Examining the influence of aggressive driving behavior on driver injury severity in traffic crashes

Rajesh Paleti
The University of Texas at Austin
Department of Civil, Architectural and Environmental Engineering
1 University Station, C1761, Austin, TX 78712-0278
Phone: 512-751-5341, Fax: 512-475-8744 Email: rajeshp@mail.utexas.edu

Naveen Eluru
The University of Texas at Austin
Department of Civil, Architectural and Environmental Engineering
1 University Station, C1761, Austin, TX 78712-0278
Phone: 512-471-4535, Fax: 512-475-8744 Email: naveeneluru@mail.utexas.edu

and

Chandra R. Bhat*
The University of Texas at Austin
Department of Civil, Architectural and Environmental Engineering
1 University Station C1761, Austin, TX 78712-0278
Phone: 512-471-4535, Fax: 512-475-8744 Email: bhat@mail.utexas.edu

*corresponding author

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Abstract

In this paper, we capture the moderating effect of aggressive driving behavior while assessing the influence of a comprehensive set of variables on injury severity. In doing so, we are able to account for the indirect effects of variables on injury severity through their influence on aggressive driving behavior, as well as the direct effect of variables on injury severity. The methodology used in the paper to accommodate the moderating effect of aggressive driving behavior takes the form of two models – one for aggressive driving and another for injury severity. These are appropriately linked to obtain the indirect and direct effects of variables. The data for estimation is obtained from the National Motor Vehicle Crash Causation Study (NMVCCS). From an empirical standpoint, we consider a fine age categorization until 20 years of age when examining age effects on aggressive driving behavior and injury severity.

There are several important results from the empirical analysis undertaken in the current paper based on post-crash data collection on aggressive behavior participation just prior to the crash and injury severity sustained in a crash. Young drivers (especially novice drivers between 16-17 years of age), drivers who are not wearing seat belt, under the influence of alcohol, not having a valid license, and driving a pickup are found to be most likely to behave aggressively. Situational, vehicle, and roadway factors such as young drivers traveling with young passengers, young drivers driving an SUV or a pick-up truck, driving during the morning rush hour, and driving on roads with high speed limits are also found to trigger aggressive driving behavior. In terms of vehicle occupants, the safest situation from a driver injury standpoint is when there are 2 or more passengers in the vehicle, at least one of whom is above the age of 20 years. These and many other results are discussed, along with implications of the result for graduated driving licensing (GDL) programs.

Keywords: Crash injury severity, graduated licensing programs (GDL), teenage drivers, driving aggressiveness, risk taking, parenting.

1. INTRODUCTION

Traffic crashes are a major cause of concern in the United States. In 2007 alone, there were about 6 million police-reported crashes in the U.S., resulting in about 41,000 fatalities and 2.5 million injured persons (NHTSA, 2007). The annual number of fatalities amounts to an average of about 112 dead individuals per day in motor vehicle crashes in the U.S. or, equivalently, one fatality every 13 minutes. While the fatality rate per 100 million vehicle miles of travel (VMT) fell to a historic low of 1.37 in 2007 (down from 1.64 in 1997), the annual number of fatalities has seen little change over the years, remaining steady between 41,000-43,500. In fact, motor vehicle crashes remain the leading cause of death for people aged 1 through 34 years of age (Cook *et al.*, 2005; NHTSA, 2007).

While there are several potential causes of traffic crashes, and the injury severity sustained in the crashes, a leading cause is aggressive driving, broadly defined as any deliberate unsafe driving behavior performed with "ill intention or disregard to safety" (Tasca, 2000, AAA Foundation for Traffic Safety, 2009; see also NHTSA, 2009).[1] A recent study by the American Automobile Association (AAA Foundation for Traffic Safety, 2009) estimated that 56% of the fatal crashes that occurred between 2003 and 2007 involved potential aggressive driving behavior, with speeding being the most common potentially aggressive action making up about 31% of total fatal crashes. Other potentially aggressive actions with contributions to fatal crashes included failure to yield right of way (11.4% of fatal crashes), reckless/careless/erratic driving (7.4%), failure to obey signs/control devices (6.6%), and improper turning (4.1%).

In this paper, we examine the effects of aggressive driving and other potential factors on the crash injury severity sustained by drivers in crashes that involved at least one light passenger vehicle being towed due to damage. The potential factors considered in the analysis include (1) Driver attributes (demographics, seat belt use, and drug/alcohol use), (2) Environmental and situational factors (weather, lighting conditions, time of day, day of week, number and age distribution of other vehicle occupants, traffic conditions, *etc.*), (3) Vehicle characteristics (type of vehicle(s) involved in the crash), (4) Roadway design attributes (number of lanes, type of roadway, and speed limits), and (5) Crash characteristics (manner of collision, role of vehicle in

[1] Aggressive driving is considered distinct from road rage, the latter being committed with the express intent to physically harm another individual, while the former being committed with "disregard to safety but not necessarily with the intent to cause physical harm" (AAA Foundation for Traffic Safety, 2009).

crash, whether there was a roll-over of one or more vehicles, *etc*.). It is essential to quantify the relative magnitudes of the impact of these factors on accident severity, so that effective countermeasures to reduce accident severity can be identified and implemented. The focus of the paper, more specifically and explicitly, is to capture the moderating effect of aggressive driving behavior while assessing the influence of a comprehensive set of variables on injury severity. This is very important to disentangle the effects of variables on injury severity through their influence on aggressive driving behavior (an *indirect* effect on injury severity) and through a *direct* effect on injury severity after accounting for aggressive driving effects.[2] For instance, consider the case that seat belt non-users are generally aggressive drivers, as has been suggested by, among others, Cohen and Einav (2003), and Eluru and Bhat (2007). Seat belt non-usage, even after controlling for aggressive driver behavior, is likely to increase crash injury severity because of the "lack of restraint" effect. In this case, a "reduced form" analysis (that co-mingles the *indirect* and *direct* effects of non-seat belt use) would artificially inflate the estimate of the effectiveness of seat belt use as a restraint device and may suggest, for instance, substantial money investment in "police officers on the beat" as part of a "Click it or Ticket" campaign. However, such an effort may not bring the predicted results of the "reduced-form" analysis in reducing injury severity. If non-seat belt use is a good indicator of aggressive driving behavior, as well as increases crash injury severity due to the lack of restraint in the vehicle, the policy suggestion would be to implement a "Click it, or Defensive Driving **and** Ticket" campaign. That is seat belt non-users, when apprehended in the act, should perhaps be subjected to mandatory enrollment in a defensive driving course (to attempt to change their aggressive driving behaviors) as well as a seat-belt use violation fine (to increase the chances that they wear seat belts to restrain themselves).

To summarize, injury severity "reduced form" models that do not consider aggressive driving behavior can provide inadequate/misinformed guidance for policy interventions. This is because of two related considerations. First the reduced form model "masks" *indirect* and *direct* effects, each of which individually may provide important information for the design of

[2] The indirect and direct effects are with respect to the aggressive driving behavior. It is possible to undertake a similar analysis with respect to other behavioral or psychological factors such as distraction and level of social responsibility. However, unlike aggressive driver behavior that can be more easily established and imputed based on post-crash data collection, information on other behavioral factors such as distraction and social responsibility are difficult to ascertain based on post-crash data collection. At the least, data on such behavioral factors are more prone to mis-classification and mis-recording.

intervention strategies. Second, and econometrically speaking, not including aggressive driving behavior as a determinant of injury severity leads to an omitted-variable bias that can leave all variable effects estimated in the "reduced form" model inconsistent. Given this situation, it is indeed surprising that there has been little research on disentangling the *indirect* and *direct* effects of variables on crash injury severity.

The methodology used in the paper to accommodate the moderating effect of aggressive driving behavior takes the form of two models – one for aggressive driving and another for injury severity. These are appropriately linked to obtain the *indirect* and *direct* effects of variables. Once estimated, the model can be used in prediction mode without having any information on aggressive driving. The data for estimation is obtained from the National Motor Vehicle Crash Causation Study (NMVCCS), which includes a binary indicator for whether an individual was driving aggressively just prior to a crash in addition to an ordinal-level characterization of the injury severity level sustained by drivers involved in the crash.

The rest of this paper is structured as follows. The next section provides an overview of the relevant literature, and positions the current study in the context of earlier studies. Section 3 presents the econometric framework. Section 4 discusses the data source and sample used in the empirical analysis. Section 5 presents the empirical results. Section 6 concludes the paper by summarizing the important findings and identifying policy implications.

2. EARLIER RESEARCH

2.1 Aggressive Driving Studies

Tasca (2000) was probably the first to attempt to formally characterize aggressive driving behavior, defining driving as being aggressive if "*it is deliberate, likely to increase the risk of collision and is motivated by impatience, annoyance, hostility and/or attempt to save time.*" Since Tasca's paper, several other studies have also attempted to characterize aggressive behavior. Some of these use a relatively narrow definition of aggressive driving as behavior that is intended to hurt others (for example, Galovski and Blanchard, 2002), while others use a more broad definition of an act that disregards safety, whether with the deliberate intent of endangering others or not (AAA Foundation for Traffic Safety, 2009).

