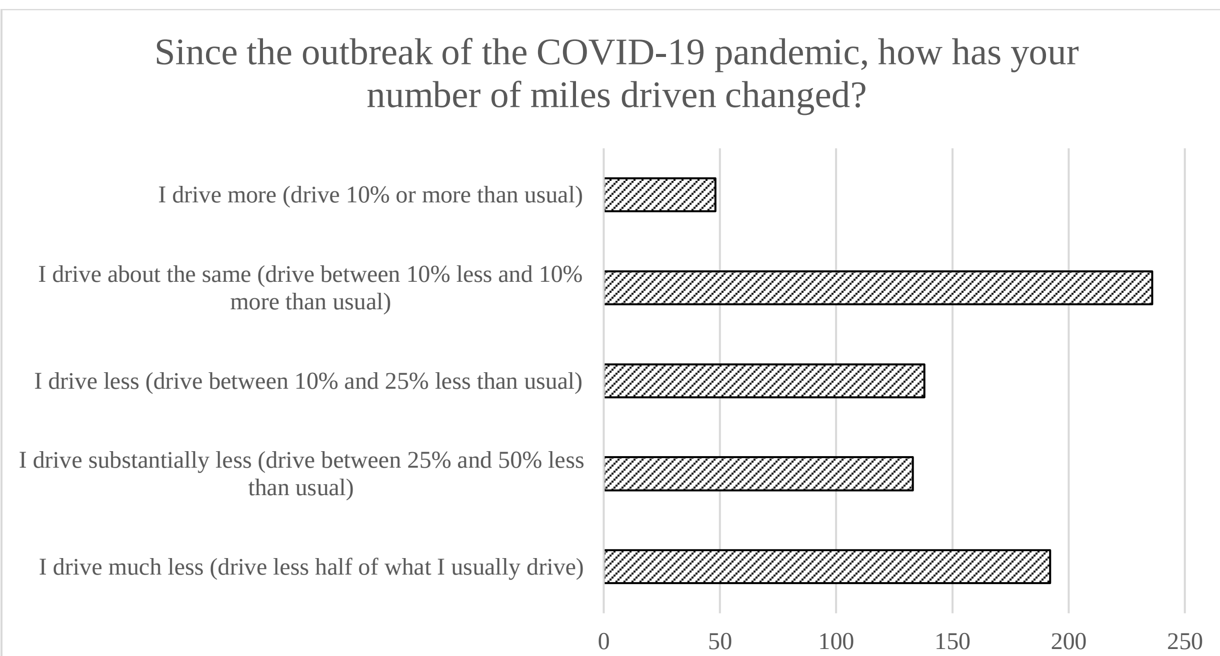

Figure 4. An illustration of responses to the question "Since the outbreak of the COVID-19 pandemic, how has your number of miles driven changed?"

Table 7. Random parameters ordered probit model estimation of respondent's change of number of miles driven since the outbreak of the COVID-19 pandemic.*

Variable description	Estimated parameters	t-Statistic
Fixed parameters		
Constant	1.43	11.27
Experience driver indicator (1 if driver has had a driver's license for more than 20 years, 0 otherwise)	-0.28	-2.51
Age indicator (1 if respondent is 55 years old or greater, 0 otherwise)	-0.20	-1.94
Education level indicator (1 if the respondent’s education level is college or higher, 0 otherwise)	-0.34	-3.66
Long commute indicator (1 if the respondent's round-trip commute to work takes more than 40 minutes, 0 otherwise)	0.40	2.87
Employment status indicator (1 if the respondent is Employed full-time, 0 otherwise)	0.29	3.24
Long walk indicator (1 if it takes more than 20 minutes to walk to the closest restaurant, 0 otherwise)	-0.19	-2.14
Bike use indicator (1 if the respondent uses bike at least one day a week, 0 otherwise)	-0.25	-2.15
***Random parameters* (*normally distributed*)**		
Crash indicator (1 if the respondent has been in at least one police-reported crash as a driver, 0 otherwise) (Standard deviation of parameter distribution)	0.06 (0.77)	0.68 (12.58)
Marital status indicator (1 if the respondent has never been married, 0 otherwise) (Standard deviation of parameter distribution)	-0.17 (0.45)	-1.71 (5.79)
Working from home indicator (1 if respondent works from home regularly, 0 otherwise) (Standard deviation of parameter distribution)	-0.60 (1.07)	-5.33 (9.54)
Children in the household indicator (1 if the respondent's household has at least one person under 15 years old, 0 otherwise) (Standard deviation of parameter distribution)	0.26 (0.70)	1.14 (3.05)
Transit use indicator (1 if the respondent uses transit at least one day a week, 0 otherwise)	-0.46 (0.92)	-2.56 (5.03)
Threshold, μ_1	0.65	12.73
Threshold, μ_2	1.26	19.61
Threshold, μ_3	2.86	26.11
Number of observations	747	
Log-likelihood (constant only)	-1098.60	
Log-likelihood at convergence	-1089.38	

* The dependent variable is; 1 = I drive much less (drive less half of what I usually drive), 2 = I drive substantially less (drive between 25% and 50% less than usual), 3 = I drive less (drive between 10% and 25% less than usual), 4 = I drive about the same (drive between 10% less and 10% more than usual), and 5 = I drive more (drive 10% or more than usual).

Table 8. Average marginal effects of the random parameters ordered probit model estimation of respondent's change of number of miles driven since the outbreak of the COVID-19 pandemic.*

Variable description	**Average marginal effects**				
	Much less	**Substantially less**	**Less**	**About the same**	**More**
Experience driver indicator (1 if driver has had a driver's license for more than 20 years, 0 otherwise)	0.076	0.034	-0.004	-0.089	-0.016
Age indicator (1 if respondent is 55 years old or greater, 0 otherwise)	0.058	0.022	-0.006	-0.063	-0.010
Education level indicator (1 if the respondent's education level is college or higher, 0 otherwise)	0.089	0.041	-0.003	-0.106	-0.020
Long commute indicator (1 if the respondent's round-trip commute to work takes more than 40 minutes, 0 otherwise)	-0.096	-0.052	-0.004	0.123	0.028
Crash indicator (1 if the respondent has been in at least one police-reported crash as a driver, 0 otherwise)	-0.017	-0.007	0.002	0.019	0.003
Marital status indicator (1 if the respondent has never been married, 0 otherwise)	0.049	0.018	-0.006	-0.053	-0.008
Employment status indicator (1 if the respondent is Employed full-time, 0 otherwise)	-0.081	-0.033	0.007	0.092	0.016
Working from home indicator (1 if respondent works from home regularly, 0 otherwise)	0.189	0.045	-0.037	-0.174	-0.022
Children in the household indicator (1 if the respondent's household has at least one person under 15 years old, 0 otherwise)	-0.066	-0.034	-0.001	0.083	0.018
Long walk indicator (1 if it takes more than 20 minutes to walk to the closest restaurant, 0 otherwise)	0.054	0.021	-0.006	-0.060	-0.010
Bike use indicator (1 if the respondent uses bike at least one day a week, 0 otherwise)	0.074	0.024	-0.011	-0.076	-0.011
Transit use indicator (1 if the respondent uses transit at least one day a week, 0 otherwise)	0.148	0.034	-0.031	-0.135	-0.016

* Much less = more than 50% less; substantially less = drive between 25% and 50% less than usual), less = drive between 10% and 25% less than usual, about the same = drive between 10% less and 10% more than usual, more = drive 10% or more than usual.

that all of these characteristics make it more likely that the respondent would drive less post-pandemic, reflecting the finding that safer drivers have reduced their vehicle usage significantly more than their riskier counterparts, post pandemic. Marginal effects in Table 8 show that drivers with more than 20 years of experience have higher probabilities of driving less than half as much (0.076) and between 25% and 50% less (0.034) post pandemic, relative to drivers with 20 years or less of experience. Drivers 55 years of age and older have higher probabilities of driving less than half as much (0.058) and between 25% and 50% less (0.022) post pandemic, relative to drivers less than 50 years old. Drivers who completed college or have graduate degrees have higher probabilities of driving less than half as much (0.089) and between 25% and 50% less (0.041) post pandemic, relative to drivers who have not achieved this level of educational attainment.

Regarding commute time, Table 8 indicates that drivers with longer commutes (commute times greater than 40 minutes) have lower probabilities of driving less than half as much (0.096 lower probability) and between 25% and 50% less (0.052 lower probability) post pandemic, relative to drivers with commutes 40 minutes are less. The fact that drivers with longer commute times/distances (which is used as a key exposure measure by automobile insurance companies) are not reducing their vehicle utilization as much as those with shorter commutes suggests that high-exposure individuals are curtailing their driving less.

The effect of past crash history generated more complex findings since the indicator variable (1 if the respondent has been in at least one police-reported crash as a driver, 0 otherwise) produced a statistically significant random parameter. For this variable the mean parameter estimate was 0.06 with a large standard deviation of 0.77. This variable produced average marginal effects indicating that drivers involved in one or more police-reported crash were less likely to reduce their post-pandemic travel relative to those drivers who never crash-involved. Table 8 shows drivers with a crash history had, on average, a 0.017 lower probability of driving less than half (post-pandemic) and a 0.007 lower probability of driving between 25% and 50% less (post pandemic) relative to non-crash involved drivers. Again, this provides evidence that risker drivers have been less likely to significantly reduce their travel, post-pandemic.

Aside from variables that reflect how safe a driver might be, there are an abundance of life-style variables that influence how much respondents changed their vehicle utilization post-pandemic. For example, Table 8 shows respondents who indicated they had never been married were less likely to reduce their mileages by 25% or more. This variable is likely capturing the effect of life-style choices on the ability to alter vehicle miles of travel but it must be noted that this variable produced a statistically significant random parameter suggesting the effect of this explanatory variable did vary across the population of respondents.

Table 8 also shows that respondents who were employed full-time were also less likely to reduce their mileages by 25% or more. While some respondents in this employment category were undoubtedly able to transition to remote work, this finding shows that full-time workers, many of whom might be classified as essential, were not able to respond to the pandemic by decreasing their vehicle utilization. An associated variable, the indicator for working from home, finds that people that were able to transition to work from home were able to substantially decrease the number of miles they drove (although this variable produced a random parameter suggesting considerable variability in its effect across the population of respondents). Interestingly, the average net effect of someone employed full-time and working from home is a 0.108 increase (0.189 minus 0.081) in the probability of driving much less (driving less than half of what they drove pre-pandemic), which is quite substantial.

Next, the long walk indicator (1 if it takes more than 20 minutes to walk to the closest restaurant, 0 otherwise) serves as a proxy for urban form near the respondent's residence. Table

8 shows that people that live in less dense areas (where longer walks are required to get to services) were more likely to reduce their vehicle-miles driven by 25% or more. Respondents who live in less dense areas understandably accumulate more miles but this finding suggests they may have greater flexibility in reducing vehicle-miles traveled relative to their counterparts who live in more densely developed areas.

The final two variables show the effect of the alternate modes of travel (biking and transit). Table 8 shows that respondents who used their bikes at least one day a week were more likely to reduce their vehicle miles of travel by 25% or more. This probably captures a combination of life-style effects (regular bike users tend to have a much different perspectives on the transportation system) as well as the additional flexibility in terms of modal alternatives that bike use provides. Similarly, respondents who indicated that they use transit at least one day a week were also more likely to reduce their vehicle miles of travel by 25% or more, which again may be capturing a combination of life-style effects as well as the additional flexibility in terms of model alternatives. However, it is important to note, in this case, that this transit indicator variable produced a statistically significant random parameter reflecting the variation in the effect of this variable across the population.

Part II

An assessment of pandemic-induced shifts in highway safety from observed crash data

2.1. Assessments of Observed Crash Data

As established in Part I of this report, the characteristics of road users with respect to their crash exposure changed substantially during and after the pandemic (relative to pre-pandemic road users) due to different people reducing/increasing their vehicle usage at different rates. The popular media have noted the apparent increase in the frequency and severity of crashes during and after the pandemic, often attributing this to changes in behavior and reduced congestion (which presumably allowed motorists to drive at higher speeds). But the complexity of the problem likely goes far beyond pandemic-related effects because fatalities and severe injuries from motor-vehicle crashes were already on the rise before the pandemic. For example, from 2011 to 2019 fatalities on US highways rose by 19% and fatalities per mile driven rose by nearly 25%.

To supplement the findings in Part I, crash data were collected from the state of Florida from 2019 (pre-pandemic) and 2020 (pandemic). Since concern in the popular media and other safety-related pandemic research has focused on fundamental changes in driver behavior, the analysis herein focuses on crashes where risky-driving behaviors were identified as a significant cause of the crash. Specifically, data on single-vehicle crashes (where driver error is indisputable) were considered where one or more of the following risky behaviors were identified in the crash report; driving while asleep/drowsy, driving too fast for conditions, driving with suspected alcohol consumption, driving while inattentive, and driving while not wearing a seatbelt.

Figure 5 provides a snapshot of what happened to driver injury severities and vehicle miles traveled in 2020, considering single vehicle crashes where one or more of the five risky behaviors indicated above contributed to the crash. In this figure, and all subsequent analysis herein, the no-injury severity level is defined as a property-damage only crash, the minor-injury level is defined as possible or non-incapacitating injury, and the severe-injury level is defined as an incapacitating injury or fatality. Figure 5 shows the proportion of injury severities fluctuates mildly across months. However, looking more closely at the vehicle miles traveled (which is superimposed over the injury-proportion values), note that the lowest vehicle-miles traveled values in the months of April and May also have the highest proportions of severe-injury crashes. This potentially gives some credence to the finding in Part I of this report which suggests that riskier drivers make up a larger proportion of vehicle miles traveled in the pandemic/post-pandemic period relative to the pre-pandemic period.