Overall, while a single standard definition of aggressive driving has not been adopted in the traffic safety literature, there have been studies that have used different ways to characterize and measure aggressive behavior and study the determinants of this behavior. These studies typically use surveys to elicit information on indicators of aggressiveness such as (a) self-reported frequency (per month or per week) of participating in such acts as “excessive speeding”, “making threatening maneuvers with the car”, failure to signal”, “tailgating”, “driving 20 mph over the speed limit”, and “driving after a few drinks (Vanlaar *et al*., 2008, Beck *et al*., 2006, Millar, 2007), (b) self-reported responses of how one may respond (for instance, “doing nothing” or “bumping the other person’s car”) when in hypothetical situations that may trigger aggressive driving behavior (see Agerwala *et al*., 2008), (c) personality inventories such as the Driver Anger Expression Inventory and the Driver Angry Thoughts Questionnaire (see Benfield *et al*., 2007), and (d) self-reported frequency of being in crash-related conditions (such as loss of concentration and loss in vehicle control) over a specified time interval and number of lifetime traffic citations and major/minor accidents (see Dahlen and White, 2006). These indicators are then combined and converted (typically) into a single binary indicator of aggressiveness, and correlated with various personality traits and some demographic/situational attributes. However, the effectiveness of these studies in studying human behavior is limited because respondents are prone to suppress undesirable responses in surveys to appear more socially pleasing. A few aggressive driving studies have used traffic crash reports filed by police officers or field observations (rather than respondent surveys) as a means to determine whether or not the driver engaged in an aggressive act (such as weaving in and out of traffic, improper overtaking, ran a red light, and failed to yield, frequency of changing lanes, gap acceptance, and acceleration/deceleration patterns; see Shinar and Compton, 2004, Cook *et al*., 2005, Kaysi and Abbany, 2007, and Hamdar *et al.*, 2008). Such observations are then correlated with the gender/age of the driver and situational/environmental factors. But, none of these studies examine the effect of aggressiveness on crash-related injury severity at the individual crash level, and most only include a limited set of easily observable determinants of aggressive behavior.

2.2 Car Driver Injury Severity Studies

The crash injury severity of car drivers has been extensively studied in the safety literature (in this study, we will use the label “car” to refer to a four-wheel passenger motor vehicle, including sports utility vehicles, pick-up trucks, vans, and minivans). A review of several different discrete variable studies of crash-related car driver injury severity is provided in Eluru and Bhat (2007).

Some other (mostly more recent) studies of car driver injury severity (either in isolation or in combination with the injury severity of other car occupants) include Yamamoto and Shankar (2004), Shimamura *et al.* (2005), Holdridge *et al.* (2005), Khorashadi *et al.* (2005), Islam and Mannering (2006), Conroy *et al.* (2006), Delen *et al.* (2006), Hill and Boyle (2006), Majdzadeh *et al.* (2008), Awadzi *et al.* (2008), Gray *et al.* (2008), Fredette *et al.* (2008), Newgard (2008), Neyens and Boyle (2008), Lapparent (2008), Huang *et al.* (2008), Yamamoto *et al.* (2008), Conroy *et al.* (2008), Angel and Hickman (2009), Dupont *et al.* (2010), Nevarez *et al*. (2009), Hasselberg and Laflamme (2009), Xie and Zhao (2009), Schneider *et al.* (2009) and Rana *et al.* (2010). Many of these recent studies focus on specific driver demographic groups (such as young adults, old adults, males, females, and age-gender combinations) and/or specific crash types (such as head-on crashes, rollovers, two-vehicle collisions including head-on collisions, crashes with fixed roadside objects and single-vehicle crashes, crashes of passenger vehicles with large trucks, and left-turn crashes).[3]

A study of *direct* relevance to the current study is the one by Nevarez *et al*. (2009), who employed a simple binary model to predict the probability of severe driver injury (incapacitating or fatal injury) versus non-severe driver injury. They used data from the Florida Traffic Crash Records Database (FTCRD) and the Florida DOT's Crash Analysis Reporting (CAR) database, and included an aggressive driving dummy variable in their injury severity model. Their aggressive driving indicator is based on whether the driver was speeding, tailgating, failed to yield right of way, changed lanes improperly, or disregarded other traffic control. This study appears to be the first to include an aggressive dummy variable indicator in a discrete choice model of injury severity, though they do not examine the moderating effect of the aggressiveness variable in assessing the impact of other variables on the propensity to be injured severely. That is, they consider only a simple dummy variable representation of the aggressiveness variable, without considering interaction effects of the dummy variable with other variables in the model. They do not also model aggressiveness as a function of exogenous variables. Rather, aggressiveness is treated purely as an exogenous variable, which does not provide insights

[3] There have been injury severity studies associated with several other different types of road users too, including car front passengers, car rear passengers, combinations of car occupants, motorcycle riders, motorcycle passengers, pedestrians, and bicyclists. Further, there have also been several accident injury severity studies examining injury severities at the level of accidents (such as no injury at all, injury to one or more individuals, and fatalities). It is beyond the scope of this paper to list all these studies.

regarding intervention strategies aimed at decreasing injury severity levels through the reduction in aggressive driving behavior. Finally, Nevarez *et al*. do not recognize the very important point that those who partake in aggressive acts may be uniformly more likely to sustain severe injuries. Econometrically speaking, and as we discuss later, this is related to the moderating effect of aggressive driving on the magnitude of the impact of unobserved factors on injury severity.

2.3 Current Study in Context

The overview of the literature indicates that several studies have examined the determinants of aggressive driving, though most of these studies have been based on self-reported aggressive driving indicators and have focused on the influence of personality traits on aggressive driving. While helpful in many ways, personality traits are not immediately observable in the population and thus the earlier studies provide only limited information for the design of intervention strategies to curb aggressive behavior. Further, these general studies of aggressive behavior do not examine the impact of aggressive driving on crash injury severity levels, though there is descriptive evidence that aggressive driving is a contributing factor. At the same time, while there has been substantial earlier research on car driver crash-related injury severity determinants, it is indeed surprising that only one recent study has considered aggressive driving along with other factors.

In this paper, we bring the two streams of earlier work (those on aggressive driving and those on car driver injury severity) together to capture both the *indirect* and *direct* effects of exogenous variables on car driver injury severity in crashes. Further, we consider random unobserved effects in the influence of variables on both aggressive behavior and injury severity level. In doing so, we recognize that the impact of aggressive behavior on injury severity may be moderated by various observed and unobserved variables specific to an individual or to a crash. For instance, aggressive driving behavior may be particularly dangerous from a crash safety standpoint for young individuals. This may be because young individuals, while risk-takers, are also inexperienced in driving and do not know how to react to decrease injury severity as a crash develops. This situation is an example of the impact of aggressive driving behavior being moderated by the observed characteristic of “being young”. Similarly, the precise sitting posture or the intrinsic reflexes of an individual may moderate the injury severity sustained in a crash involving an aggressive driving act. This is an instance where unobserved characteristics (sitting posture or intrinsic reflexes) moderate the effect of aggressive driving behavior on injury severity. In general, one could argue that there are several subtle, unobserved, characteristics that moderate the effect of aggressive driving behavior and other exogenous factors influencing injury severity. Ignoring such unobserved heterogeneity can, and in general will, result in inconsistent estimates in nonlinear models (see Chamberlain, 1980; Bhat, 2001).

From an empirical standpoint, an emphasis of the current research is on examining the effects of age on car driver injury severity. In particular, though we consider all age groups represented in the crash data, we consider a very fine age categorization until 20 years of age when examining age effects on aggressive driving behavior and injury severity. The specific focus on younger drivers is because young drivers are significantly more likely than adult drivers to engage in aggressive driving acts, including not wearing seat belts and speeding (Simons-Morton *et al*., 2005). In part because of this, there is also a significant over-representation of young drivers (age between 15 and 20) in traffic related crashes. In 2007, young drivers represented about 6.4% of the driving population, but accounted for 13% of all fatal crashes and 15% of all police reported crashes (NHTSA, 2007). Further, 16-year olds are found to be particularly at risk of serious crashes (34.5 per million miles) relative to 17-year olds (20.2 per million miles) and 18-year olds (13.8 per million miles). For drivers in their 20s, this falls to 7.8 (see Preusser and Leaf, 2003 and Williams, 2000). NCHRP (2007) also indicates that the relative contributions of the factors that determine injury severity can vary significantly with each year in the young adult group. Clearly, these statistics indicate the need to retain a fine resolution of age among young drivers. In contrast, almost all earlier studies of aggressive driving and injury severity have grouped 15-20 year olds in a single category.

3. STUDY FRAMEWORK

Earlier research on aggressive driving behavior supports the hypothesis that there are a number of psychological, personality, and situational factors that trigger aggressive driving behavior. These may include driving anger, sensation seeking nature, extraversion, agreeableness, openness, conscientiousness, and emotional state on the trip on which crash occurred. Such factors are not observed in crash data bases, so we will refer to them collectively as "latent aggressive driving act propensity" just prior to the crash. Figure 1 presents the conceptual framework, with this latent aggressive driving act propensity toward the center-top of the figure.