Figure 6 gives an illustration of how driver injury severities changed between 2019 and 2020. This figure shows that the number of severe crashes in 2020 increased in every month relative to 2019. This is even true in March, April, and May where there was a very substantial drop in vehicle miles travelled relative to 2019. In the case of these months, one would expect the number of severe-injury crashes shown in Figure 6 to decline from 2019 to 2020 simply because the vehicle mile traveled dropped by very large amounts (nearly 45% in April), but these months still show an uptick in the number of severe injuries. Again, it is speculated that this aggregate finding could be a combination of behavioral changes and the fact that riskier drivers may be responsible for a larger proportion of the vehicle miles travelled during periods where vehicle miles traveled declined.

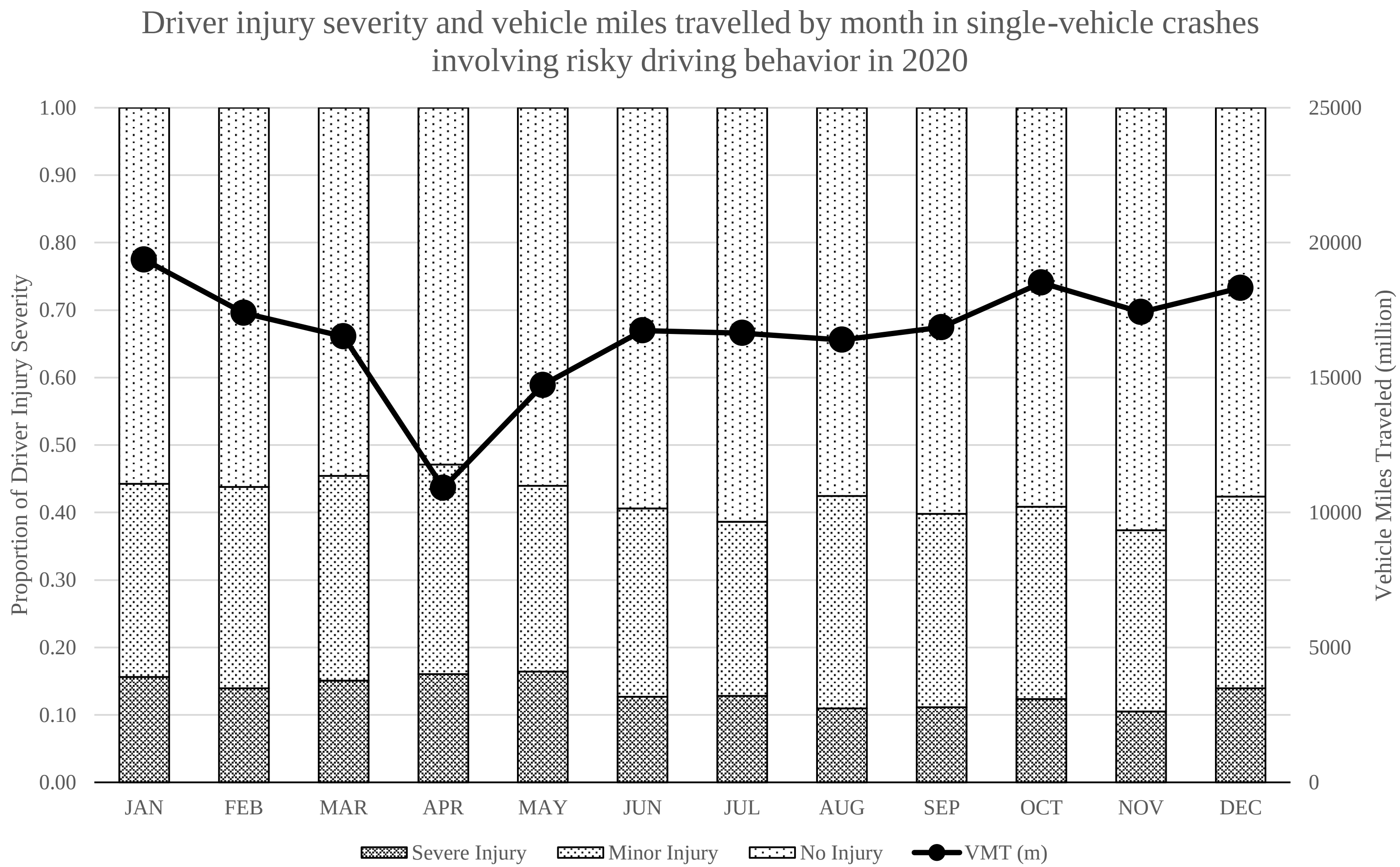

Figure 5. Driver injury severity and vehicle miles travelled by month in single-vehicle crashes involving risky driving behavior in 2020.

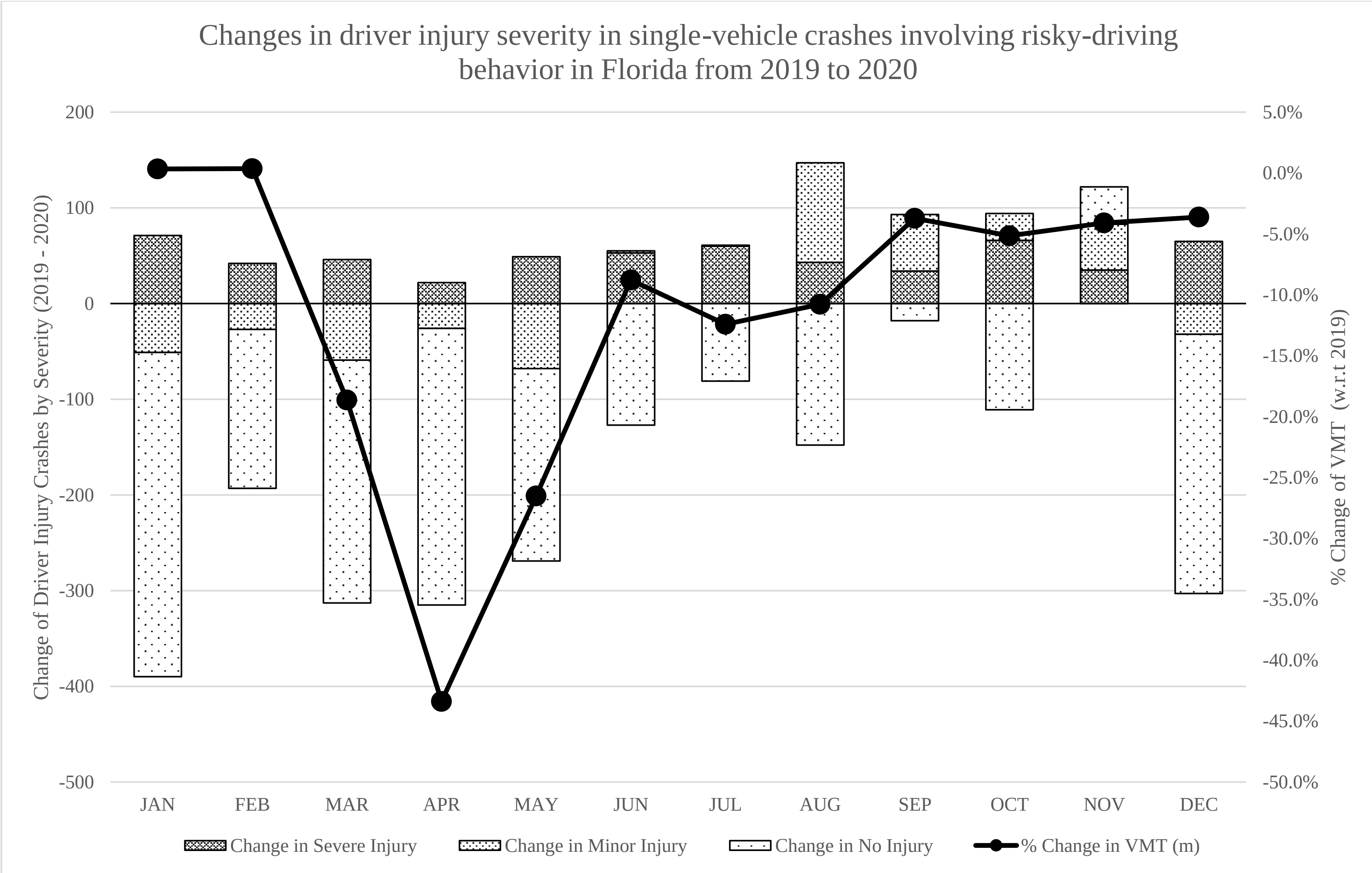

Figure 6. Changes in driver injury severity in single-vehicle crashes involving risky-driving behavior in Florida from 2019 to 2020.

There are of course many other factors that could explain this observed shift in the aggregate observed data, including the characteristics of the crashes that are experienced between the 2019 and 2020 time periods. To explore this, crash injury severity models need to be estimated for 2019 and 2020, and a more thorough statistical assessment would then be possible. The methodological approach for this assessment is discussed in the next section.

2.2 Methodological Approach – Random Parameters Multinomial Logit

Past studies focusing on traffic safety addressed possible unobserved heterogeneity in the statistical analysis crash-injury severity using random parameters and/or latent class approaches (please see Mannering et al., 2016 for a review of these approaches). The current study uses a random parameters logit model while considering possible heterogeneity in the means and variances of the random parameters to account for possible unobserved heterogeneity.[2]

Three injury severity levels are considered in this paper: no injury, minor injury (possible injury and non-incapacitating injury) and severe injury (incapacitating injury and fatality). To arrive at the random parameters logit, a function that determines injury severity probabilities is defined as,

$$S_{kn} = \boldsymbol{\beta}_k \mathbf{X}_{kn} + \varepsilon_{kn} \tag{10}$$

where S_{kn} is an injury-severity function determining the probability of injury-severity outcome k in crash n, $\mathbf{X}_{kn}$ is a vector of explanatory variables that affect fatigued drivers' injury-severity level k, $\boldsymbol{\beta}_k$ is a vector of estimable parameters, and ε_{kn} is the error term. If ε_{kn} is assumed to be generalized extreme value distributed, the standard multinomial logit model results as

[2] For recent injury severity applications of random parameters models with heterogeneity in means and variances, please see Seraneeprakarn et al. (2017), Behnood and Mannering (2017a,2017b), Waseem et al. (2019), Alnawmasi and Mannering (2019), Behnood and Mannering (2019), Al-Bdairi et al. (2020), Islam and Mannering (2020), Islam et al. (2020), Yu et al. (2020), Islam and Mannering (2021), Islam (2021), Li et al. (2021), Hou et al. (2021), Yan et al. (2021), Song et al. (2021), Se et al. (2021), Zamani et al. (2021), Zubaidi et al. (2021), Alogaili and Mannering (2022) and Alnawmasi and Mannering (2022a, 2022b), Hou et al. (2022).

(McFadden, 1981),

$$P_n(k) = \frac{EXP[\boldsymbol{\beta}_k \mathbf{X}_{kn}]}{\sum_{\forall K} EXP[\boldsymbol{\beta}_k \mathbf{X}_{kn}]} \tag{11}$$

where, $P_n(k)$ is the probability that crash n that will result in driver-injury severity outcome k and K is the set of the three possible injury-severity outcomes. A mixing distribution can be added to this formulation to account for unobserved heterogeneity and effectively allow the possibility of one or more parameter estimates in the vector $\boldsymbol{\beta}_k$ vary across crash observations. With this mixing distribution, Equation 11 can be rewritten as (Washington et al., 2020)

$$P_n(k) = \int \frac{EXP(\boldsymbol{\beta}_k \mathbf{X}_{kn})}{\sum_{\forall K} EXP(\boldsymbol{\beta}_k \mathbf{X}_{kn})} f(\boldsymbol{\beta}_k | \boldsymbol{\varphi}_k) d\boldsymbol{\beta}_k \tag{12}$$

where, $f(\boldsymbol{\beta}_k|\boldsymbol{\varphi}_k)$ is the density function of $\boldsymbol{\beta}_k$ and $\boldsymbol{\varphi}_k$ is a vector of parameters describing the mixing density function (mean and variance), and all other terms are as previously defined. To provide more flexibility in accounting for unobserved heterogeneity, with the mixing distribution now allowing parameters to vary across crashes n, the $\boldsymbol{\beta}_{kn}$ vector can be made to be a function of variables that affect its mean and variance as (Washington et al., 2020)

$$\boldsymbol{\beta}_{kn} = \beta_k + \Theta_{kn}\mathbf{Z}_{kn} + \sigma_{kn} EXP(\Psi_{kn}\mathbf{W}_{kn})\, \nu_{kn} \tag{13}$$

where, β_k is the mean parameter estimate across all crashes, $\mathbf{Z}_{kn}$ is a vector of crash-specific explanatory variables that captures heterogeneity in the mean that affects fatigued drivers' injury-severity level k, $\boldsymbol{\Theta}_{kn}$ is a corresponding vector of estimable parameters, $\mathbf{W}_{kn}$ is a vector of crash-specific explanatory variables that captures heterogeneity in the standard deviation σ_{kn} with corresponding parameter vector Ψ_{kn}, and v_{kn} is a disturbance term.

Numerous density functions can be considered for the term $f(\boldsymbol{\beta}_k|\boldsymbol{\varphi}_k)$ in Equation 12. In the forthcoming empirical analysis, the normal distribution was used and none of the other distributional alternatives considered were found to produce a statistically superior model.

Estimation of the mixed logit model is undertaken by simulated maximum likelihood approaches because the required integration for parameter estimation is not closed form. Previous studies have shown that Halton draws provide a more efficient distribution of simulation draws than purely random draws (McFadden and Ruud, 1994; Bhat, 2003; Train, 2009). In the forthcoming model estimations 1,000 Halton draws are used in the simulated likelihood functions, a number that has been shown to be more than sufficient to provide accurate parameter estimates (Halton, 1960; Bhat, 2003; Milton et al., 2008). In this study, the normal distribution has been used in estimation of the explanatory variables because it provided the best overall statistical fit (other distributions such as the log-normal, uniform and exponential were not found to produce statistically better results than the normal distribution).