This propensity is a function of observed driver, environmental/situational, vehicle, roadway and crash factors, as well as unobserved (random) factors that directly affect the latent aggressive driving act propensity and moderate the effect of the observable factors on the latent aggressive driving act propensity (captured through random coefficients). In our crash data set, a trained group of researchers arrived at the crash site immediately after a crash and made an informed determination regarding driver aggressiveness act participation prior to the crash (see center of the figure). This information is available to us, though it is not likely to be available in other data bases and is certainly not available when predicting injury severity levels given observed exogenous variables. In estimation, we use this dummy aggressive act participation variable as a determinant factor of the latent propensity associated with injury severity level, along with other observed and unobserved (random) factors. The unobserved factors affect the latent propensity determining injury severity both directly and through moderating the effects of observed factors on the injury severity propensity. Finally, the latent propensity governing injury severity determines the observed driver injury severity level in the usual ordered-response fashion.[4]

Overall, the estimation phase entails two independent equations – one for estimating the determinants of driver aggressiveness act participation (labeled as "1" in Figure 1) and the second for estimating the determinants of injury severity (labeled as "2" and "3" in Figure 1). However, for evaluating the effectiveness of intervention policies or to predict injury severity levels for a certain combination of observed characteristics, we do not have the driver aggressive act participation variable. Thus, the relationship labeled "3" in Figure 1 cannot be explicitly used. However, one can use the determinants of aggressive act participation (the relationship labeled "1" in Figure 1) to determine the probability of aggressive act participation, and then write the probability of injury severity level purely as a function of observable factors. In this prediction mode, the probability structure is similar to a latent segmentation scheme (see Basar and Bhat, 2004 for an example of such a model in travel demand, and Malyshkina and

[4] Most earlier studies with multiple injury severity levels have used either an ordered-response discrete choice formulation to recognize the ordinal nature in which injury severity is typically recorded (for instance, "no injury", "possible injury", "non-incapacitating injury", "incapacitating injury", and "fatal injury"), or an unordered model formulation such as the multinomial logit, nested logit, latent segmentation logit, and mixed logit for modeling injury severity. The traditional ordered-response model may have the advantage that its data generation process is more consistent with the ordinal nature of the injury severity variable. However, a limitation of the traditional ordered-response structure is that it imposes a certain kind of monotonic effect of exogenous variables on injury severity levels. Ideally, one should consider generalizations of the traditional ordered-response and multinomial logit models, and examine predictive ability and behavioral validity. This is an avenue for future research.

Mannering, 2009 for such a model in injury severity analysis). However, the fact that we have the driver aggressive act participation dummy indicator based on the determination of a trained team of safety experts allows us not only to substantially simplify the estimation, but add richness and flexibility to the overall model structure in a way that would be impossible to accommodate in a latent segmentation scheme without the aggressive act participation variable.

The econometric framework corresponding to the study framework just discussed is presented next.

3.1 Econometric Framework

Let q (q = 1, 2, …, Q) be an index to represent drivers, and let k (k = 1, 2, 3, …, K) be an index to represent injury severity. The index k, for example, may take values of "no injury" $(k=1)$, "possible injury" $(k=2)$, "non-incapacitating injury" $(k=3)$, and "incapacitating/fatal injury" $(k=4)$, as in the empirical analysis in the current paper. The equations for aggressive act participation and injury severity are:

$$a_q^* = (\beta' + \vartheta_q')x_q + \varepsilon_q\,,\; a_q = 1 \text{ if } a_q^* > 0\,;\; a_q = 0 \text{ otherwise}$$

$$y_q^* = (\alpha' + \delta_q')z_q + (\theta + \mu' w_q)a_q + \xi_q\,,\; y_q = k \text{ if } \psi_{k-1} < y_q^* < \psi_k \qquad (1)$$

The first equation is associated with the latent aggressive driving act propensity a_q^* for driver q, and a_q is the actual observed binary aggressive act participation indicator for driver q. x_q is an (M x 1) column vector of attributes (including a constant) associated with driver q and her/his crash environment. β represents a corresponding (M x 1) column vector of the coefficients to be estimated, while ϑ_q is another (M x 1)- column vector with its m^{th} element representing unobserved factors specific to driver q and her/his crash environment that moderates the influence of the corresponding m^{th} element of the vector x_q. ε_q is an idiosyncratic random error term assumed to be independently and identically logistic distributed across individuals q.

The second equation is associated with the latent propensity y_q^* associated with the injury severity sustained by driver q in the accident. This latent propensity y_q^* is mapped to the actual injury severity level y_q by the ψ thresholds ($\psi_0 = -\infty$ and $\psi_k = \infty$) in the usual ordered-response fashion. z_q is an (L x 1) column vector of attributes (not including a constant and not including aggressive act participation) that influences the propensity associated with injury severity. α is a corresponding (L x 1)-column vector of coefficients to be estimated, and δ_q is another (L x 1)-column vector of unobserved factors moderating the influence of attributes in z_q on the injury severity propensity for driver q. θ is a scalar constant, w_q is a set of driver/crash attributes that moderate the effect of aggressive driving on injury severity, and μ is a corresponding vector of coefficients. ξ_q is an idiosyncratic random error term assumed to be independently standard logistic distributed across individuals q. However, we allow the scale of ξ_q to vary based on whether or not driver q participates in an aggressive act. This is to allow the possibility that the level of unobserved variation in the injury severity propensity may be different between the group of drivers who participate in an aggressive act and those who do not. For instance, it is possible that drivers who partake in aggressive acts just before a crash leave themselves less space cushions to reduce the effects of an accident, which may make them uniformly more likely to sustain severe injuries, while there may be more variation in injury severity level in the group that does not behave aggressively. To allow such scale heterogeneity, we specify the scale of ξ_q to be as follows: $\pi_q = \exp(\gamma \cdot a_q)$. The exponential form guarantees that the scale is positive. The scale for drivers who do not participate in an aggressive act is normalized to one for identification.[5]

We assume independence between the elements of the ϑ_q and δ_q elements that correspond to any common variables in x_q and z_q. We also assume independence between the ε_q and ξ_q

[5] The current study uses a random-coefficients heteroscedastic ordered-response model and not a "traditional" ordered-response model as has been used in many earlier injury severity studies. Eluru *et al.* (2008) also used a similar random-coefficients ordered-response model as the one we use here, though they also allowed the thresholds to vary across observations due to observed and unobserved variables. The advantage of the formulation used in the current paper is that the effects of variables are not based on the combined effects on both the risk propensity and thresholds, making the interpretation of effects simpler. In the context of the current study where the focus is on disentangling the direct and indirect effects of variables, the simpler but still more general (than the simple ordered-response logit or ORL) model structure used here is attractive.

terms.[6] The result is a substantial simplification in the estimation. But, to complete the model structure of the system in Equation (1), we need to specify the structure for the unobserved vectors ϑ_q and δ_q. In the current paper, we assume that the ϑ_q and δ_q elements are independent realizations from normal population distributions; $\vartheta_{qm} \sim N(0,\sigma_m^2)$, and $\delta_{ql} \sim N(0,\omega_l^2)$.

3.2 Model Estimation

The parameters to be estimated in the joint model system of Equation (1) are the β, α and μ vectors, the θ scalar, the ψ thresholds, and the following variance terms: σ_m^2, ω_l^2, and γ scalar (embedded in π_q). Let Ω represent a vector that includes all these parameters to be estimated. Let σ be another vertically stacked vector of standard errors σ_m, and let ω be a vertically stacked vector of standard errors ω_l. Let $\Omega_{-\sigma,\omega}$ represent a vector of all parameters except the standard error terms. Finally, let $g_q = 2a_q - 1$ and $b_q = \{(\alpha' + \delta_q')z_q + (\theta + \mu' w_q)a_q\}$. Then, the likelihood function, for a given value of $\Omega_{-\sigma,\omega}$ and error vector (ϑ_q, δ_q) may be written for driver *q* as:

$$L_q(\Omega_{-\sigma,\omega} \mid \vartheta_q, \delta_q) = G\left[g_q\left\{(\beta' + \vartheta_q')x_q\right\}\right] \times \left\{ G\left[\frac{\psi_k - b_q}{\pi_q}\right] - G\left[\frac{\psi_{k-1} - b_q}{\pi_q}\right]\right\}^{d_{qk}}, \qquad (2)$$

where *G*(.) is the cumulative distribution of the standard logistic distribution and d_{qk} is a dummy variable taking the value 1 if driver *q* sustains an injury of level *k* and 0 otherwise. Finally, the unconditional likelihood function can be computed for driver *q* as:

$$L_q(\Omega) = \int_{\vartheta_q} \left\{ \int_{\delta_q} (L_q(\Omega_{-\sigma,\omega} \mid \delta_q, \vartheta_q) d\Phi(\delta_q \mid \omega) \right\} d\Phi(\vartheta_q \mid \sigma), \qquad (3)$$

[6] It is possible that aggressiveness is endogenous to injury severity in the sense that there may be unobserved effects (such as weather conditions and poor visibility) that may affect aggressive driving behavior and injury severity sustained. Ignoring such correlations, as we have done here, can render the parameter estimates in the injury severity model inconsistent (see, for example, Eluru and Bhat, 2007). However, in the context of the current paper that focuses on the direct and indirect effects of aggressiveness on injury severity, accommodating such potential endogeneity leads to estimation and interpretational challenges.

where Φ is the multidimensional cumulative normal distribution of the appropriate dimension. Fortunately, the likelihood function above collapses to the product of two likelihoods, as follows:

$$L_q(\Omega)=\left\{\int_{\vartheta_q} G[g_q\left\{(\beta'+\vartheta_q')x_q\right\}]d\Phi(\vartheta_q\big|\omega)\right\}\times \\ \left\{\int_{\delta_q}\left(\left\{G\left[\frac{\psi_k-b_q}{\pi_q}\right]-G\left[\frac{\psi_{k-1}-b_q}{\pi_q}\right]\right\}^{d_{qk}}\Bigg|\delta_q\right)d\Phi(\delta_q\,|\,\omega)\right\} \tag{4}$$

The first component corresponds to a random-coefficients binary logit model, while the second corresponds to a random-coefficients heteroscedastic ordered response logit model. The log-likelihood function then corresponds to separate components for these two models. The multidimensional integrals may be evaluated using now well-established Halton-based simulation techniques (see Eluru and Bhat, 2007, Bhat, 2003, Bhat, 2001).

3.3 Model Application

In model application, the analyst may want to estimate the probability of participating in an aggressive act and incurring an injury of each severity level, given a set of driver and crash characteristics. This is needed to quantify the relative and absolute magnitudes of the effects of variables on aggressive driving behavior and injury severity levels, and can be useful to inform the design of countermeasures to reduce aggressive driving behavior and driver injury severity levels in crashes.

The probability that a driver will participate in an aggressive act may be computed using the following expression:

$$P(a_q=1)=\int_{\vartheta_q}\left\{G\left[\left\{(\beta'+\vartheta_q')x_q\right\}\right]d\Phi(\vartheta_q\,|\,\sigma)\right. \tag{5}$$

The probability that a driver will sustain an injury severity level of *k*, conditioned on participating in an aggressive act is:

$$P(y_q=k)\,|\,(a_q=1)=\int_{\delta_q}\left(\left\{G\left[\frac{\psi_k-b_q}{\pi_q}\right]-G\left[\frac{\psi_{k-1}-b_q}{\pi_q}\right]\right\}\Bigg|(a_q=1,\delta_q)\right)d\Phi(\delta_q\,|\,\omega) \tag{6}$$

Similarly, the probability that a driver will sustain an injury severity level of *k*, conditioned on not participating in an aggressive act is:

$$P(y_q = k) \,|\, (a_q = 0) = \int_{\delta_q} \Big(\Big\{ G\big[\psi_k - b_q\big] - G\big[\psi_{k-1} - b_q\big] \Big\} \Big| (a_q = 0, \delta_q) \Big) d\Phi(\delta_q \,|\, \omega) \tag{7}$$

The unconditional probability that a driver will sustain an injury severity level of *k* may be obtained as a probability mixture as follows:

$$P(y_q = k) = [1 - P(a_q = 1)] \cdot [P(y_q = k) \,|\, (a_q = 0)] + [P(a_q = 1)] \cdot [P(y_q = k) \,|\, (a_q = 1)] \tag{8}$$

This takes a latent segmentation form, where an individual is probabilistically assigned to the non-aggressive or aggressive regimes, and then the corresponding injury severity probabilities are applied for each regime. However, the important point is that, in estimation, we have a unique data set that provides direct information on whether or not a driver in the sample behaved aggressively prior to the crash, and so we are able to estimate each of the aggressiveness and injury severity models separately while allowing a rich and flexible structure for each model including scale heterogeneity between the aggressive and non-aggressive driving injuries.

4. THE DATA

4.1 Data Source

The data source used in this study is the National Motor Vehicle Crash Causation Study (NMVCCS). This dataset includes details of 6950 crashes involving light passenger vehicles (weighing less than 10,000 pounds) that occurred during the period January, 2005-December, 2007. A sound methodology approved by a panel of experts was used for data collection and recording. The NMVCCS researcher team was granted special permission from the local law enforcement and emergency responders to be at the site of crash immediately after it had been reported, and before the crash site was cleaned. In this manner, researchers could discuss crash details with the drivers, passengers and witnesses while it was still fresh on their minds and with as less bias as possible before other communications set in.

The NMVCCS researcher report of a crash provides much richer detail and information about the crash site and crash characteristics than does a traditional police report that forms the basis for most other national-level crash data bases. Further, the examination of police reports during the construction of these other data bases is undertaken several days or weeks after the crash event, bringing into question the reliability of the "pre-crash scenarios, critical pre-crash events, and the reason underlying the critical pre-crash events" (NHTSA, 2008). After a thorough evaluation of all interviews and crash site details, NMVCCS researchers were able to make informed decisions about the pre-crash events leading up to the crash, including whether or not each driver involved in the crash was participating in an aggressive act just prior to the crash.[7] As such, this indicator should be extremely reliable, given the scientific rigor of the data collection effort. The injury severity of each individual involved in the accident was collected by researchers on a five point ordinal scale: (1) No injury, (2) possible injury, (3) Non-incapacitating injury, (4) Incapacitating injury, and (5) Fatal injury.

4.2 Overview of the Sampling Design and Weighting Scheme

The target population for the NMVCCS data collection was "crashes that result in a harmful event and involve at least one light vehicle weighing less than 10,000 pounds that was towed due to damage." (see Choi *et al*., 2008 for complete details of the target population, sampling design, and weighting scheme). The sampling design used is rather complex, and it is infeasible to cover all specific details of the approach in this paper; rather, we will only provide an essential overview of the approach.

A two-dimensional sampling frame of 24 pre-determined geographic locations in the country (that formed the primary sampling units) and the time of crash occurrence was used in the crash sampling plan. The researchers selected combinations of geographic locations, time strips for monitoring emergency response communications, and days of week based on a systematic probability sampling plan proportional to the number of crashes coded in the National

[7] A driver is characterized as acting aggressively if s/he participates in one or more of the following: speeding, tailgating, changing lanes frequently, flashing lights, obstructing the path of others, making obscene gestures, ignoring traffic control devices, accelerating rapidly from stop, and stopping suddenly. Researchers considered the totality of all circumstances and considerations based on actual observations and interviews at the crash site to determine aggressive act participation. However, it is still possible that some drivers are mis-classified as participating in aggressive acts prior to a crash. Such mis-classification will, in general, lead to inconsistent estimates in the aggressive driving act binary choice model (where the mis-classification represents a form of measurement error in the dependent binary variable) as well as in the injury severity ordered-response model (where the mis-classification represents a form of measurement error in the independent aggressive driving act variable). Hausman *et al.* (1998) and Lewbel (2000) discuss the case of measurement error in the dependent variable in a binary choice model, while Edgerton and Jochumzen (2003) discuss measurement error in the independent variables in discrete choice models. While some correction mechanisms are discussed in these papers, the correction mechanisms themselves require some strong assumptions about the nature of mis-classification and/or become rather cumbersome.

Automotive Sampling System (NASS) – Crashworthiness Data System (CDS) in the previous year for that combination of geographic location, time strip, and day of week. Research personnel then monitored EMS/police radio frequencies for the selected combination of location, time strip, and day of week, and responded to all crashes until a crash eligible for NMVCCS was found in the time strip or the time strip expired. However, due to operational challenges, only crashes occurring between 6 am-12 midnight were considered by the NMVCCS team. Further, only those crashes that satisfied the following criteria were finally considered for inclusion in the data base:

1) Crash must have involved a vehicle on a roadway and resulted in property damage or injury.
2) EMS was dispatched to crash scene.
3) For crashes involving three vehicles or less, at least one of the vehicles involved in the crash was present at the site when researchers arrived; For crashes involving three vehicles or more, at least one of the first three vehicles involved in the crash was present at the site when researchers arrived.
4) At-least one of the vehicles involved in the crash (at least one of the first three vehicle involved in the crash if more than three vehicles were involved) was a light passenger vehicle that was towed (or was going to be towed as researchers left the site).
5) Police was at the site of crash when researchers arrived.
6) A detailed police accident report was available.

The final NMVCCS sample included in the data base after considering the above criteria was weighted to make it nationally representative of all crashes that involved the towing of at least one light vehicle (as coded in the current year in the NASS-CDS data base).[8] These weights are based on the inverse of the probability of inclusion of a crash based on the sampling procedure, further adjusted to account for missed crashes due to operational issues.

[8] Technically, the results of the current paper are applicable only to the case of driver injury in crashes where at least one vehicle was towed due to the damage. However, these are precisely the kinds of crashes that are more likely to lead to harmful injuries and substantial property damage, and which would be particularly worthwhile to seek to reduce. The NMVCCS data collection was approved by the US Congress to study the pre-crash events leading up to such harmful crashes and the development of possible countermeasures.

4.3 Sample Preparation and Characteristics

In the current research effort, we examine the aggressive act participation and injury severity of drivers of light passenger vehicles. The attention is on collision-related crashes, excluding non-collision crashes such as rolling over and skidding. We further consider only one vehicle crashes (collision with a fixed object) or two vehicle crashes (collision with another vehicle), which constitute nearly 86% of the total sample crashes. Several cleaning and screening steps were implemented for consistency and to remove crash observations with missing information. We then matched the dependent variable (*i.e.*, the car driver injury severity level) proportions in the resulting sample to the weighted version of the NMVCCS sample to obtain the final sample for the current analysis. This final analysis sample may be viewed as nationally representative of car driver injury severity levels incurred in crashes that involved at least one light vehicle being towed away from the crash scene.[9]

The final data sample includes 2315 driver crash observations. The aggressive act participation in this sample is as follows: participated in aggressive acts (7.5%) and did not participate in aggressive acts (92.5%). The distribution of driver injury severity levels in the crash data sample is as follows: no injury (45.4%), possible injury (24.4%), non-incapacitating injury (17.9%), incapacitating injury (10.9%), and fatal injuries (1.4%). Due to the very low share of fatal injuries in the sample, we combined the incapacitating injury category and the fatal injury category into a single "incapacitating and fatal injuries" category. The aggregate cross-tabulation of aggressive driving act participation and injury severity levels is presented in Table 1. The table shows a positive association between injury severity and aggressive driving behavior. The emphasis in the current research is to identify the group of people who are more likely to participate in aggressive acts, and accommodate the *indirect* effects (through aggressive act participation) and *direct* effects of exogenous factors on driver injury severity.