Finally, marginal effects were computed to determine the effect of explanatory variables on injury-severity probabilities. The marginal effect provides the effect that a one-unit increase in an explanatory variable has on the injury-outcome probabilities. The average marginal effect over all crash observations were reported (please see Hou et al., 2022, for issues associated with the computation of marginal effects for random parameters logit models).

2.3 Model Estimation Results: 2019 vs. 2020

Summary statistics of the variables found to be statistically significant in the 2019 and 2020 model estimations are presented in Table 9. While Table 9 shows modest differences between 2019 and 2020 variable means and standard deviations, one thing that stands out prominently is the percent of Florida residents involved in the crashes. In 2019, the table indicates that only 32.2% of risky-behavior single-vehicle crashes involved a Florida-licensed driver. In 2020, with this percentage swelled to 90.8%. Much of this increase can be attributed to the rapid decline in the tourism industry (including retiree seasonal re-locations to Florida

Table 9. Descriptive Statistics of key variables in the driver injury severity models in 2019 and 2020.

Variable	2019		2020	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
Spatial characteristics				
District 5 indicator (1 if crash occurred in District 5, 0 otherwise)	0.222	0.416	0.215	0.411
District 6 indicator (1 if crash occurred in District 6, 0 otherwise)	0.062	0.241	0.062	0.240
Temporal characteristics				
Afternoon indicator (1 if crash occurred between 12 and 4 PM, otherwise)	0.148	0.355	0.145	0.352
4th quarter indicator (1 if crash occurred between October and December, 0 otherwise)	0.276	0.447	0.260	0.438
Traffic characteristics				
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise)	0.162	0.368	0.207	0.406
Crash characteristics				
Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise)	0.635	0.481	0.609	0.487
Harmful non-fixed object indicator (1 if harmful event occurred with non-fixed object, 0 otherwise)	0.214	0.411	0.229	0.4190
Roadway characteristics				
Urban principal arterial indicator (1 if crash occurred on urban principal arterials, 0 otherwise)	0.078	0.268	0.101	0.302
Urban interstate indicator (1 if crash occurred on urban interstate, 0 otherwise)	0.064	0.245	0.067	0.251
Urban freeway and interstate indicator (1 if crash occurred on urban freeway and interstate, 0 otherwise)	0.095	0.292	0.095	0.294
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise)	0.129	0.336	0.115	0.319
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0 otherwise)	0.076	0.266	0.097	0.296
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median barrier, 0 otherwise)	0.301	0.458	0.321	0.466
Driver characteristics				
Female driver indicator (1 if driver is female, 0 otherwise)	0.281	0.449	0.297	0.457
Young male driver indicator (1 if driver age is below 30 years, 0 otherwise)	0.316	0.465	0.302	0.459
Older-aged male driver indicator (1 if male driver age is between 50 to 65 years, 0 otherwise	0.101	0.301	0.104	0.306
Normal driving indicator (1 if driving without any physical/emotional impairment, 0 otherwise)	0.501	0.500	0.491	0.499
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise)	0.107	0.310	0.116	0.321
Florida registered driver indicator (1 if drivers are registered with Florida license, 0 otherwise)	0.322	0.467	0.908	0.288

Variable	2019		2020	
	Mean	Std. Dev.	Mean	Std. Dev.
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise)	0.025	0.156	0.024	0.154
Driver violation indicator (1 if driver had previous violation history, 0 otherwise)	0.537	0.498	0.551	0.497
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise)	0.108	0.311	0.136	0.343
Fatigue and inattentive driving indicator (1 if drivers were identified for fatigue and inattentive driving at the time of crash, 0 otherwise)	0.043	0.203	0.054	0.225
Driving too fast and alcohol consumption indicator (1 if driver was identified driving too fast for conditions and suspected of alcohol consumption, 0 otherwise)	0.018	0.134	0.016	0.128
Careless driving indicator (1 if driver operated in careless or reckless manner, 0 otherwise)	0.409	0.492	0.418	0.493
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise)	0.167	0.373	0.134	0.341
Driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was less than the speed limit by more than 10 mi/hr, 0 otherwise)	0.130	0.336	0.154	0.361
Running off road indicator (1 if driver ran off the road, 0 otherwise)	0.094	0.292	0.102	0.302
Improper lane keeping indicator (1 if failed to keep in proper lane, 0 otherwise)	0.068	0.253	0.063	0.154
No contributing driver factor indicator (1 if no contributing factor from driving action was determined, 0 otherwise)	0.519	0.499	0.511	0.499
Driving under the influence indicator (1 if driver was identified under the influence of alcohol, medication, and drug, 0 otherwise)	0.241	0.427	0.244	0.429
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise)	0.082	0.274	0.084	0.429
Driver's physical impairment indicator (1 if driver was identified to be physically impaired due to seizure, epilepsy, or blackout, 0 otherwise)	0.004	0.064	0.004	0.064

in the winter months) during the pandemic year of 2020. This alone could cause a rather substantial change in resulting injury severities. What is clear from this observation is that there are compelling reasons to believe the driving population is much different between 2019 and 2020, not only for the aforementioned finding that riskier drivers are making up a greater proportion of vehicle miles traveled, but also the State-mix of drivers had shifted. Regarding possible differences between in-State and out-of-State drivers, the study conducted by Alogaili and Mannering (2020) suggests that this difference may not be trivial.

Before presenting the model estimation results, it is important to establish that there are statistically significant differences between the 2019 and 2020 model estimation results (see Mannering, 2018). To statistically test the difference between 2019 and 2020 crash-injury severity models, two likelihood ratio tests are conducted to assess whether the determinants of crash-injury severity are temporally stable between 2019 and 2020. For these tests, the first χ^2 distributed test statistic is,

$$X^2 = -2[LL(\boldsymbol{\beta}_{2019,2020}) - LL(\boldsymbol{\beta}_{2020})] \tag{14}$$

where, $LL(\boldsymbol{\beta}_{2019,2020})$ is the log-likelihood at convergence of a model containing converged parameters based on 2019's data, while using data from time-period 2020, and $LL(\boldsymbol{\beta}_{2020})$ is the log-likelihood at convergence of the model using 2020's data (with parameters are no longer restricted to using 2019's converged parameters as is the case for $LL(\boldsymbol{\beta}_{2019,2020})$. The result of this test gave an X^2 value of 3,774.18 with 29 degrees of freedom which, from the χ^2 distribution, means that the null hypothesis that the two models are equal can be rejected with over 99.99% confidence.

The second χ^2 distributed test statistic is,

$$X^2 = -2[LL(\boldsymbol{\beta}_{2020,2019}) - LL(\boldsymbol{\beta}_{2019})] \tag{15}$$

where, $LL(\boldsymbol{\beta}_{2020,2019})$ is the log-likelihood at convergence of a model containing converged parameters based on 2020's data, while using data from time-period 2019, and $LL(\boldsymbol{\beta}_{2019})$ is the log-likelihood at convergence of the model using 2019's data (with parameters are no longer restricted to using 2020's converged parameters as is the case for $LL(\boldsymbol{\beta}_{2020,2019})$. The result of this test gave an X^2 value of 3,235.52 with 29 degrees of freedom which, again from the χ^2 distribution, means that the null hypothesis that the two models are equal can be rejected with over 99.99% confidence. The results of these two tests indicate that there is a clear structure shift in the effects of the model parameters from 2019 to 2020.

Moving forward with estimating separate statistical models of crash injury severity for 2019 and 2020 data, Table 10 presents the estimation results of the random parameters multinomial logit for driver injury severity in single-vehicle crashes involving risky driving behaviors in Florida in 2019, using data from 17,692 observed crashes. Estimation results and corresponding marginal effects show that a wide range of factors were found to influence injury severities including spatial characteristics, roadway characteristics and driver characteristics. In addition, statistically significant unobserved heterogeneity was found to exist in the data with the minor-injury's constant mean being a function of the careless driving indicator and its variance being a function of an indicator for non-collision factors (such as overturn/rollover). It should be noted that the overall statistical fit of this model is quite good with a ρ^2 value of 0.300.

Table 11 provides the model results of the random parameters multinomial logit for driver injury severity in single-vehicle crashes involving risky driving behaviors in Florida in 2020, based on 13,993 crash observations. Many of the same variables are found to be statistically significant, but there are notable exceptions (more on this below in the discussion of the difference in 2019 and 2020 marginal effects). In the 2020 model, unobserved

Table 10. Model results of random parameters multinomial logit for driver injury severity in single-vehicle crashes involving risky driving behaviors in Florida in 2019.

Variable	Parameter Estimates	t-stat	Marginal Effects		
			No Injury	Minor Injury	Severe Injury
Constant [SI]	-2.655	-37.28			
Random parameter (normally distributed)					
Constant [MI]	-2.779	-16.06			
(*Standard deviation of parameter distribution*)	(*2.427*)	(*10.14*)			
Heterogeneity in the mean of random parameter					
Constant: Careless driving indicator (1 if driver operated in careless or reckless, 0 otherwise) [MI]	0.413	3.91			
Heterogeneity in the variance of random parameter					
Constant: Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise) [MI]	0.365	2.72			
Spatial characteristics					
District 5 indicator (1 if crash occurred in District 5, 0 otherwise) [NI]	-0.171	-3.02	-0.0053	0.0032	0.0021
District 6 indicator (1 if crash occurred in District 6, 0 otherwise) [MI]	-0.611	-4.21	0.0029	-0.0033	0.0004
Roadway characteristics					
Urban principal arterial indicator (1 if crash occurred on urban principal, 0 otherwise) [SI]	0.454	4.84	-0.0029	-0.0008	0.0037
Unban freeways and interstate indicator (1 if crash occurred on urban freeways and interstate, 0 otherwise) [SI]	0.261	2.53	-0.0014	-0.0003	0.0017
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise) [SI]	0.518	6.35	-0.0046	-0.0013	0.0059
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0otherwise) [NI]	-0.432	-5.64	-0.0063	0.0036	0.0027
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median barrier, 0 otherwise)	0.132	1.90	-0.0037	0.0043	-0.0006
Crash characteristics					
Harmful non-fixed object indicator (1 if harmful event occurred with non-fixed object, 0 otherwise) [SI]	-0.862	-8.93	0.0054	0.0010	-0.0064
Driver characteristics					
Female driver indicator (1 if drivers are female, 0 otherwise) [MI]	0.341	4.67	-0.0093	0.0105	-0.0012

Variable	Parameter Estimates	t-stat	Marginal Effects		
			No Injury	Minor Injury	Severe Injury
Older-aged male driver indicator (1 if male driver age between 50 to 65 years, 0 otherwise) [SI]	0.283	3.12	-0.0019	-0.0005	0.0023
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise) [NI]	0.776	3.49	-0.0308	0.0192	0.0192
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise) [NI]	-1.141	-7.79	-0.0045	0.0025	0.0020
Normal driving indicator (1 if driving without any physical/emotional impairment, 0 otherwise) [SI]	-1.522	-6.32	0.0576	-0.0662	0.0085
Driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was less than the speed limit by more than 10 mi/hr, 0 otherwise) [SI]	-0.231	-2.41	0.0014	0.0003	-0.0017
Running off road indicator (1 if driver ran off the road, 0 otherwise) [NI]	-1.199	-14.12	-0.0200	0.0107	0.0092
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise) [MI]	0.255	2.56	-0.0037	0.0041	-0.0004
Driver violation indicator (1 if driver had previous violation history, 0 otherwise) [SI]	-1.075	-17.13	0.0225	0.0056	-0.0281
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise) [NI]	-1.141	-16.56	-0.0253	0.0131	0.0122
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise) [MI]	-0.857	-6.31	0.0059	-0.0070	0.0011
Fatigue and inattentive driving indicator (1 if drivers were identified for fatigue and inattentive driving at the time of crash, 0 otherwise) [SI]	-0.978	-5.60	0.0013	0.0004	-0.0017
No contributing driver factor indicator (1 if no contributing factor from driving action was determined, 0 otherwise) [MI]	0.776	3.49	-0.0310	0.0355	-0.0045
Improper lane keeping indicator (1 if failed to keep in proper lane, 0 otherwise) [MI]	1.059	7.39	-0.0067	0.0074	-0.0007
Careless driving indicator (1 if driver operated in careless or reckless manner, 0 otherwise)	-0.985	-14.81	-0.0636	0.0394	0.0242
Driver's physical impairment indicator (1 if driver was identified to be physically impaired due to seizure, epilepsy, or blackout, 0 otherwise) [NI]	-3.111	-8.05	-0.0014	0.0005	0.0008
Number of observations	17,692				
Log-likelihood at zero	-19,436.648				
Log-likelihood at convergence	-13,592.408				
$\rho^2 = 1 - LL(\boldsymbol{\beta})/LL(0)$	0.300				

SI = Severe Injury; MI = Minor Injury; NI = No Injury

Table 11. Model results of random parameters multinomial logit for driver injury severity in single-vehicle crashes involving risky driving behaviors in Florida in 2020.