[9] Note that, in choice modeling, the exogenous sample maximum likelihood (ESML) procedure (*i.e.*, the usual maximum likelihood procedure based on a strictly random sample) is entirely appropriate to other samples as long as the dependent variable proportions in the sample match up to the corresponding population proportions. Whether the sample is also representative of the population on the exogenous variables or not is irrelevant. The reader is referred to Manski and Lerman (1977) and Cosslett (1981) for further details.

5. EMPIRICAL RESULTS

5.1 Variables Considered

The variables considered in the empirical analysis included driver characteristics, environmental/situational factors, vehicle characteristics, roadway design attributes, and crash characteristics.

Driver characteristics included driver demographics (age, sex and race) and driver alcohol and seat belt use. Environmental/situational factors related to the crash that were considered included day of the week, time of day (AM peak (6am-9am), midday (9am-3pm), PM peak (3pm-7pm), and evening (7pm-12pm)), lighting conditions (dawn, daylight, dusk, dark, and dark and lit), weather conditions (no adverse weather, rain, snow, and fog), whether traffic congestion was present at the time of the crash, and age distribution of any other vehicle occupants. The only vehicle characteristics included in the current study are the vehicle types involved in the crash (the vehicle types include passenger cars, sports utility vehicles, pickup trucks, and minivans). The roadway design attributes considered in the analysis are speed limit, type of roadway (divided two-way with positive barrier, divided two-way without positive barrier, one way, *etc*.) and number of lanes. Finally, the crash characteristics included if the vehicle rolled over, whether the crash was with a stationary object or another vehicle, the manner of collision in crashes with another vehicle (head-on, rear end, sideswipe and other), and the role of the driver's vehicle in crashes with another vehicle (*i.e.*, whether the driver's vehicle struck other vehicle, or the driver's vehicle was struck by the other vehicle, or both vehicles struck each other).[10]

In addition to the variables discussed above, we also considered several interaction effects among the variables in both the aggressive act participation and injury severity models. The final specification was based on a systematic process of removing statistically insignificant variables and combining variables when their effects were not significantly different. The

[10] Some variables such as seat belt use and vehicle type may be endogenous to driver injury severity, as discussed in Eluru and Bhat (2007) and Winston *et al.* (2006). In fact, one could argue that roadway conditions and roadway speed limits under which driving, night-time driving, and pretty much each and every other exogenous variable could potentially be endogenous. In fact, the endogeneity problem can be raised with any econometric model. But, in the process of practical modeling, the analyst needs to make judgments and assumptions regarding what may be considered exogenous variables. We suggest that an examination of potential endogeneity issues be a direction for future research in the injury severity area to provide meaningful guidance regarding which variables may be considered more endogenous than others.

specification process was also guided by prior research and intuitiveness/parsimony considerations. We should also note here that, for the continuous variables in the data (such as age and speed limits), we tested alternative functional forms that included a linear form, a spline (or piece-wise linear) form, and dummy variables for different ranges. Further, we tested the effects of the age variables at a very fine resolution of one year intervals between 16-20 years of age, given our empirical focus on young adults. However, if there were no statistically significant differences in some of the age effects (either as main effects or as interactions with other variables), the age categories were combined (this is the reason that the age variable may be retained at a fine resolution for some effects and in a somewhat coarser resolution for some other effects). Finally, random coefficients were extensively tested, and only those that turned out to be statistically significant were retained in the final specification.

The results of the aggressive participation act component and the injury severity component are presented in Tables 2 and 3, respectively**,** and are discussed in turn below. For the aggressiveness component, the results are based on post-crash data collection on aggressive behavior participation prior to the crash. The results for the injury severity model discussed below are conditional on the driver being involved in a crash.

5.2 Estimation Results

5.2.1 Aggressive Driving Behavior Component

The coefficients in Table 2 represent the effects of the variables on the latent aggressive driving act propensity a_q^*. Though we attempted several random coefficients on exogenous variables, none of these came out to be statistically significant. Thus, the final specification for the aggressive driving component of the model was a regular binary choice model.

An important point is in order here, and is a tangible side benefit of the aggressive driving behavior model collapsing to a simple binary logit model. From an econometric perspective, one would expect that the level of pre-crash aggressiveness based on data collected post-crash would be higher than the level of aggressiveness that may be observed in an unconditional field observation of driver aggressiveness (that is, a data collection effort regardless of whether there is a crash or not). This may suggest that the results of the aggressive driving component in this paper are not generalizable to the entire population of drivers. However, as long as the observation of pre-crash aggressive behavior in the post-crash data collection effort is objective (that is, not misclassified systematically based on values of “exogenous” variables), the only result of the post-crash data collection in terms of aggressive driving behavior is that the proportion of drivers classified as driving aggressively will likely be inflated relative to the proportion of drivers classified as driving aggressively from an unconditional field experiment.[11] But this inflation turns out to be innocuous for the estimation of the *relationship between exogenous variables and the binary aggressiveness indicator*, because of the binary logit structure for the aggressive act participation model in our empirical specification. In particular, it is well-established that all the parameters in a binary logit model (excepting the constant) are consistently estimated even when the sample is skewed in the dependent variable toward one alternative (see Manski and Lerman, 1977, Cosslett, 1981). Thus, the relationship between the exogenous variables and driver aggressiveness is indeed generalizable to the entire population under the conditions just discussed.

5.2.1.1 Driver Characteristics

The specific effects of the driver characteristics indicate that men, younger individuals, those not wearing a seat belt, those driving under the influence of alcohol, and those driving without a valid license are more likely to exhibit aggressive driving behavior compared to women, older individuals, those driving sober, and driving with a valid license, respectively (these results are consistent with those of earlier aggressive driving behavior studies such as Cohen and Einav, 2003, Shinar and Compton, 2004, and Dahlen and White, 2006). It is particularly interesting to note that there is a substantial difference in aggressive driving behavior within the category of young individuals. Teenagers in the 16-17 year age group are more likely to participate in aggressive driving acts than those in the 18-20 year category, who, in turn, are more likely to drive aggressively than those above 20 years. While earlier studies have identified young drivers as participating more in aggressive driving, most of these studies use broad categorizations of being “young”, such as “less than 45 years of age” (Beck *et al*., 2006, Vanlaar *et al*., 2008) or “less than 26 years of age” (Shinar and Compton, 2004), or teenagers versus non-teenagers

[11] In the NMVCCS data collection effort, substantial effort was expended on the methodology to classify drivers as being aggressive or not. In this regard, the opportunity to introduce subjective biases (such as a bias toward “marking” that a driver was behaving aggressively just because s/he was accompanied by young adults or because s/he was not wearing a seat belt) is rather small. That is, it is not unreasonable to assume that the pre-crash aggressive behavior classifications are not influenced by the circumstances surrounding the crash.

(Agerwala *et al.*, 2008). Our study indicates that such broad categories may mask variations within finer age groups, and reinforces the notion that the over-representation of 16-17 year old drivers in traffic crashes (see, for example, NHTSA, 2007 and Preusser and Leaf, 2003) is not simply due to lack of experience, but also because of aggressive driving acts. Of course, whether 16-17 year olds drive aggressively because they fundamentally underestimate the risk of being involved in a crash (due to a sense of invincibility from harm or due to optimism bias or simply as a way of insulating themselves from personal concerns; see Jasanoff, 1998; Arnett *et al.*, 2002, McKnight and McKnight, 2003), or because of an exaggerated sense of how good their driving skills are (Williams *et al*., 1995), or because of peer pressure related to bravado and braggadocio (Gray *et al*., 2008) is still a very open question for research. Ongoing research studies in the area of brain development, information processing/cognition mechanisms, motor skills development, and neuropsychological issues in teenagers through magnetic resonance imaging (MRI) and other techniques may provide safety specialists with more informed ways to communicate the dangers of aggressive driving to young drivers (NCHRP, 2007).

A better understanding of teenagers' neuropsychological and cognitive mechanisms would be particularly helpful given the result that young drivers (16-20 years of age), when under the influence of alcohol, are particularly likely to drive aggressively. A possible explanation for this result is that public self-consciousness nosedives for young adults under the influence of alcohol more so than for older individuals (individuals in a state of low public self-consciousness care less about what other people think about them). Previous studies have shown a positive association between low public self-consciousness and aggressive driving (see, for example, Millar, 2007). In any event, from the standpoint of countermeasures to reduce alcohol consumption and driving among young adults, it is clear that enacting laws making it illegal to sell alcohol to anyone below 21 years, as well as zero-tolerance laws making it an offense for young adults under 21 years to drive with any positive blood alcohol concentration (BAC), has not resolved away the issue of alcohol and young adult driving. This is one place where more awareness campaigns targeted toward young people about the existence and the consequences of zero tolerance laws, stricter enforcement and publicity about the law enforcement, and parental involvement may help (see Ferguson and Williams, 2002 and Simons-Morton *et al*., 2008). On the issue of parental involvement, Beck *et al*. (2002) have found that most parents were not aware of their teen's drinking and driving behaviors, and Simons-Morton *et al*. (2008) state that "many parents are less involved with their teens than they could be" and recommend intervention programs to motivate parents to be more proactive in managing their teens' driving habits, including imposing driving restrictions on their newly licensed teens.

5.2.1.2 Environmental and Situational Factors

Aggressive behavior participation is also influenced by environmental and situational factors. The increased aggressiveness behavior during the morning peak period (6am to 9am) is presumably a reflection of time pressures as several commuters try to reach their offices on time. As indicated by Shinar and Compton (2004), time pressures, when combined with traffic congestion, can cause driver aggressive behavior. The morning peak period is a perfect combination of the two. In our analysis, we also examined the effect of a traffic congestion dummy variable (as recorded by NMVCCS researchers to characterize traffic conditions at the time of the accident based on eyewitness accounts and personal observation) independent of time-of-day, but found no statistically significant effect of this variable on aggressive driving after including the 6-9 am dummy variable. The implication is that traffic congestion, by itself, does not trigger aggressive driving acts. This result is consistent with those of Parker *et al*. (2002), and Shinar and Compton (2004).

In the event of rain and/or sleet, drivers are likely to drive cautiously and participate less in aggressive acts, as borne out by the results in Table 2. Also, young adults (16-20 years of age) are more likely to pursue aggressive driving acts when accompanied by other young adults (16-20 years of age and without any adult supervision). This is consistent with earlier studies indicating that 16-17 year old drivers, when traveling with teenage passengers, are more likely to be fatally injured if in a crash (Chen *et al*., 2000, Williams, 2003). These earlier studies have suggested that teenage passengers may distract 16-17 year old drivers as well as encourage young drivers to participate in aggressive acts. Our study provides direct evidence for the aggressive driving hypothesis, and reinforces a similar finding by Simons-Morton *et al*. (2005). An important point to note is that we found both 16-17 year old drivers and 18-20 year old drivers to be equally likely to participate in aggressive driving acts when accompanied by other young passengers. Further, unlike earlier studies, we did not find any statistical difference in driver aggressive behavior based on the gender of the passengers or the number of passengers. The overall suggestion is that graduated driver licensing (GDL) programs should consider implementing a strict no-young adult passenger restriction for young drivers if one is not already in place. Further, most GDL programs last only until the age of 18 years, though our results suggest that young adults are likely to continue driving aggressively until about 20 years of age when accompanied by other young adults. Obviously imposing passenger restrictions beyond 18 years becomes close to impractical, but concerted education and awareness campaigns in the older age group of young adults may be considered.

5.2.1.3 Vehicle Characteristics

According to the results in Table 2, individuals driving vans are, in general, less likely to partake in aggressive driving acts than those driving other kinds of vehicles (sedans, sports utility vehicles, and pick-up trucks). Earlier results have shown that middle-aged adults with family and children are most likely to own and drive vans (see Bhat *et al.*, 2008). Such drivers tend to have more familial and financial responsibilities, which may make them act less aggressively when driving. However, in the group of young adults, those who drive a sports utility vehicle (SUV) or a pick-up truck (PUT) are likely to drive more aggressively than those who drive a sedan or a van. This is presumably because of the powerful engine capability combined with the versatile handling ability of SUVs and PUTs, which can lead to an increase in the young driver's adventure seeking behavior.

5.2.1.4 Roadway Characteristics

Aggressive driving is positively associated with driving on roads with low and high speed limits (relative to driving on roads with medium speed limits). Low speed limit loads are typically associated with lesser spacing between vehicles. Drivers can also feel more "boxed-in" on all sides when traveling on low speed roads. Both of these considerations may trigger aggressive driving behavior. The possible reasons for the increased likelihood of aggressive act participation on high speed roadways is not immediately apparent, and needs further examination in future research.

5.2.2 Driver's Injury Severity Component

Table 3 presents the results of the injury severity component (the coefficients represent the effects of the variables on the latent propensity y_q^* associated with injury severity). The results are discussed by variable group below.

5.2.2.1 Aggressive Driving Act Participation-Related Variables

The coefficient on the aggressive driving act indicator is positive, implying that aggressive driving is a clear contributor to the severity of injuries in crashes. While earlier studies have provided suggestive evidence of the relationship between aggressive driving and crash injury severity level using aggregate statistics, to our knowledge, ours is only the second study to show this conclusively at the individual crash level (the first being the very recent study by Nevarez *et al.*, 2009). Our study also considered the potential moderating effect of aggressive driving on the impact of other exogenous variables on injury severity level (see the introduction section for a discussion). However, the results indicated that the only moderating variable is the age of the driver, with young individuals (16-20 years of age) who pursue aggressive driving acts more likely to end up with crash-related serious injuries than those above 20 years of age. This result lends support to our hypothesis earlier that the driving inexperience of young individuals, when combined with aggressive driving, is a volatile combination because inexperienced in driving implies not knowing how to react to decrease injury severity as a crash caused by aggressive driving starts to develop.

An important empirical result from our analysis is regarding scale heterogeneity of the error term ξ_q. The scale π_q is normalized to 1 for identification for those not participating in an aggressive driving act, but is estimated for those participating in an aggressive driving act. The scale is estimated to be 0.5979, with a t-statistic of 4.81 (relative to the null hypothesis that it is equal to 1; that is, relative to the null hypothesis that the scale is not different between the groups of aggressive and non-aggressive drivers). The high t-statistic reported in Table 3 for the scale is a clear indication that those who partake in aggressive acts just before a crash are uniformly more likely to sustain severe injuries than other drivers. Put another way, by driving aggressively, individuals reduce their margin of good luck of getting out of a crash relatively unscathed.

5.2.2.2 Driver Characteristics

The impact of driver characteristics show variations based on demographics, seat belt use and alcohol influence. Specifically, men are, in general, less likely to sustain severe injuries compared to women, though our results show unobserved variation in the impact of driver gender on injury severity, as reflected by the high value of the standard deviation on this coefficient. Further, young drivers are generally likely to sustain less severe injuries compared to older adults, with young adults (16-20 years of age) being the least likely to be severely injured. These results are similar to those reported in earlier studies of injury severity (see, for example, O'Donnell and Connor, 1996; Kim *et al*., 1994; Srinivasan, 2002; and Eluru and Bhat, 2007), but with one very important difference. As indicated in the introduction section of this paper, the results from the earlier injury severity studies regarding gender/age effects would suggest that countermeasures should focus on reducing injury severity particularly for female drivers and older drivers. However, our study controls for driving aggression. As discussed in Section 5.2.1, male and younger drivers are more likely to partake in aggressive driving acts than female and older drivers, respectively. Thus, there is an *indirect* positive effect of being male and young on injury severity (through aggressive driving behavior) and a remaining *direct* negative effect of being male and young on injury severity (as estimated by the coefficients on these variables in Table 3). We disentangle these two separate effects in the current paper, while earlier studies combine these two and underplay the need for targeted defensive driving campaigns aimed at young drivers in the context of reducing crash injury severity.

The positive effects of seat belt non-use and being under the influence of alcohol are consistent with earlier findings. However, these variables also have "*indirect*" effects through the aggressive driving act variable, which we control for. Thus, the results in Table 3 provide the "*direct*" effects of these variables.

5.2.2.3 Environmental and Situational Factors

In the category of environmental and situation factors, the results of the number of passengers and "all passengers young" variables need to be considered together. The safest situation (the base situation in Table 3) from a driver injury standpoint is when there are 2 or more passengers in the vehicle, at least one of whom is above the age of 20 years. The results also indicate that it is safer for drivers (of any age) to have two or more young passengers (<20 years of age) than to have a single young passenger. Note that the injury severity propensity effect for two or more young passengers, relative to the base situation is 0.3401, while the corresponding effect for a single young passenger is 0.6831 (=0.3430+0.3401). Also, note that these effects of young passengers may be attributed to a *direct* distraction-related effect because of which drivers may not see a crash developing and may not take last-minute evasive actions to reduce injury severity (because we have already controlled for the aggressive act variable). In this context, a single young passenger may distract the driver more through engaging in conversation or trying to draw attention, while having more than one young passenger may allow the young passengers to keep each other occupied. The results in Table 3 regarding the number/age of passengers, when combined with the results from Table 2, also have important implications for graduated driver licensing programs, as we discuss later. Another rather intriguing result is that, for drivers of any age, it is safer to have two or more young passengers than to be driving alone, perhaps attributable to boredom and/or sleep-related reasons. The same reason may underlie the result that, for drivers of any age, having an adult passenger is safer than driving alone. Overall, though, having a single young passenger poses the greatest risk of high crash-related injury severity for drivers of any age, and particularly for young drivers (16-20 years of age).

The presence of traffic congestion and adverse weather conditions (rain or sleet) at the time of the crash reduces injury severity level, possibly due to low prevalent speeds at the time of the crash.