Variable	Parameter Estimates	t-stat	Marginal Effects		
			No Injury	Minor Injury	Severe Injury
Constant [SI]	-2.307	-26.07			
Random parameter (normally distributed)					
Constant [MI]	-3.396	-12.05			
(*standard deviation of parameter distribution*)	(*4.776*)	(*10.68*)			
Heterogeneity in the mean of random parameter					
Constant: Driving below the speed limit by more than 10 mi/h indicator (1 if travel speed was less than the speed limit by more than 10 mi/hr, 0 otherwise) [MI]	-1.071	-5.06			
Heterogeneity in the variance of random parameter					
Constant: Alcohol and inattentive driving indicator (1 if driver was suspected of alcohol consumption and identified for inattentive driving at the time of crash, 0 otherwise) [MI]	0.309	3.49			
Spatial characteristics					
District 5 indicator (1 if crash occurred in District 5, 0 otherwise) [NI]	-0.119	-1.85	-0.0035	0.0013	0.0021
District 6 indicator (1 if crash occurred in District 6, 0 otherwise) [MI]	-1.576	-5.21	0.0042	-0.0051	0.0008
Temporal characteristics					
Afternoon indicator (1 if crash occurred between 12 and 4 PM, otherwise) [MI]	-0.333	-1.93	0.0024	-0.0030	0.0006
4th quarter indicator (1 if crash occurred between October and December, 0 otherwise) [NI]	0.142	2.33	0.0049	-0.0020	-0.0029
Traffic characteristics					
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise) [MI]	-0.526	-3.17	0.0040	-0.0053	0.0013
Roadway characteristics					
Urban principal arterial indicator (1 if crash occurred on urban principal, 0 otherwise) [SI]	0.821	8.46	-0.0067	-0.0011	0.0078
Urban interstate indicator (1 if crash occurred on urban interstate, 0 otherwise) [SI]	0.546	5.05	-0.0034	-0.0006	0.0040
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise) [SI]	0.389	4.92	-0.0050	-0.0010	0.0059
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0 otherwise) [NI]	-0.435	-4.56	-0.0076	0.0026	0.0050

Variable	Parameter Estimates	t-stat	Marginal Effects: No Injury	Marginal Effects: Minor Injury	Marginal Effects: Severe Injury
Crash characteristics					
Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise) [SI]	0.917	11.13	-0.0497	-0.0066	0.0563
Driver characteristics					
Young male driver indicator (1 if male driver age below 30 years, 0 otherwise) [SI]	-0.255	-4.07	0.0059	0.0010	-0.0070
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise) [NI]	-2.710	-26.28	-0.0408	0.0098	0.0310
Florida registered driver indicator (1 if drivers are registered with Florida license, 0 otherwise) [MI]	0.892	5.75	-0.0146	0.0196	-0.0050
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise) [NI]	-0.356	-1.98	-0.0012	0.0004	0.0008
Driver violation indicator (1 if driver had previous violation history, 0 otherwise) [SI]					
Driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was less than the speed limit by more than 10 mi/hr, 0 otherwise) [SI]	-0.436	-4.31	0.0034	0.0004	-0.0038
Running off road indicator (1 if driver ran off the road, 0 otherwise) [NI]	-0.561	-6.31	-0.0076	0.0026	0.0050
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise) [MI]	1.874	7.60	-0.0125	0.0149	-0.0024
Driver violation indicator (1 if driver had previous violation history, 0 otherwise) [SI]	-1.148	-19.18	0.0348	0.0050	-0.0398
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise) [NI]	-1.235	-17.82	-0.0313	0.0091	0.0223
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise) [MI]	-2.461	-7.37	0.0073	-0.0094	0.0020
Fatigue and inattentive driving indicator (1 if drivers were identified for fatigue and inattentive driving at the time of crash, 0 otherwise) [SI]	-0.727	-3.79	0.0013	0.0003	-0.0016
Driving under the influence indicator (1 if driver was identified under the influence of alcohol, medication, and drug, 0 otherwise) [MI]	0.595	3.44	-0.0070	0.0086	-0.0016
Driving too fast and alcohol consumption indicator (1 if driver was identified driving too fast for conditions and suspected of alcohol consumption, 0 otherwise) [MI]	-0.726	-2.07	0.0011	-0.0014	0.0003
Driver's physical impairment indicator (1 if driver was identified to be physically impaired due to seizure, epilepsy, or blackout, 0 otherwise) [NI]	-2.227	-5.30	-0.0013	0.0002	0.0010
Number of observations	13,993				
Log-likelihood at zero	-15,372.882				
Log-likelihood at convergence	-11,978.465				
$\rho^2 = 1 - LL(\boldsymbol{\beta})/LL(0)$	0.221				

SI = Severe Injury; MI = Minor Injury; NI = No Injury

heterogeneity was again statistically significant, and also expressed in the constant term for minor injury. However in this case the constant's parameter mean was a function of the driving below the speed limit by more than 10 mi/h indicator (1 if travel speed was less than the speed limit by more than 10 mi/hr, 0 otherwise), and the constant's variance was a function of the alcohol and inattentive driving indicator (1 if driver was suspected of alcohol consumption and identified for inattentive driving at the time of crash, 0 otherwise). Again, the overall statistical fit of the models was good with a ρ^2 value of 0.221.

In comparing the model results from the two years, it is revealing to look at a side-by-side comparison of the marginal effects, as presented in Table 12. The table shows that 17 of the variables were found to be statistically significant in only 2019 or 2020 (but not both years), reflecting considerable temporal instability as indicated by the earlier likelihood ratio tests. However, 16 explanatory variables did produce statistically significant parameter estimates in both 2019 and 2020, but even these parameters showed instability between 2019 and 2020 as the marginal effects fluctuated between the two years. As an example, consider the driver violation indicator (1 if driver had previous violation history, 0 otherwise). In 2019, having a violation history was associated with a decrease in severe injury and an increase in the probability of no injury, which would seem to go against expectations. In contrast, in 2020 there was positive impact on the likelihood of severe injury (albeit quite small at 0.0008) and a slight decrease in the probability of no injury, which is more of what would be expected but with very small magnitudes. In general, the variation in marginal effects, even among explanatory variables that were found to be statistically significant in both yearly models, is a telling reflection of the temporal shifts that occurred.

Table 12. Marginal effects of driver injury severity in 2019 and 2020 (variables producing significant parameters in both years are shaded).

Variable	No Injury		Minor Injury		Severe Injury	
	2019	2020	2019	2020	2019	2020
Spatial characteristics						
District 5 indicator (1 if crash occurred in District 5, 0 otherwise)	-0.0053	-0.0035	0.0032	0.0013	0.0021	0.0021
District 6 indicator (1 if crash occurred in District 6, 0 otherwise)	0.0029	0.0042	-0.0033	-0.0051	0.0004	0.0008
Temporal characteristics						
Afternoon indicator (1 if crash occurred between 12 and 4 PM, otherwise)	–	0.0024	–	-0.0030	–	0.0006
4th quarter indicator (1 if crash occurred between October and December, 0 otherwise)	–	0.0049	–	-0.0020	–	-0.0029
Traffic characteristics						
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise)	–	0.0040	–	-0.0053	–	0.0013
Crash characteristics						
Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise)	–	-0.0497	–	-0.0066	–	0.0563
Harmful non-fixed object indicator (1 if harmful event occurred with non-fixed object, 0 otherwise)	–	0.0054	–	0.0010	–	-0.0064
Roadway characteristics						
Urban principal arterial indicator (1 if crash occurred on urban principal arterials, 0 otherwise)	-0.0029	-0.0067	-0.0008	-0.0011	0.0037	0.0078
Urban interstate indicator (1 if crash occurred on urban interstate, 0 otherwise)	–	-0.0034	–	-0.0006	–	0.0040
Urban freeway and interstate indicator (1 if crash occurred on urban freeway and interstate, 0 otherwise)	-0.0014	–	-0.0003	–	0.0017	–
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise)	-0.0046	-0.0050	-0.0013	-0.0010	0.0059	0.0059
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0 otherwise)	-0.0063	-0.0076	0.0036	0.0026	0.0027	0.0050
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median barrier, 0 otherwise)	-0.0037	–	0.0043	–	-0.0006	–
Driver characteristics						
Female driver indicator (1 if driver is female, 0 otherwise)	-0.0093	–	0.0105	–	-0.0012	–

Variable	No Injury		Minor Injury		Severe Injury	
	2019	2020	2019	2020	2019	2020
Young male driver indicator (1 if driver age is below 30 years, 0 otherwise)	–	0.0059	–	0.0010	–	-0.0070
Older-aged male driver indicator (1 if male driver age is between 50 to 65 years, 0 otherwise	-0.0019	–	-0.0005	–	0.0023	–
Normal driving indicator (1 if driving without any physical/emotional impairment, 0 otherwise)	0.0576	–	-0.0662	–	0.0085	–
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise)	-0.0308	-0.0408	0.0192	0.0098	0.0192	0.0310
Florida registered driver indicator (1 if drivers are registered with Florida license, 0 otherwise)	–	-0.0146	–	0.0196	–	-0.0050
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise)	-0.0045	-0.0012	0.0025	0.0004	0.0020	0.0008
Driver violation indicator (1 if driver had previous violation history, 0 otherwise)	0.0225	-0.0012	0.0056	0.0004	-0.0281	0.0008
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise)	-0.0037	-0.0125	0.0041	0.0149	-0.0004	-0.0024
Fatigue and inattentive driving indicator (1 if drivers were identified for fatigue and inattentive driving at the time of crash, 0 otherwise)	0.0013	0.0013	0.0004	0.0003	-0.0017	-0.0016
Driving too fast and alcohol consumption indicator (1 if driver was identified driving too fast for conditions and suspected of alcohol consumption, 0 otherwise)	-0.0636	0.0011	-0.0636	-0.0014	-0.0636	0.0003
Careless driving indicator (1 if driver operated in careless or reckless manner, 0 otherwise)	-0.0636	–	0.0394	–	0.0242	–
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise)	-0.0253	-0.0313	0.0131	0.0091	0.0122	0.0223
Driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was less than the speed limit by more than 10 mi/hr, 0 otherwise)	0.0014	0.0034	0.0003	0.0004	-0.0017	-0.0038
Running off road indicator (1 if driver ran off the road, 0 otherwise)	-0.0200	-0.0076	0.0107	0.0026	0.0092	0.0050
Improper lane keeping indicator (1 if failed to keep in proper lane, 0 otherwise)	-0.0067	–	0.0074	–	-0.0007	–
No contributing driver factor indicator (1 if no contributing factor from driving action was determined, 0 otherwise)	-0.0310	–	-0.0045	–	-0.0045	–

Variable	No Injury		Minor Injury		Severe Injury	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**
Driving under the influence indicator (1 if driver was identified under the influence of alcohol, medication, and drug, 0 otherwise)	–	-0.0070	–	0.0086	–	-0.0016
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise)	0.0059	0.0073	-0.0070	-0.0094	0.0011	0.0020
Driver's physical impairment indicator (1 if driver was identified to be physically impaired due to seizure, epilepsy, or blackout, 0 otherwise)	-0.0014	-0.0013	0.0005	0.0002	0.0008	0.0010

2.4 Individual Models by Risky Behavior Types

To explore the characteristics of 2020 crashes further, separate statistical models were estimated for each of the five risky behaviors considered herein; driving while asleep/drowsy, driving too fast for conditions, driving with suspected alcohol consumption, driving while inattentive, and driving while not wearing a seatbelt. Table 13 presents the descriptive statistics of these five risky driving behaviors. There are a few important noteworthy aspects with these risky behaviors. For example, driving too fast for conditions were overrepresented in rainy weather, harmful event at right shoulder, on urban freeways, roadways with positive median barrier, suspected alcohol consumption, in non-distractive driving, and driving over the speed limit by more than 10 mi/hr. Likewise, drowsy driving was overrepresented in crashes on roadways with shoulder with 4 to 8 feet and inattentive driving. Moreover, suspected alcohol consumption was overrepresented in driver with violations (reflecting a pattern of risky behavior). Finally, not wearing seatbelt was overrepresented in crashes where the law enforcement officer did not attribute any driving action was contributed to crashes.

To understand why it is important to focus on the identified risky behaviors, Figure 7 provides the proportion of driver injury severities by risky vs. non-risky driving behavior in Florida in 2020. It is clear to see here that the risky behaviors all have notably higher proportions of injuries (severe and minor) relative to their safe-driving counterparts (driving while not drowsy, driving with normal speed, sober driving, driving attentive, and driving restrained). None of the effects are more noticeable than driving restrained vs. unrestrained, with a third of unrestrained drivers experiencing severe injury and only 4% of restrained drivers experience severe injury.

Table 13. Descriptive statistics of key variables found significant in the risky behavior models (standard deviation in parenthesis).

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Spatial characteristics					
District 3 indicator (1 if crash occurred in District 3, 0 otherwise)	0.092 (0.289)	0.106 (0.308)	0.092 (0.289)	0.104 (0.306)	0.113 (0.316)
District 4 indicator (1 if crash occurred in District 4, 0 otherwise)	0.167 (0.373)	0.172 (0.377)	0.134 (0.341)	0.143 (0.351)	0.137 (0.344)
District 5 indicator (1 if crash occurred in District 5, 0 otherwise)	0.243 (0.429)	0.201 (0.401)	0.165 (0.371)	0.299 (0.457)	0.176 (0.381)
District 6 indicator (1 if crash occurred in District 6, 0 otherwise)	0.078 (0.268)	0.046 (0.211)	0.035 (0.184)	0.078 (0269)	0.075 (0.263)
District 7 indicator (1 if crash occurred in District 7, 0 otherwise)	0.133 (0.340)	0.161 (0.368)	0.208 (0.406)	0.143 (0.351)	0.158 (0.365)
Temporal characteristics					
Early morning indicator (1 if crash occurred between midnight and 6 AM, 0 otherwise)	0.438 (0.496)	0.162 (0.369)	0.357 (0.479)	0.212 (0.408)	0.265 (0.442)
Evening indicator (1 if crash occurred between 6 PM and 9 PM, 0 otherwise)	0.070 (0.255)	0.169 (0.375)	0.196 (0.397)	0.155 (0.362)	0.171 (0.376)
Afternoon indicator (1 if crash occurred between 12 and 4 PM, otherwise)	0.111 (0.314)	0.204 (0.403)	0.073 (0.261)	0.186 (0.389)	0.142 (0.349)
Weekend indicator (1 if crash occurred in weekend, 0 otherwise)	0.384 (0.486)	0.352 (0.477)	0.429 (0.494)	0.319 (0.466)	0.378 (0.484)
2nd quarter indicator (1 if crash occurred between April and June, 0 otherwise)	0.209 (0.406)	0.228 (0.419)	0.219 (0.414)	0.218 (0.413)	0.241 (0.427)
4th quarter indicator (1 if crash occurred between October and December, 0 otherwise)	0.299 (0.458)	0.260 (0.438)	0.286 (0.452)	0.271 (0.445)	0.274 (0.446)
Weather/Ambient characteristics					
Rainy weather indicator (1 if weather was rainy, 0 otherwise)	0.044 (0.207)	0.518 (0.499)	0.072 (0.259)	0.111 (0.314)	0.083 (0.276)
Dark indicator (1 if it was dark, 0 otherwise)	0.587 (0.492)	0.401 (0.490)	0.720 (0.449)	0.426 (0.494)	0.536 (0.498)
Traffic characteristics					
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise)	0.216 (0.411)	0.210 (0.407)	0.139 (0.346)	0.141 (0.348)	0.162 (0.369)

Variables / Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Vehicle characteristics					
Passenger car indicator (1 if passenger car, 0 otherwise)	0.569 (0.495)	0.619 (0.485)	0.519 (0.499)	0.519 (0.499)	0.471 (0.499)
Sport Utility Vehicle (SUV) indicator (1 if SUV, 0 otherwise)	0.207 (0.405)	0.145 (0.352)	0.200 (0.400)	0.182 (0.386)	0.177 (0.382)
Pickup truck indicator (1 if pickup truck, 0 otherwise)	0.158 (0.365)	0.131 (0.337)	0.193 (0.395)	0.146 (0.353)	0.165 (0.372)
Newer vehicle indicator (1 if crash occurred in 2015 model year or newer vehicle, 0 otherwise)	0.340 (0.473)	0.315 (0.464)	0.329 (0.469)	0.367 (0.482)	0.302 (0.459)
Harmful event characteristics					
Harmful shoulder indicator (1 if harmful event occurred at right shoulder, 0 otherwise)	0.131 (0.338)	0.464 (0.364)	0.100 (0.300)	0.110 (0.313)	0.097 (0.295)
Harmful median indicator (1 if harmful event occurred in the median, 0 otherwise)	0.066 (0.249)	0.060 (0.238)	0.047 (0.213)	0.039 (0.194)	0.046 (0.210)
Harmful non-fixed object indicator (1 if harmful event occurred with non-fixed object, 0 otherwise)	0.182 (0.386)	0.185 (0.388)	0.232 (0.422)	0.243 (0.429)	0.183 (0.387)
Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise)	0.678 (0.467)	0.668 (0.470)	0.648 (0.477)	0.632 (0.482)	0.578 (0.493)
Roadway characteristics					
Urban principal arterial indicator (1 if crash occurred on urban principal arterials, 0 otherwise)	0.104 (0.305)	0.071 (0.257)	0.090 (0.286)	0.068 (0.252)	0.075 (0.263)
Urban freeway indicator (1 if crash occurred on urban freeway, 0 otherwise)	0.095 (0.293)	0.198 (0.398)	0.037 (0.188)	0.098 (0.298)	0.069 (0.254)
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise)	0.102 (0.303)	0.198 (0.398)	0.129 (0.335)	0.101 (0.301)	0.131 (0.337)
Narrow shoulder width indicator (1 if shoulder width is below 4 feet, 0 otherwise)	0.124 (0.330)	0.116 (0.321)	0.107 (0.310)	0.098 (0.297)	0.102 (0.303)
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0 otherwise)	0.101 (0.301)	0.105 (0.306)	0.054 (0.226)	0.073 (0.261)	0.077 (0.266)
Roadways with Two-way turn-lane indicator (1 if crash occurred at roadway with two-way undivided left-turn lane, 0 otherwise)	0.023 (0.151)	0.019 (0.137)	0.022 (0.145)	0.016 (0.127)	0.019 (0.136)

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median barrier, 0 otherwise)	0.363 (0.481)	0.426 (0.494)	0.252 (0.434)	0.291 (0.454)	0.245 (0.431)
Driver characteristics					
Male driver indicator (1 if driver is male, 0 otherwise)	0.738 (0.439)	0.682 (0.465)	0.723 (0.447)	0.657 (0.474)	0.751 (0.432)
Female driver indicator (1 if driver is female, 0 otherwise)	0.258 (0.437)	0.297 (0.297)	0.268 (0.268)	0.319 (0.466)	0.228 (0.420)
Young driver age indicator (1 if driver age is below 30 years, 0 otherwise)	0.449 (0.497)	0.393 (0.488)	0.381 (0.485)	0.429 (0.494)	0.477 (0.499)
Middle aged driver indicator (1 if driver age is between 30 to 50 years, 0 otherwise)	0.358 (0.479)	0.291 (0.454)	0.405 (0.491)	0.323 (0.467)	0.341 (0.474)
Older-aged driver indicator (1 if driver age is between 50 to 65 years, 0 otherwise	0.132 (0.339)	0.096 (0.294)	0.168 (0.374)	0.153 (0.361)	0.126 (0.333)
Young male driver age indicator (1 if driver age is below 30 years, 0 otherwise)	0.340 (0.473)	0.393 (0.488)	0.279 (0.448)	0.279 (0.448)	0.350 (0.477)
Middle aged male driver indicator (1 if male driver age is between 30 to 50 years, 0 otherwise)	0.264 (0.441)	0.198 (0.399)	0.291 (0.454)	0.220 (0.414)	0.261 (0.439)
Normal driving indicator (1 if driving without any physical/emotional impairment, 0 otherwise)	0.0 (0.0)	0.874 (0.322)	0.111 (0.314)	0.713 (0.452)	0.516 (0.499)
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise)	0.091 (0.288)	0.112 (0.315)	0.083 (0.275)	0.080 (0.271)	0.191 (0.393)
Non-geometry related factors (1 if non-geometry related factor, 0 otherwise)	0.968 (0.174)	0.601 (0.489)	0.939 (0.238)	0.929 (0.256)	0.907 (0.291)
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise)	0.002 (0.051)	0.0 (0.0)	0.047 (0.212)	0.010 (0.096)	0.056 (0.230)
Driver violation indicator (1 if driver had previous violation history, 0 otherwise)	0.517 (0.499)	0.458 (0.498)	0.677 (0.467)	0.553 (0.497)	0.409 (0.492)
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise)	1.0 (0.0)	0.038 (0.058)	0.009 (0.093)	0.064 (0.245)	0.028 (0.167)
Inattentive driving indicator (1 if driver was found inattentive, 0 otherwise)	0.261 (0.439)	0.091 (0.287)	0.142 (0.349)	1.0 (0.0)	0.088 (0.283)

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Driver's in-vehicle distraction (1 if driver's in-vehicle distraction, 0 otherwise)	0.039 (0.194)	0.006 (0.079)	0.024 (0.155)	0.0 (0.0)	0.019 (0.139)
No distractive driving indicator (1 if no distractive driving from driver was determined, 0 otherwise)	0.592 (0.491)	0.746 (0.435)	0.571 (0.494)	0.0 (0.0)	0.587 (0.492)
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise)	0.085 (0.279)	0.209 (0.406)	0.196 (0.396)	0.093 (0.292)	0.255 (0.435)
Exceeding speed limit by more than 20 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 20 mi/hr, 0 otherwise)	0.026 (0.159)	0.079 (0.270)	0.089 (0.285)	0.035 (0.185)	0.123 (0.328)
Driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise)	0.104 (0.305)	0.094 (0.292)	0.133 (0.339)	0.163 (0.369)	0.112 (0.315)
Running off road indicator (1 if driver ran off the road, 0 otherwise)	0.188 (0.391)	0.0 (0.0)	0.138 (0.345)	0.070 (0.255)	0.125 (0.331)
Improper lane keeping indicator (1 if failed to keep in proper lane, 0 otherwise)	0.188 (0.391)	0.0 (0.0)	0.073 (0.261)	0.087 (0.282)	0.076 (0.265)
No contributing driver factor indicator (1 if no contributing factor from driving action was determined, 0 otherwise)	0.048 (0.214)	0.0 (0.0)	0.045 (0.208)	0.028 (0.166)	0.538 (0.498)
Suspected alcohol consumption indicator (1 if alcohol consumption was suspected of driver, 0 otherwise)	0.026 (0.159)	0.482 (0.214)	1.0 (0.0)	0.105 (0.307)	0.189 (0.392)
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise)	0.002 (0.042)	0.003 (0.058)	0.246 (0.431)	0.028 (0.165)	0.062 (0.242)
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise)	0.894 (0.307)	0.868 (0.337)	0.746 (0.435)	0.873 (0.332)	0.0 (0.0)

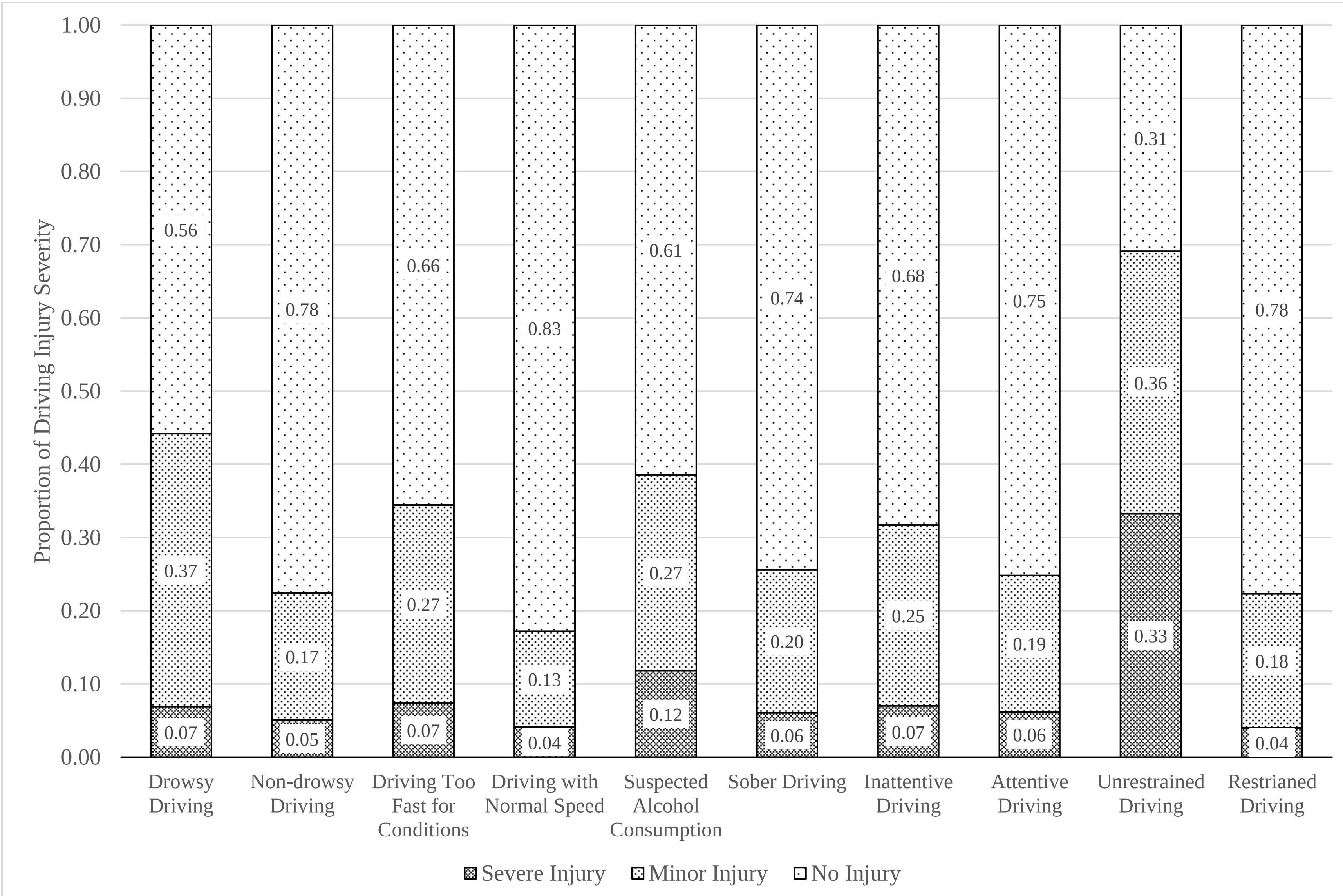

Figure 7. Proportion of driver injury severities by risky vs. non-risky driving behavior in Florida in 2020.

Regarding model estimation, a random parameters multinomial logit model with possible heterogeneity in the means and variances are again estimated, this time for each of the five identified risky behaviors (driving while drowsy, driving too fast for conditions, driving with suspected alcohol consumption, driving while inattentive, and driving while not wearing a seatbelt). It should be noted that an extensive series of likelihood ratio tests were conducted as described in Hou et al. (2022) to determine if estimating separate models for the risky behavior types was statistically justified. In all cases, the null hypotheses that the models were the same could be rejected with over 95% confidence, thus justifying the separate-model technique undertaken herein.

Tables 14, 15, 16, 17 and 18 give model estimation results for the risky behaviors; driving while drowsy, driving too fast for conditions, driving with suspected alcohol consumption, driving while inattentive, and driving while not wearing a seatbelt, respectively. All five of the models presented in these tables had the constant for minor injury varying across observations as a parameter, with statistically significant heterogeneity in the means and variances (although the variables that influenced these means and variances did vary from one model to the next). Tables 14 through 18 show all models had good overall statistical fit with a wide variety of variables influencing resulting injury severities. However, there is considerable disparity in the variables found to be significant in each of these risky-behavior types. This disparity is underscored in Tables 19, 20 and 21, which provide marginal effects summaries for severe, minor, and no-injury severities, respectively, for the five risky behaviors being considered. The tables show great differences in the variables found to significantly determine injury severity, with only the indicator for driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise) and the restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise) being statistically significant in all of the risky-behavior models (note here that restraint use indicator is not used in the “driving while not wearing a seatbelt” model because this model is conditional on non-usage so all values of this indicator would be zero, but clearly it is an important element in injury severity nonetheless. The results of these estimations show that each type of risky behavior results in a rather unique sequence of events that influence injury severity. Thus, the decision to focus on risky behaviors underscores the need to understand the types of drivers that are engaging in these behaviors and how these drivers are represented in the crash data bases. This goes back to the argument made in Part I of this report that a substantial portion of the rise in fatality rates may be due to riskier drivers making up a greater proportion of the vehicle miles traveled.