5.2.2.4 Vehicle Characteristics

There are "*direct*" effects of the type of the driver's vehicle and the vehicle type of the other vehicle involved in two-vehicle crashes. Specifically, drivers in an SUV are, in general the safest, while those driving a pick-up are at the greatest risk to sustain severe injury. Of course, the injury severity sustained by a driver in an SUV relative to other vehicles is moderated by unobserved factors, as reflected in the statistically significant standard deviation on the SUV coefficient. Between sedan and vans, vans appear to be safer. When the results of Table 3 are combined with the *indirect* effect of vehicle type through the aggressiveness driving act variable, the implication is that a pick-up truck in the driving hands of a young adult is particularly dangerous, since young adults are more predisposed to aggressive acts, as well as are more likely to be injured severely in a crash, when driving a pick-up. The reverse is the case for vans in the hands of young adults, due to a complementary negative *indirect* and *direct* effect on injury severity. Also, compared to sedans, SUVs in the hands of young adults seems to engender more aggressive driving, but also reduces driver crash injury severity. The overall impact of sedans versus SUVs will be based on a combination of the *direct* and *indirect* effects.

The vehicle type effects relating to the colliding vehicle in two-vehicle crashes suggest that, in general, drivers who are involved in a crash with an SUV or a van have a higher injury severity propensity compared to a crash involving a sedan or a pick-up truck. However, there is substantial variation in the injury severity propensity when struck by an SUV, with the injury severity propensity being higher (than when a sedan/pick-up is involved) in 87% of crashes and lower in 13% of crashes.

5.2.2.5 Roadway Characteristics

The roadway design attributes considered in the current analysis are speed limit and cross-section design elements of the roadway (whether a divided two-way with barrier, divided two-way without barrier, or one way roadway, and number of lanes). However, the only variable that turned out to be statistically significant was the roadway speed limit. The results indicate that, as expected, driver injury tends to be less severe for crashes on low speed limit roads (< 50 km/h).

5.2.2.6 Crash Characteristics

Several crash characteristics are strong determinants of injury severity. As expected, a driver in a vehicle that rolled over is likely to sustain severe injuries. The "type of collision in two vehicle crashes" and "crash with a stationary object" group of variables needs to be considered together. The results indicate that, on average, rear-end collisions and sideswipe/angled crashes with another vehicle are the least dangerous, while head-on collisions with another vehicle are the most dangerous, followed by crashes with a stationary object (such as a concrete traffic barrier, post, pole, culvert, ditch, trees, *etc*.). Also, crashes with a stationary object tend to be more dangerous to a novice driver (16 years old) than to other drivers, and rear-end collisions with another vehicle are more dangerous to young drivers (16-20 years of age) relative to their older peers. There is also a large standard deviation of the "sideswipe or angle" collision type coefficient; the mean and the standard deviation of this coefficient imply that, in a majority of cases (83%) when a young driver is not involved, angle crashes involving two vehicles are less severe than single vehicle crashes with a stationary object. But, about 17% of the time, ‘sideswipe or angle” crashes lead to higher injury severity than single vehicle crashes with stationary object. Finally, in the set of crash characteristics, the “vehicle role in two vehicle crashes” set of variables suggests a higher injury severity level if the driver is struck, or is struck and strikes another vehicle, relative to striking another vehicle.

5.2.2.7 Threshold Parameters The threshold parameters map the injury severity latent index to the reported injury severity categories. As such, they do not have any substantive interpretation.

5.2.3 Likelihood-Based Measures of Fit

The log-likelihood value at convergence of the complete model system is -3218.93. As indicated in Section 3.2, this value is the sum of the individual log-likelihood values for the aggressive driving act binary choice model and the random coefficients injury severity ordered-response injury severity model. The corresponding value for the “constants only” model with only the constant in the aggressive act binary choice model and only the three thresholds in the injury severity ordered logit model is -3550.81. Clearly, one can reject the null hypothesis that none of the exogenous variables provide any value to predicting aggressive act behavior and injury severity propensity at any reasonable level of significance (the likelihood ratio statistic returns a value of 663.8, which is larger than the table chi-squared value with 47 degrees of freedom at almost a zero p-value). Further, the model system can be compared with one that ignores the driving aggressiveness variable in the injury severity model. The likelihood ratio statistic for testing the absence of any moderating or *direct* effect of aggression on injury severity, as well as the absence of scale effects associated with aggressiveness, is 29.82 which is higher than the chi-squared statistic with three degrees of freedom at even the 0.000002 p-value.

5.3 Elasticity Effects

The parameters on the exogenous factors in Tables 2 and 3 do not directly provide the magnitude of the effects of the factors on the probability of participating in an aggressive driving act and sustaining a given injury severity level, respectively. To do so, we compute elasticity effects to discern the magnitude and direction of variable impacts.[12]

5.3.1 Aggressive Behavior Elasticity Effects

We compute aggregate level elasticity effects of each dummy exogenous variable in the aggressive driving model (all exogenous variables in this model are dummy variables) by changing the value of the variable to one for the subsample of observations for which the variable takes a value of zero and to zero for the subsample of observations for which the variable takes a value of one. We then sum the shifts in expected aggregate shares in the two subsamples after reversing the sign of the shifts in the second subsample, and compute an effective percentage change in expected aggregate shares in the entire sample due to change in the dummy variable from 0 to 1. Note that the probability of being involved in an aggressive act just prior to the crash is provided by Equation (5). This can be used in a straight-forward fashion to compute the aggregate "elasticity effects" of variables on aggressive driving act participation.

Table 4 provides the elasticity effects for aggressive driving behavior. To our knowledge, this is the first study to estimate the magnitude of effects of several observable variables on aggressive driving probability. Besides, unlike earlier studies, we use a fine categorization of age until 20 years. The numbers in Table 4 may be interpreted as the percentage change in the probability of participating in aggressive act due to a change in each exogenous variable from 0 to 1. For instance, the first number in the table indicates that the probability of a man driving aggressively is about 55% higher than the probability of a woman driving aggressively, other characteristics being equal. The results reveal that individuals who are 16-17 years of age are about 368% more likely (or, equivalently, about 4.5 times more likely) than those 65 years of age to participate in aggressive driving behavior, while 18-20 year olds are about 195% more likely (about 3 times more likely) than those 65 years or more of age to pursue aggressive driving behavior. Those in the age group of 21-65 years are also about twice as likely to drive aggressively as those above 65 years of age. Another important determinant is whether the driver is under the influence of alcohol or not. Specifically, the probability of a drunk driver being

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[12] The elasticity measure computed here is a kind of a "pseudo-elasticity" measure that determines the aggregate percentage change in the probability of a injury severity category due to a change in a dummy variable from 0 to 1 for each (and all) observations.

aggressive when driving is 285% higher than (or about 4 times) the probability of a sober driver being aggressive when driving. Overall, and as indicated earlier, there is a clear need for awareness campaigns and very strict enforcement (including delays in full licensing, as adopted by some States such as California, Illinois, Texas, *etc.* in their GDL programs) targeted toward young people (and their parents) regarding drinking and driving. Other variable effects in Table 4 may be similarly interpreted and are self-explanatory. These are all consistent with the discussion in Section 5.2.1.

5.3.2 Injury Severity Elasticity Effects

The aggregate-level elasticity effects for the variables in the injury severity model can be computed in a fashion similar to the procedure for the aggressive driving model. However, to clearly bring out the distinction between the *indirect* and *direct* effects of exogenous variables, we use a different procedure to present the "elasticity effects" for the injury severity model (note again that the *indirect and direct* effects discussed here are with respect to aggressive driving behavior prior to the crash). In particular, we first develop a synthetic profile of a person/crash combination with the following attributes: Female, age 16-17 years, seat belt used, not under the influence of alcohol, has valid license, not traveling during the 6-9 AM time period and not traveling under congested traffic conditions, not traveling during adverse weather conditions, driving a pick-up truck with 2 or more passengers and at least one adult passenger on a road, involved in a rear-end collision with a pick-up truck that strikes the driver's pick-up truck on a road with a speed limit between 50 kmph and 90 kmph (we focus on the 16-17 year age category in this section to illustrate the implications for graduated driving licensing or GDL programs). Next, we compute the probability of each injury severity level for this combination using Equation (8). Then, we change each of the variables from the base condition to an altered state (such as seat belt used to seat belt not used) without changing any other variable (except that, when the 6-9 AM travel variable "fires up", so does the traffic congestion variable). The percentage difference in the probability for each variable provides the *total* elasticity effect for that variable. Note that these are univariate elasticity effects, based off the synthetic profile. Thus, for example, the elasticity effect for a male driver would provide the percentage increase in probability for each injury severity level because of being a male relative to a female for 16-17 year olds, who use seat belts, are not under the influence of alcohol, and so on. Of course, the model can provide the injury severity level probabilities for any combination of variables, but we restrict ourselves to univariate elasticities for presentation ease. However, we partition the *total* elasticity effect into an *indirect* effect through the driving aggressiveness influence and a *direct* effect. To compute the *indirect* effect, we change each exogenous variable as earlier. Then, using Equation (8), we compute the probability of each injury severity level, but only allowing the probability of aggressiveness/non-aggressiveness to change in Equation (8), while holding the conditional probabilities $[P(y_q = k) | (a_q = 0)]$ and $[P(y_q = k) | (a_q = 1)]$ unchanged. The resulting percentage change in probability from the base situation for each injury severity level then provides the *indirect* effect of the exogenous variable solely through the aggressiveness impact (note that, for a variable that does not appear in the aggressiveness equation, the *indirect* elasticity is zero). Finally, the implied *direct* elasticity may be computed as the difference between the total elasticity effect and the *indirect* elasticity effect.