Table 14. Model results of random parameters multinomial logit for driver injury severity in single-vehicle crashes involving drowsy driving in Florida in 2020.

Variable	**Parameter Estimates**	**t-stat**	**Marginal Effects**		
			No Injury	**Minor Injury**	**Severe Injury**
Constant [SI]	-0.751	-2.18			
Random parameter (normally distributed)					
Constant [MI] (*standard deviation of parameter distribution*)	1.065 (5.645)	2.03 (2.86)			
Heterogeneity in the mean of random parameter					
Constant: Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise) [MI]	2.722	2.36			
Heterogeneity in the variance of random parameter					
Constant: Newer vehicle indicator (1 if crash occurred in 2015 model year or newer vehicle, 0 otherwise) [MI]	-0.394	-1.71			
Spatial characteristics					
District 3 indicator (1 if crash occurred in District 3, 0 otherwise) [MI]	-1.453	-1.67	0.0076	-0.0086	0.0009
District 5 indicator (1 if crash occurred in District 5, 0 otherwise) [SI]	0.615	1.94	-0.0088	-0.0016	0.0104
District 7 indicator (1 if crash occurred in District 7, 0 otherwise) [SI]	0.631	1.71	-0.0047	-0.0009	0.0056
Temporal characteristics					
Early morning indicator (1 if crash occurred between midnight to 6 AM, 0 otherwise) [NI]	0.459	1.83	0.0203	-0.0126	-0.0077
Afternoon indicator (1 if crash occurred between 12 to 4 PM, 0 otherwise) [SI]	0.778	2.13	-0.0065	-0.0012	0.0076
Vehicle characteristics					
Sport Utility Vehicle (SUV) indicator (1 if SUV, 0 otherwise) [MI]	-0.957	-1.64	0.0118	-0.0133	0.0015
Environmental characteristics					
Rainy weather indicator (1 if weather was rainy, 0 otherwise) [NI]	1.294	1.88	0.0047	-0.0035	-0.0012
Roadway characteristics					
Urban freeway or interstates indicator (1 if crash occurred on urban freeway/interstate, 0 otherwise) [NI]	-0.721	-1.78	-0.0084	0.0042	0.0042
Crash characteristics					
Harmful shoulder indicator (1 if harmful event occurred at right shoulder, 0 otherwise) [SI]	0.862	2.48	-0.0088	-0.0016	0.0104

Traffic characteristics					
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise) [SI]	1.096	3.66	-0.0169	-0.0030	0.0200
Driver characteristics					
Middle aged male driver indicator (1 if male driver age is between 30 to 50 years, 0 otherwise) [NI]	0.693	2.34	0.0180	-0.0114	-0.0067
Driving below the speed limit by more than 10 mi/h indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise) [MI]	-2.026	-2.21	0.0109	-0.0125	0.0016
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise) [NI]	2.193	6.59	0.2070	-0.1249	-0.0821
Number of observations		1114			
Log-likelihood at zero		-1223.854			
Log-likelihood at convergence		-919.465			
$\rho^2 = 1 - LL(\boldsymbol{\beta})/LL(0)$		0.249			

SI = Severe Injury; MI = Minor Injury; NI = No Injury

Table 15. Model results of random parameters multinomial logit for driver injury severity in single-vehicle crashes involving driving too fast for conditions in Florida in 2020.

Variable	**Parameter Estimates**	**t-stat**	**Marginal Effects**		
			No Injury	**Minor Injury**	**Severe Injury**
Constant [SI]	0.548	2.12			
Random parameter (normally distributed)					
Constant [MI] (*standard deviation of parameter distribution*)	0.603 (2.947)	1.61 (5.02)			
Heterogeneity in the mean of random parameter					
Constant: Middle aged male driver indicator (1 if male driver age is between 30 to 50 years, 0 otherwise) [MI]	2.947	5.02			
Heterogeneity in the variance of random parameter					
Constant: Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise) [MI]	0.524	2.98			
Spatial characteristics					
District 4 indicator (1 if crash occurred in District 4, 0 otherwise) [MI]	-0.616	-2.04	0.0074	-0.0082	0.0009
District 6 indicator (1 if crash occurred in District 6, 0 otherwise) [MI]	-1.418	-2.43	0.0037	-0.0042	0.0005
Environmental characteristics					
Dark indicator (1 if it was dark, 0 otherwise) [MI]	0.533	2.31	-0.0160	0.0186	-0.0026
Roadway characteristics					
Urban freeway or interstates indicator (1 if crash occurred on urban freeway/interstate, 0 otherwise) [SI]	-0.474	-1.64	0.0027	0.0005	-0.0032
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise) [SI]	0.424	1.96	-0.0049	-0.0012	0.0061
Crash characteristics					
Harmful median indicator (1 if harmful event occurs in the median, 0 otherwise) [MI]	0.778	1.83	-0.0040	0.0044	-0.0004
Harmful non-fixed object indicator (1 if harmful event occurred with non-fixed object, 0 otherwise) [SI]	-0.773	-2.71	0.0042	0.0009	-0.0051
Driver characteristics					
Female driver indicator (1 if driver is female, 0 otherwise) [NI]	-0.374	-2.19	-0.0137	0.0089	0.0049
Young driver indicator (1 if driver age is below 30 years, 0 otherwise) [NI]	0.411	2.62	0.0273	-0.0180	-0.0094
Driver violation indicator (1 if the driver has previous violation, 0 otherwise) [SI]	-0.394	-2.35	0.0014	0.0014	-0.0079

Normal driving indicator (1 if driving without any physical/emotional impairment, 0 otherwise) [NI]	0.735	3.72	0.0742	-0.0483	-0.0259
Driving below the speed limit by more than 10 mi/h indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise) [SI]	-0.801	-1.99	0.0021	0.0005	-0.0026
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise) [NI]	-1.193	-5.58	-0.0193	0.0090	0.0104
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise) [NI]	2.411	12.34	0.2362	-0.1613	-0.0749
Number of observations		2342			
Log-likelihood at zero		-2575.950			
Log-likelihood at convergence		-1740.974			
$\rho^2 = 1 - LL(\boldsymbol{\beta})/LL(0)$		0.323			

SI = Severe Injury; MI = Minor Injury; NI = No Injury

Table 16. Model results of random parameter multinomial logit for driver injury severity in single-vehicle crashes involving suspected alcohol consumption in Florida in 2020.

Variable	Parameter Estimates	t-stat	Marginal Effects		
			No Injury	Minor Injury	Severe Injury
Constant [SI]	-1.232	-5.40			
Random parameter (normally distributed)					
Constant [MI] (*standard deviation of parameter distribution*)	-2.622 (5.606)	-4.26 (5.76)			
Heterogeneity in the mean of random parameter					
Constant: Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise) [MI]	0.883	2.76			
Heterogeneity in the variance of random parameter					
Constant: Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise) [MI]	0.415	3.46			
Spatial characteristics					
District 5 indicator (1 if crash occurred in District 5, 0 otherwise) [MI]	0.714	1.78	-0.0051	0.0063	-0.0012
Temporal characteristics					
Evening indicator (1 if crash occurred between 6 to 9 PM, 0 otherwise) [MI]	-0.675	-1.73	0.0051	-0.0063	0.0011
Vehicle characteristics					
Pickup truck indicator (1 if pickup truck, 0 otherwise) [NI]	0.351	1.94	0.0063	-0.0029	-0.0035
Newer vehicle indicator (1 if crash occurred in 2015 model year or newer vehicle, 0 otherwise) [NI]	0.395	2.67	0.0120	-0.0054	-0.0066
Roadway characteristics					
Narrow shoulder width indicator (1 if shoulder width is below 4 feet, 0 otherwise) [MI]	0.879	1.82	-0.0041	0.0052	-0.0011
Urban principal arterial indicator (1 if crash occurred on urban principal, 0 otherwise) [SI]	0.672	2.79	-0.0041	-0.0007	0.0048
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise) [SI]	0.608	2.91	-0.0062	-0.0011	0.0073
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median barrier, 0 otherwise) [NI]	-0.748	-4.87	-0.0203	0.0077	0.0126
Crash characteristics					
Harmful fixed object indicator (1 if harmful event occurred with fixed object, 0 otherwise) [SI]	1.534	7.19	-0.0636	-0.0086	0.0722

Driver characteristics					
Middle aged driver indicator (1 if driver age is between 30 and 50 years, 0 otherwise) [MI]	-0.604	-1.91	0.0098	-0.0119	0.0020
Driver violation indicator (1 if the driver has previous violation, 0 otherwise) [SI]	-1.933	-13.30	0.0485	0.0058	-0.0543
Inattentive driving indicator (1 if driver was found inattentive, 0 otherwise) [MI]	0.783	1.83	-0.0051	0.0060	-0.0009
Exceeding speed limit by more than 20 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 20 mi/hr, 0 otherwise) [SI]	1.455	6.84	-0.0117	-0.0022	0.0139
Driving below the speed limit by more than 10 mi/h indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise) [SI]	-0.716	-2.99	0.0036	0.0005	-0.0041
Improper lane keeping indicator (1 if failed to keep in proper lane, 0 otherwise) [NI]	-0.839	-3.34	-0.0071	0.0024	0.0047
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise) [NI]	-3.45	-12.40	-0.0317	0.0068	0.0250
Blood alcohol content more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise) [MI]	-2.485	-4.72	0.0201	-0.0247	0.0046
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise) [NI]	1.863	12.71	0.1216	-0.0608	-0.0607
Number of observations		3357			
Log-likelihood at zero		-2553.565			
Log-likelihood at convergence		-3688.041			
$\rho^2 = 1 - LL(\boldsymbol{\beta})/LL(0)$		0.307			

SI = Severe Injury; MI = Minor Injury; NI = No Injury

Table 17. Model results of random parameters multinomial logit for driver injury severity in single-vehicle crashes involving inattentive driving in Florida in 2020.

Variable	**Parameter Estimates**	**t-stat**	**Marginal Effects**		
			No Injury	**Minor Injury**	**Severe Injury**
Constant [SI]	-2.087	-9.05			
Random parameter (normally distributed)					
Constant [MI] (*standard deviation of parameter distribution*)	-2.148 (3.122)	-5.91 (8.12)			
Heterogeneity in the mean of random parameter					
Constant: Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise) [MI]	1.598	8.14			
Heterogeneity in the variance of random parameter					
Constant: Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise) [MI]	0.821	4.23			
Spatial characteristics					
District 5 indicator (1 if crash occurred in District 5, 0 otherwise) [MI]	0.407	5.23	-0.0181	0.0205	-0.0024
Temporal characteristics					
Weekend indicator (1 if crash occurred in weekend, 0 otherwise) [MI]	0.143	1.88	-0.0072	0.0083	-0.0011
2nd quarter indicator (1 if crash occurred between April and June, 0 otherwise) [SI]	0.390	2.57	-0.0044	-0.0010	0.0055
Vehicle characteristics					
Passenger car indicator (1 if passenger car, 0 otherwise) [NI]	-0.285	-2.59	-0.0169	0.0104	0.0064
Newer vehicle indicator (1 if crash occurred in 2015 model year or newer vehicle, 0 otherwise) [NI]	0.406	3.45	0.0151	-0.0098	-0.0053
Roadway characteristics					
Urban principal arterial indicator (1 if crash occurred on urban principal, 0 otherwise) [SI]	0.873	3.83	-0.0037	-0.0009	0.0046
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise) [SI]	0.355	1.88	-0.0022	-0.0005	0.0027
Urban freeway indicator (1 if crash occurred on urban freeway, 0 otherwise) [MI]	0.532	2.13	-0.0043	0.0049	-0.0006
Crash characteristics					
Harmful fixed object indicator (1 if harmful event occurred with fixed object, 0 otherwise) [SI]	1.609	7.63	-0.0494	-0.0090	0.0584

Driver characteristics					
Male driver indicator (1 if driver is male, 0 otherwise) [NI]	0.254	2.23	0.0182	-0.0113	-0.0069
Older age driver indicator (1 if driver age is between 50 and 65 years, 0 otherwise) [MI]	-0.794	-3.27	0.0070	-0.0081	0.0011
Suspected alcohol consumption indicator (1 if alcohol consumption was suspected of driver, 0 otherwise) [MI]	0.623	2.50	-0.0047	0.0055	-0.0008
Driving below the speed limit by more than 10 mi/h indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise) [SI]	-0.634	-2.74	0.0025	0.0006	-0.0031
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise) [NI]	-3.436	-13.94	-0.0408	.0151	0.0258
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise) [NI]	2.517	14.80	.1992	-0.1308	-0.0684
Number of observations	4532				
Log-likelihood at zero	-4978.911				
Log-likelihood at convergence	-3193.406				
$\rho^2 = 1 - LL(\boldsymbol{\beta})/LL(0)$	0.359				

SI = Severe Injury; MI = Minor Injury; NI = No Injury

Table 18. Model results of random parameters multinomial logit for driver injury severity in single-vehicle crashes involving unrestrained driving in Florida in 2020.

Variable	Parameter Estimates	t-stat	Marginal Effects		
			No Injury	Minor Injury	Severe Injury
Constant [SI]	-0.630	-4.39			
Random parameter (normally distributed)					
Constant [MI] (*standard deviation of parameter distribution*)	-1.57 (3.733)	-3.37 (4.52)			
Heterogeneity in the mean of random parameter					
Constant: Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise) [MI]	0.764	3.50			
Heterogeneity in the variance of random parameter					
Constant: Exceeding speed limit by more than 20 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 20 mi/hr, 0 otherwise) [MI]	-0.549	-2.38			
Spatial characteristics					
District 5 indicator (1 if crash occurred in District 5, 0 otherwise) [NI]	-0.340	-2.39	-0.0085	0.0025	0.0061
Temporal characteristics					
4th quarter indicator (1 if crash occurred between October and December, 0 otherwise) [NI]	0.297	2.53	0.0125	-0.0040	-0.0085
Traffic characteristics					
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise) [MI]	-1.164	-3.30	0.0056	-0.0151	0.0095
Roadway characteristics					
Urban principal arterial indicator (1 if crash occurred on urban principal, otherwise) [SI]	1.152	5.47	-0.0090	-0.0050	0.0139
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise) [SI]	0.598	3.47	-0.0075	-0.0045	0.0120
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0otherwise) [NI]	-0.948	-4.25	-0.0086	0.0018	0.0068
Roadways with Two-way turn-lane indicator (1 if crash occurred at roadway with two-way undivided left-turn lane, 0 otherwise) [MI]	1.317	1.74	-0.0012	0.0025	-0.0012
Crash characteristics					
Harmful fixed object indicator (1 if harmful event occurred with fixed object, 0 otherwise) [SI]	1.011	7.17	-0.0665	-0.0266	0.0931

Driver characteristics					
Young male driver indicator (1 if male driver age below 30 years, 0 otherwise) [SI]	-0.473	-4.07	0.0164	0.0071	-0.0235
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise) [NI]	-1.341	-9.25	-0.0395	0.0094	0.0301
Non-geometry related factors (1 if non-geometry related factor, 0 otherwise) [MI]	-0.795	-2.22	0.0324	-0.0652	0.0328
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise) [NI]	2.096	11.40	-0.0069	0.0026	0.0042
Driver violation indicator (1 if driver had previous violation history, 0 otherwise) [SI]	-1.264	-10.65	0.0490	0.0173	-0.0663
Driving below the speed limit by more than 10 mi/h indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise) [SI]	-0.336	-1.87	0.0038	0.0013	-0.0051
Running off road indicator (1 if driver ran off the road, 0 otherwise) [NI]	-0.577	-3.16	-0.0092	0.0022	0.0069
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise) [MI]	2.532	3.49	-0.0032	0.0070	-0.0038
Driver’s in-vehicle distraction (1 if driver’s in-vehicle distraction, 0 otherwise) [SI]	-2.122	-3.68	0.0022	0.0006	-0.0028
No distractive driving indicator (1 if no distractive driving from driver was determined, 0 otherwise) [MI]	0.490	2.15	-0.0137	0.0271	-0.0134
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise) [NI]	-0.844	-6.28	-0.0302	0.0089	0.0213
No contributing driver factor indicator (1 if no contributing factor from driving action was determined, 0 otherwise) [MI]	0.849	3.15	-0.0226	0.0440	-0.0213
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise) [MI]	-2.005	-3.39	0.0033	-0.0074	0.0041
Number of observations	2648				
Log-likelihood at zero	-2909.125				
Log-likelihood at convergence	-2595.975				
$\rho^2 = 1 - LL(\boldsymbol{\beta})/LL(0)$	0.108				

SI = Severe Injury; MI = Minor Injury; NI = No Injury

Table 19. Marginal effects of severe injury in risky driving behaviors in Florida, 2020.

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Spatial characteristics					
District 3 indicator (1 if crash occurred in District 3, 0 otherwise)	0.0009	–	–	–	–
District 4 indicator (1 if crash occurred in District 4, 0 otherwise)	–	0.0009	–	–	–
District 5 indicator (1 if crash occurred in District 5, 0 otherwise)	0.0104	–	-0.0012	-0.0024	0.0061
District 6 indicator (1 if crash occurred in District 6, 0 otherwise)	–	0.0005	–	–	–
District 7 indicator (1 if crash occurred in District 7, 0 otherwise)	0.0056	–	–	–	–
Temporal characteristics					
Early morning indicator (1 if crash occurred between midnight and 6 AM, 0 otherwise)	-0.0077	–	–	–	–
Evening indicator (1 if crash occurred between 6 PM and 9 PM, 0 otherwise)	–	–	0.0011	–	–
Afternoon indicator (1 if crash occurred between 12 and 3 PM, otherwise)	0.0076	–	–	–	–
Weekend indicator (1 if crash occurred in weekend, 0 otherwise)	–	–	–	-0.0011	–
2nd quarter indicator (1 if crash occurred between April and June, 0 otherwise)	–	–	–	0.0055	–
4th quarter indicator (1 if crash occurred between October and December, 0 otherwise)	–	–	–	–	-0.0085
Weather/Ambient characteristics					
Rainy weather indicator (1 if weather was rainy, 0 otherwise)	-0.0012	–	–	–	–
Dark indicator (1 if it was dark, 0 otherwise)	–	-0.0026	–	–	–
Traffic characteristics					
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise)	0.0200	–	–	–	0.0095

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Vehicle characteristics					
Passenger car indicator (1 if passenger car, 0 otherwise)	–	–	–	0.0064	–
Sport Utility Vehicle (SUV) indicator (1 if SUV, 0 otherwise)	0.0015	–	–	–	–
Pickup truck indicator (1 if pickup truck, 0 otherwise)	–	–	-0.0035	–	–
Newer vehicle indicator (1 if crash occurred in 2015 model year or newer vehicle, 0 otherwise)	–	–	-0.0066	-0.0053	–
Harmful event characteristics					
Harmful shoulder indicator (1 if harmful event occurred at right shoulder, 0 otherwise)	0.0104	–	–	–	–
Harmful median indicator (1 if harmful event occurs in the median, 0 otherwise)	–	-0.0004	–	–	–
Harmful non-fixed object indicator (1 if harmful event occurred with non-fixed object, 0 otherwise)	–	-0.0051	–	–	–
Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise)	–	–	0.0722	0.0584	0.0931
Roadway characteristics					
Urban principal arterial indicator (1 if crash occurred on urban principal arterials, 0 otherwise)	–	–	0.0048	0.0046	0.0139
Urban freeway indicator (1 if crash occurred on urban freeway, 0 otherwise)	–	-0.0032	–	-0.0006	–
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise)	–	0.0061	0.0073	0.0027	0.0120
Narrow shoulder width indicator (1 if shoulder width is below 4 feet, 0 otherwise)	–	–	-0.0011	–	–
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0 otherwise)	–	–	–	–	0.0068
Roadways with Two-way turn-lane indicator (1 if crash occurred at roadway with two-way undivided left-turn lane, 0 otherwise)	–	–	–	–	-0.0012
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median	–	–	0.0126	–	–

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
barrier, 0 otherwise)					
Driver characteristics					
Male driver indicator (1 if driver is male, 0 otherwise)	–	–	0.0115	-0.0069	–
Female driver indicator (1 if driver is female, 0 otherwise)	–	0.0049	–	–	–
Young driver age indicator (1 if driver age is below 30 years, 0 otherwise)	–	-0.0094	–	–	–
Middle aged driver indicator (1 if driver age is between 30 to 50 years, 0 otherwise)	–	–	0.0020	–	–
Older-aged driver indicator (1 if driver age is between 50 to 65 years, 0 otherwise	–	–	–	0.0011	–
Young male driver age indicator (1 if driver age is below 30 years, 0 otherwise)	–	–	–	–	-0.0235
Middle aged male driver indicator (1 if male driver age is between 30 to 50 years, 0 otherwise)	-0.0067	–	–	–	–
Normal driving indicator (1 if driving without any physical/emotional impairment, 0 otherwise)	–	-0.0259	–	–	–
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise)	–	0.0104	0.0250	0.0258	0.0301
Non-geometry related factors (1 if non-geometry related factor, 0 otherwise)	–	–	–	–	0.0328
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise)	–	–	–	–	0.0042
Driver violation indicator (1 if driver had previous violation history, 0 otherwise)	–	-0.0079	-0.0543	–	-0.0663
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise)	–	–	–	–	-0.0038
Inattentive driving indicator (1 if driver was found inattentive, 0 otherwise)	–	–	-0.0009	–	–
Driver's in-vehicle distraction (1 if driver's in-vehicle distraction, 0 otherwise)	–	–	–	–	-0.0028
No distractive driving indicator (1 if no distractive	–	–	–	–	-0.0134

Variables \ Risky driving behaviors	**Drowsy Driving**	**Driving Too Fast for Conditions**	**Suspected Alcohol Consumption**	**Inattentive Driving**	**Not wearing seatbelt**
driving from driver was determined, 0 otherwise)					
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise)	–	–	–	–	0.0213
Exceeding speed limit by more than 20 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 20 mi/hr, 0 otherwise)	–	–	0.0139	–	–
Driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise)	0.0016	-0.0026	-0.0041	-0.0031	-0.0051
Running off road indicator (1 if driver ran off the road, 0 otherwise)	–	–	–	–	0.0069
Improper lane keeping indicator (1 if failed to keep in proper lane, 0 otherwise)	–	–	0.0047	–	–
No contributing driver factor indicator (1 if no contributing factor from driving action was determined, 0 otherwise)	–	–	–	–	-0.0213
Suspected alcohol consumption indicator (1 if alcohol consumption was suspected of driver, 0 otherwise)	–	–	–	-0.0008	–
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise)	–	–	0.0046	–	0.0041
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise)	-0.0821	-0.0749	-0.0607	-0.0684	–

Table 20. Marginal effects of minor injury in risky driving in Florida, 2020.

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Spatial characteristics					
District 3 indicator (1 if crash occurred in District 3, 0 otherwise)	-0.0086	–	–	–	–
District 4 indicator (1 if crash occurred in District 4, 0 otherwise)	–	-0.0082	–	–	–
District 5 indicator (1 if crash occurred in District 5, 0 otherwise)	-0.0016	–	0.0063	0.0205	0.0025
District 6 indicator (1 if crash occurred in District 6, 0 otherwise)	–	-0.0042	–	–	–
District 7 indicator (1 if crash occurred in District 7, 0 otherwise)	-0.0009	–	–	–	–
Temporal characteristics					
Early morning indicator (1 if crash occurred between midnight and 6 AM, 0 otherwise)	-0.0126	–	–	–	–
Evening indicator (1 if crash occurred between 6 PM and 9 PM, 0 otherwise)	–	–	-0.0063	–	–
Afternoon indicator (1 if crash occurred between 12 and 3 PM, otherwise)	-0.0012	–	–	–	–
Weekend indicator (1 if crash occurred in weekend, 0 otherwise)	–	–	–	0.0083	–
2nd quarter indicator (1 if crash occurred between April and June, 0 otherwise)	–	–	–	-0.0010	–
4th quarter indicator (1 if crash occurred between October and December, 0 otherwise)	–	–	–	–	-0.0040
Weather/Ambient characteristics					
Rainy weather indicator (1 if weather was rainy, 0 otherwise)	-0.0035	–	–	–	–
Dark indicator (1 if it was dark, 0 otherwise)	–	0.0186	–	–	–
Traffic characteristics					
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise)	-0.0030	–	–	–	-0.0151

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Vehicle characteristics					
Passenger car indicator (1 if passenger car, 0 otherwise)	–	–	–	0.0104	–
Sport Utility Vehicle (SUV) indicator (1 if SUV, 0 otherwise)	-0.0133	–	–	–	–
Pickup truck indicator (1 if pickup truck, 0 otherwise)	–	–	-0.0029	–	–
Newer vehicle indicator (1 if crash occurred in 2015 model year or newer vehicle, 0 otherwise)	–	–	-0.0054	-0.0098	–
Harmful event characteristics					
Harmful shoulder indicator (1 if harmful event occurred at right shoulder, 0 otherwise)	-0.0016	–	–	–	–
Harmful median indicator (1 if harmful event occurs in the median, 0 otherwise)	–	0.0044	–	–	–
Harmful non-fixed object indicator (1 if harmful event occurred with non-fixed object, 0 otherwise)	–	0.0009	–	–	–
Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise)	–	–	-0.0086	-0.0090	-0.0266
Roadway characteristics					
Urban principal arterial indicator (1 if crash occurred on urban principal arterials, 0 otherwise)	–	–	-0.0007	-0.0009	-0.0050
Urban freeway indicator (1 if crash occurred on urban freeway, 0 otherwise)	0.0042	0.0005	–	0.0049	–
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise)	–	-0.0012	-0.0011	-0.0005	-0.0045
Narrow shoulder width indicator (1 if shoulder width is below 4 feet, 0 otherwise)	–	–	0.0052	–	–
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0 otherwise)	–	–	–	–	0.0018
Roadways with Two-way turn-lane indicator (1 if crash occurred at roadway with two-way undivided left-turn lane, 0 otherwise)	–	–	–	–	0.0025
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median	–	–	0.0077	–	–

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
barrier, 0 otherwise)					
Driver characteristics					
Male driver indicator (1 if driver is male, 0 otherwise)	–	–	–	-0.0113	–
Female driver indicator (1 if driver is female, 0 otherwise)	–	0.0089	–	–	–
Young driver age indicator (1 if driver age is below 30 years, 0 otherwise)	–	-0.0180	–	–	–
Middle aged driver indicator (1 if driver age is between 30 to 50 years, 0 otherwise)	–	–	-0.0119	–	–
Older-aged driver indicator (1 if driver age is between 50 to 65 years, 0 otherwise	–	–	–	-0.0081	–
Young male driver age indicator (1 if driver age is below 30 years, 0 otherwise)	–	–	–	–	0.0071
Middle aged male driver indicator (1 if male driver age is between 30 to 50 years, 0 otherwise)	-0.0114	–	–	–	–
Normal driving indicator (1 if driving without any physical/emotional impairment, 0 otherwise)	–	-0.0483	–	–	–
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise)	–	0.0090	0.0068	0.0151	0.0094
Non-geometry related factors (1 if non-geometry related factor, 0 otherwise)	–	–	–	–	-0.0652
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise)	–	–	–	–	0.0026
Driver violation indicator (1 if driver had previous violation history, 0 otherwise)	–	0.0014	0.0058	–	0.0173
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise)	–	–	–	–	0.0070
Inattentive driving indicator (1 if driver was found inattentive, 0 otherwise)	–	–	0.0060	–	–
Driver’s in-vehicle distraction (1 if driver’s in-vehicle distraction, 0 otherwise)	–	–	–	–	0.0006
No distractive driving indicator (1 if no distractive	–	–	–	–	0.0271

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
driving from driver was determined, 0 otherwise)					
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise)	–	–	–	–	0.0089
Exceeding speed limit by more than 20 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 20 mi/hr, 0 otherwise)	–	–	-0.0022	–	–
Driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise)	-0.0125	0.0005	0.0005	0.0006	0.0013
Running off road indicator (1 if driver ran off the road, 0 otherwise)	–	–	–	–	0.0022
Improper lane keeping indicator (1 if failed to keep in proper lane, 0 otherwise)	–	–	0.0024	–	–
No contributing driver factor indicator (1 if no contributing factor from driving action was determined, 0 otherwise)	–	–	–	–	0.0440
Suspected alcohol consumption indicator (1 if alcohol consumption was suspected of driver, 0 otherwise)	–	–	–	0.0055	–
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise)	–	–	-0.0247	–	-0.0074
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise)	-0.1249	-0.1613	-0.0608	-0.1308	–

Table 21. Marginal effects of no injury in risky driving in Florida, 2020.

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Spatial characteristics					
District 3 indicator (1 if crash occurred in District 3, 0 otherwise)	0.0076	–	–	–	–
District 4 indicator (1 if crash occurred in District 4, 0 otherwise)	–	0.0074	–	–	–
District 5 indicator (1 if crash occurred in District 5, 0 otherwise)	-0.0088	–	-0.0051	-0.0181	-0.0085
District 6 indicator (1 if crash occurred in District 6, 0 otherwise)	–	0.0037	–	–	–
District 7 indicator (1 if crash occurred in District 7, 0 otherwise)	-0.0047	–	–	–	–
Temporal characteristics					
Early morning indicator (1 if crash occurred between midnight and 6 AM, 0 otherwise)	0.0203	–	–	–	–
Evening indicator (1 if crash occurred between 6 PM and 9 PM, 0 otherwise)	–	–	0.0051	–	–
Afternoon indicator (1 if crash occurred between 12 and 4 PM, otherwise)	-0.0065	–	–	–	–
Weekend indicator (1 if crash occurred in weekend, 0 otherwise)	–	–	–	-0.0072	–
2nd quarter indicator (1 if crash occurred between April and June, 0 otherwise)	–	–	–	-0.0044	–
4th quarter indicator (1 if crash occurred between October and December, 0 otherwise)	–	–	–	–	0.0125
Weather/Ambient characteristics					
Rainy weather indicator (1 if weather was rainy, 0 otherwise)	0.0047	–	–	–	–
Dark indicator (1 if it was dark, 0 otherwise)	–	-0.0160	–	–	–
Traffic characteristics					
Low traffic condition indicator (1 if AADT is below 40,000 vehicles/day, 0 otherwise)	-0.0169	–	–	–	0.0056

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Vehicle characteristics					
Passenger car indicator (1 if passenger car, 0 otherwise)	–	–	–	-0.0169	–
Sport Utility Vehicle (SUV) indicator (1 if SUV, 0 otherwise)	0.0118	–	–	–	–
Pickup truck indicator (1 if pickup truck, 0 otherwise)	–	–	0.0063	–	–
Newer vehicle indicator (1 if crash occurred in 2015 model year or newer vehicle, 0 otherwise)	–	–	0.0120	0.0151	–
Harmful event characteristics					
Harmful shoulder indicator (1 if harmful event occurred at right shoulder, 0 otherwise)	-0.0088	–	–	–	–
Harmful median indicator (1 if harmful event occurs in the median, 0 otherwise)	–	-0.0040	–	–	–
Harmful non-fixed object indicator (1 if harmful event occurred with non-fixed object, 0 otherwise)	–	0.0042	–	–	–
Harmful fixed object indicator (1 if harmful event occurred with roadside fixed object, 0 otherwise)	–	–	-0.0636	-0.0494	-0.0665
Roadway characteristics					
Urban principal arterial indicator (1 if crash occurred on urban principal arterials, 0 otherwise)	–	–	-0.0041	-0.0037	-0.0090
Urban freeway indicator (1 if crash occurred on urban freeway, 0 otherwise)	-0.0084	0.0027	–	-0.0043	–
Left curved segment indicator (1 if roadway curves to the left of travel direction, 0 otherwise)	–	-0.0049	-0.0062	-0.0022	-0.0075
Narrow shoulder width indicator (1 if shoulder width is below 4 feet, 0 otherwise)	–	–	-0.0041	–	–
Medium shoulder width indicator (1 if shoulder width is between 4 to 8 feet, 0 otherwise)	–	-0.0040	–	–	-0.0086
Roadways with Two-way turn-lane indicator (1 if crash occurred at roadway with two-way undivided left-turn lane, 0 otherwise)	–	–	–	–	-0.0012

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Roadway with positive median barrier indicator (1 if crash occurred at roadways with positive median barrier, 0 otherwise)	–	–	-0.0203	–	–
Driver characteristics					
Male driver indicator (1 if driver is male, 0 otherwise)	–	–	–	0.0182	–
Female driver indicator (1 if driver is female, 0 otherwise)	–	-0.0137	–	–	–
Young driver age indicator (1 if driver age is below 30 years, 0 otherwise)	–	0.0273	–	–	–
Middle aged driver indicator (1 if driver age is between 30 to 50 years, 0 otherwise)	–	–	0.0098	–	–
Older-aged driver indicator (1 if driver age is between 50 to 65 years, 0 otherwise	–	–	–	0.0070	–
Young male driver age indicator (1 if driver age is below 30 years, 0 otherwise)	–	–	–	–	0.0164
Middle aged male driver indicator (1 if male driver age is between 30 to 50 years, 0 otherwise)	0.0180	–	–	–	–
Normal driving indicator (1 if driving without any physical/emotional impairment, 0 otherwise)	–	0.0742	–	–	–
Non collision related factor indicator (1 if non-collision related factor including overturn/rollover, 0 otherwise)	–	-0.0193	-0.0317	-0.0408	-0.0395
Non-geometry related factors (1 if non-geometry related factor, 0 otherwise)	–	–	–	–	0.0324
Aggressive driving indicator (1 if driver was driving aggressively, 0 otherwise)	–	–	–	–	-0.0069
Driver violation indicator (1 if driver had previous violation history, 0 otherwise)	–	0.0065	0.0485	–	0.0490
Fatigue driving indicator (1 if driver was found fatigued/ drowsy, 0 otherwise)	–	–	–	–	-0.0032
Inattentive driving indicator (1 if driver was found inattentive, 0 otherwise)	–	–	-0.0051	–	–

Variables \ Risky driving behaviors	Drowsy Driving	Driving Too Fast for Conditions	Suspected Alcohol Consumption	Inattentive Driving	Not wearing seatbelt
Driver’s in-vehicle distraction (1 if driver’s in-vehicle distraction, 0 otherwise)	–	–	–	–	0.0022
No distractive driving indicator (1 if no distractive driving from driver was determined, 0 otherwise)	–	–	–	–	-0.0137
Exceeding speed limit by more than 10 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 10 mi/hr, 0 otherwise)	–	–	–	–	-0.0305
Exceeding speed limit by more than 20 mi/hr indicator (1 if travel speed exceeded the speed limit by more than 20 mi/hr, 0 otherwise)	–	–	-0.0117	–	-0.0302
Driving below the speed limit by more than 10 mi/hr indicator (1 if travel speed was below the speed limit by more than 10 mi/hr, 0 otherwise)	0.0109	0.0021	0.0036	0.0025	0.0038
Running off road indicator (1 if driver ran off the road, 0 otherwise)	–	–	–	–	-0.0092
Improper lane keeping indicator (1 if failed to keep in proper lane, 0 otherwise)	–	–	-0.0071	–	
No contributing driver factor indicator (1 if no contributing factor from driving action was determined, 0 otherwise)	–	–	–	–	-0.0226
Suspected alcohol consumption indicator (1 if alcohol consumption was suspected of driver, 0 otherwise)	–	–	–	-0.0047	–
Blood alcohol content (BAC) more than 0.15 indicator (1 if BAC is more than 0.15 g/dl, 0 otherwise)	–	–	0.0201	–	0.0033
Restraint usage indicator (1 if shoulder and lap belt used, 0 otherwise)	0.2070	0.2362	0.1216	0.1992	–

Conclusions and policy implications

Research in highway safety has struggled to deal adequately with two issues: the role that perception/attitudes may play in resulting crash and injury-severity likelihoods; and the issue of identification in safety modeling caused by self-selective sampling of safety data (the fact that riskier drivers are likely to be over-represented in crash data bases). This study addresses these two points by first collecting data that focused on highway safety perceptions. With these data, two statistical models were developed. The first statistical model addressed the question of how people thought highway safety has changed in the last five years and the second model analyzed their opinions on the suitability of current speed limits. Both of these statistical models found that a wide range of household characteristics determine safety perceptions and accounting for these characteristics in traditional crash data can be difficult and often impossible, suggesting the need for statistical methods that address the issue of missing perception data and the perception-attitudes they imply.

The study then moved on to address the issue of identification, specifically addressing the possibility that COVID-19 may have fundamentally changed the mix of drivers on the road and that this may be a contributing factor in the observed rise in the proportion of more severe crashes. For example, the observation of more severe crashes during and after the COVID-19 pandemic could lead to two distinct interpretations. The first interpretation is what almost all COVID-19 crash-related research has assumed by default, that COVID-19 has fundamentally altered driving behavior and opened up roads to be less congested, both of which have resulted in a higher proportion of severe injuries in observed crashes. However, this study also considered the second interpretation that would say that the COVID-19 pandemic caused a shift in safe/risky driver vehicle miles traveled, and that the characteristics of drivers that continued to drive during and post-COVID-19 were a sub-sample of riskier drivers that naturally would tend to be involved in higher injury level crashes, thus increasing the proportion of severe injuries in observed crashes. Model estimation results that address the question of how vehicle usage has changed post-pandemic indicate that safer drivers have reduced their vehicle usage significantly more than riskier drivers. With a greater proportion of vehicle miles travelled now being riskier drivers, this has likely resulted in fundamental shift in injury severity probabilities in observed crashes.[3]

To explore this shift in injury severity probabilities, Florida crash data from 2019 (pre-pandemic) and 2020 (pandemic) were gathered and focus was directed toward single-vehicle crashes (where driver error is indisputable) and crashes where one or more of the following risky behaviors were identified in the crash report; driving while asleep/drowsy, driving too fast for conditions, driving with suspected alcohol consumption, driving while inattentive, and driving while not wearing a seatbelt. A series of random parameters multinomial logit models were estimated and the estimation results confirmed that there was a statistically significant shift in the factors that determined injury severities in highway crashes between 2019 and 2020. The source of this shift is likely a combination of both fundamental changes in behavior (which has been the argument made in the traditional temporal instability literature (Mannering, 2018)) and, a shift in the proportion of vehicle miles travelled by risky and safe drivers as indicated in the study's earlier finding that riskier drivers are responsible for a greater proportion of vehicle miles traveled relative to their pre-pandemic levels. Then, using the 2020 pandemic crash data from Florida, the study

[3] As a further example of the issue here, consider a statistical model of injuries in motorcycle crashes. Suppose model estimates show that motorcycle crashes occurring in the rain have a higher probability of severe injury. There are two interpretations. One is that rain makes the roads inherently more dangerous and more severe injuries result. The other is that the safest motorcyclists avoid riding in the rain, so rain-observed crashes include only risky riders that naturally have more severe crashes. Thus it could be that rain itself has no physical effect on crashes but merely captures the self-selectivity of people choosing to ride in the rain. The policy implications are quite different. Ignoring self-selectivity would indicate that focus should be directed toward increasing wet-weather friction, where focusing on self-selectivity would suggest that policies making riskier riders safer would be the correct countermeasure.

moved on to provide multiple injury-severity model estimates based on individual models of the five (risky-behaviors driving while asleep/drowsy, driving too fast for conditions, driving with suspected alcohol consumption, driving while inattentive, and driving while not wearing a seatbelt) and these models results underscore the importance of capturing safety perceptions and attitudes in model estimations (in this case by using mixing distributions with heterogeneity in the means and variances).

There are two key policy recommendations from this study. The first recommendation is that the role of safety attitudes and perceptions are important considerations in the analysis of highway crash data and must be considered in highway-safety practice. The findings of this study clearly show that mixing distributions (random parameters) are a statistically viable approach of capturing unobserved effects (which include motorist perceptions and attitudes toward safety). Based on the findings in this report, and the findings of a growing body of recently published research, it is essential that highway safety practice incorporate unobserved heterogeneity in their safety handbooks, most importantly the Highway Safety Manual (AASHTO, 2010).

The second recommendation is that more attention needs to be directed toward the identification problem in the analysis of highway safety data. Understanding whether the observed statistical estimates of highway safety models are due entirely to the effect of specific explanatory variables or due in some part to the possibility that the mix of risky and safe drivers is changing, which would potentially result in much different policy implications.

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