Table 5 provides the elasticities. To conserve on space, we present the elasticity effects only for the most serious injury category of "incapacitating/fatal" (IFA) injuries. The values in the first row may be interpreted as follows. Men are about 6% (5.96% in the table) more likely to incur IFA injuries in a crash relative to females because of their aggressive driving behavior. But they are also about 27% (26.76% of the table) less likely to sustain IFA injuries after controlling for aggressive driving behavior. The total elasticity effect indicates that men are about 21% (20.80% in the table) less likely to be severely injured relative to women. Other estimates may be similarly interpreted. Some important observations from the table are as follows:

- The vehicle type of the driver is the single most important determinant of injury severity, with a 16-17 year old driver in a non-pick-up vehicle being about 100% (or two times) less likely to incur severe injuries in a crash compared to a 16-17 year old driver in a pick-up vehicle. Other important determinants include head-on crashes, crashes with fixed object, roll-over crashes, driving without a seat belt, and driving while drinking.
- Traveling with a single young passenger poses the greatest risk of high crash-related injury severity for 16-17 year old drivers. It is more dangerous than driving alone or having two young passengers (as also discussed in Section 5.2).
- The indirect effects of variables contribute quite significantly to the total effect for several exogenous variables. For instance, the results suggest that aggressive driving behavior due to

driving under the influence of alcohol is more to blame for severe injuries in DWI crashes than the slower reaction time caused by being in an inebriated state.

- 16-17 year old drivers with young passengers are more likely to be severely injured in crashes because of increased participation in aggressive driving acts (as characterized by the indirect effect) as well as because of distraction effects (as characterized by the direct effect). There is a drop in the overall probability of severe injury when there are two or more young passengers rather than one young passenger, attributable to less distraction effects (see the lower direct elasticity effect for two young passengers compared to one young passenger).

6. CONCLUSIONS

In this paper, we capture the moderating effect of aggressive driving behavior while assessing the influence of a comprehensive set of variables on car driver injury severity. In doing so, we are able to account for the *indirect* effects of variables on car driver injury severity through their influence on aggressive driving behavior, as well as the *direct* effect of variables on car driver injury severity. Injury severity "reduced form" models that do not consider such *indirect* and *direct* effects of variables can provide inadequate/misinformed guidance for policy interventions.

The methodology used in the paper to accommodate the moderating effect of aggressive driving behavior takes the form of two models – one for aggressive driving and another for injury severity. These are appropriately linked to obtain the *indirect* and *direct* effects of variables. Once estimated, the model can be used in prediction mode without having any information on aggressive driving. The data for estimation is obtained from the National Motor Vehicle Crash Causation Study (NMVCCS), which includes a binary indicator for whether an individual was driving aggressively just prior to a crash in addition to an ordinal-level characterization of the injury severity level sustained by drivers involved in the crash. From an empirical standpoint, an emphasis of the current research is on examining the effects of age on car driver injury severity. In particular, though we consider all age groups represented in the crash data, we consider a very fine age categorization until 20 years of age when examining age effects on aggressive driving behavior and injury severity.

There are several important results from the empirical analysis. First, young drivers (especially novice drivers between 16-17 years of age), drivers who are not wearing seat belt, under the influence of alcohol, not having a valid license, and driving a pickup are found to be most likely to behave aggressively. The results provide direct evidence that the over-representation of 16-17 year old drivers in traffic crashes (and serious traffic crashes) is not simply due to lack of experience, but also because of aggressive driving acts. Further, young drivers (16-20 years of age), when under the influence of alcohol, are particularly likely to drive aggressively. A better understanding of teenagers' neuropsychological and cognitive mechanisms would be helpful to design countermeasures to reduce aggressive driving in young individuals. For now, perhaps more awareness campaigns targeted toward young people about the existence and the consequences of zero tolerance laws, stricter enforcement and publicity about the law enforcement, and promoting parental involvement would help. Second, situational, vehicle, and roadway factors such as young drivers traveling with young passengers, young drivers driving an SUV or a pick-up truck, driving during the morning rush hour, and driving on roads with high speed limits are also found to trigger aggressive driving behavior. Unlike some earlier studies, we did not find any statistical difference in driver aggressive behavior based on the gender of the passengers or the number of passengers. Third, our results clearly indicate the positive relationship between aggressive driving and crash injury severity level. This relationship is particularly strong for young individuals (16-20 years of age), lending support to the hypothesis that the driving inexperience of young individuals, when combined with aggressive driving, is a volatile combination. Also, by driving aggressively, individuals reduce their "margin of good luck" of getting out of any crash relatively unscathed. Fourth, the same exogenous variable may have different effects on injury severity because of *indirect* effects and *direct* effects. For instance, males, young drivers, those driving an SUV, and those driving on low speed roads (<50 kmph) are more likely to partake in aggressive driving acts than females, older drivers, those driving a sedan, and those driving on medium speed roads (50-90 kmph), respectively. However, males, young drivers, those driving an SUV, and those driving on low speed roads, after controlling for their aggressive driving behavior, are also likely to incur less severe crash-related injuries than females, older drivers, those driving on medium speed roads, and those driving a sedan, respectively. On the other hand, the same exogenous variable may also have the same direction of *indirect* and *direct* effects on injury severity, such as in the case of seat belt non-use, driving under the influence of alcohol, having young passengers, driving a pick-up truck, driving a van, and adverse weather conditions. The current analysis disentangles these two separate effects. Not doing so can lead to a masking of the two separate effects, and can lead to misinformed countermeasure strategies and policies. Fifth, the safest situation from a driver injury standpoint is when there are 2 or more passengers in the vehicle, at least one of whom is above the age of 20 years. The most dangerous situation from a driver injury standpoint is when there is a single young passenger in the vehicle. Further, it is safer for drivers (of any age) to have two or more young passengers (<20 years of age) than to have a single young passenger, and to have one or more adult passengers rather than driving alone. The latter result may be used as another element of an information campaign to promote carpooling to work and other activities, as a means to reduce traffic congestion. Sixth, pick-up trucks appear to be more dangerous in terms of injury severity in crashes relative to sedans, vans, and SUVs, a result that needs more exploration in future studies. Seventh, in general, rear-end collisions and sideswipe/angled crashes with another vehicle are the least dangerous, while head-on collisions with another vehicle are the most dangerous, followed by crashes with a stationary object (such as a concrete traffic barrier, post, pole, culvert, ditch, trees, *etc*.). Also, crashes with a stationary object tend to be more dangerous to a novice driver (16 years old) than to other drivers, and rear-end collisions with another vehicle are more dangerous to young drivers (16-20 years of age) relative to their older peers.

The results also have direct implications for graduated driving licensing (GDL) programs. First, drinking and driving is a particularly volatile mixture for young adults, and parental lack of involvement may be a contributing factor (Simons-Morton *et al*., 2008). As part of the GDL program, it may make sense to require parents also to go through a short (perhaps community-based) course, motivating them to be proactive in managing their teens' driving habits, including imposing driving restrictions on their newly licensed teens. Second, our results suggest that young adults are likely to continue driving aggressively until about 20 years of age when accompanied by other young adults. Obviously imposing passenger restrictions beyond 18 years becomes close to impractical, but concerted education and awareness campaigns in the older age group of young adults may be considered. One option would be to allow full licensing at 18 years, but with the restriction that students should undertake a "refresher" course regarding defensive driving within a year. Such a multi-stage driver education approach would align well with the notion that "the part of the brain responsible for decision making and impulse control does not fully mature until the mid-20s" (Giedd, 2004; NCHRP, 2007). Third, our results indicate that the morning rush hour (6-9 AM) is a period when drivers tend to be more aggressive-prone, presumably due to time pressures to reach offices/schools on time, combined with closer vehicle spacings. The morning period has also been shown in the literature to be the time that teenagers tend to be excessively sleepy because of late sleep patterns and adolescent biological considerations (see Wolfson and Carskadon, 2003 and Millman, 2005). Thus, GDL programs may consider prohibiting school driving during the entire GDL period (until 18 years of age). Fourth, as per the finding from this study, a single young passenger poses the greatest risk of high crash-related injury severity for drivers of any age (relative to driving alone or with one or more adult passengers or even with 2 or more young passengers). This suggests that GDL programs prohibit drivers from carrying a single young passenger, regardless of whether or not the young passenger is a family member. Many states, on the other hand, allow one young passenger and/or allow one young family member as part of their GDL programs, potentially because of concerns that (a) driving alone may not be safe for young women or (b) placing passenger restrictions may imply more young drivers on the road with its own consequent risks, or (c) parents may not support this and may not assist in enforcing this. However, as indicated in NCHRP (2007), there is no documented empirical evidence of the detrimental effects of strict passenger restrictions. Fifth, there is clear evidence in our results that, in the group of young adults, those who drive a pick-up truck (PUT) are likely to drive aggressively as well as be involved in serious injuries if in a crash. The overall effect of driving a PUT relative to other vehicle types is the single most important determinant of crash-related injury severity for all individuals and particularly for young adults. This information should be communicated to parents as part of the GDL program, even if an outright ban on the use of pick-up trucks during the GDL period is impractical. Also, crashes with a stationary object tend to be more dangerous to a novice driver (16 years old) than to other drivers, and rear-end collisions with another vehicle are more dangerous to young drivers (16-20 years of age) relative to their older peers. These results suggest that GDL programs related to the in-car portion of the training emphasize issues associated with perceiving and noticing hazards, in addition to training on motor vehicle operation and control skills.

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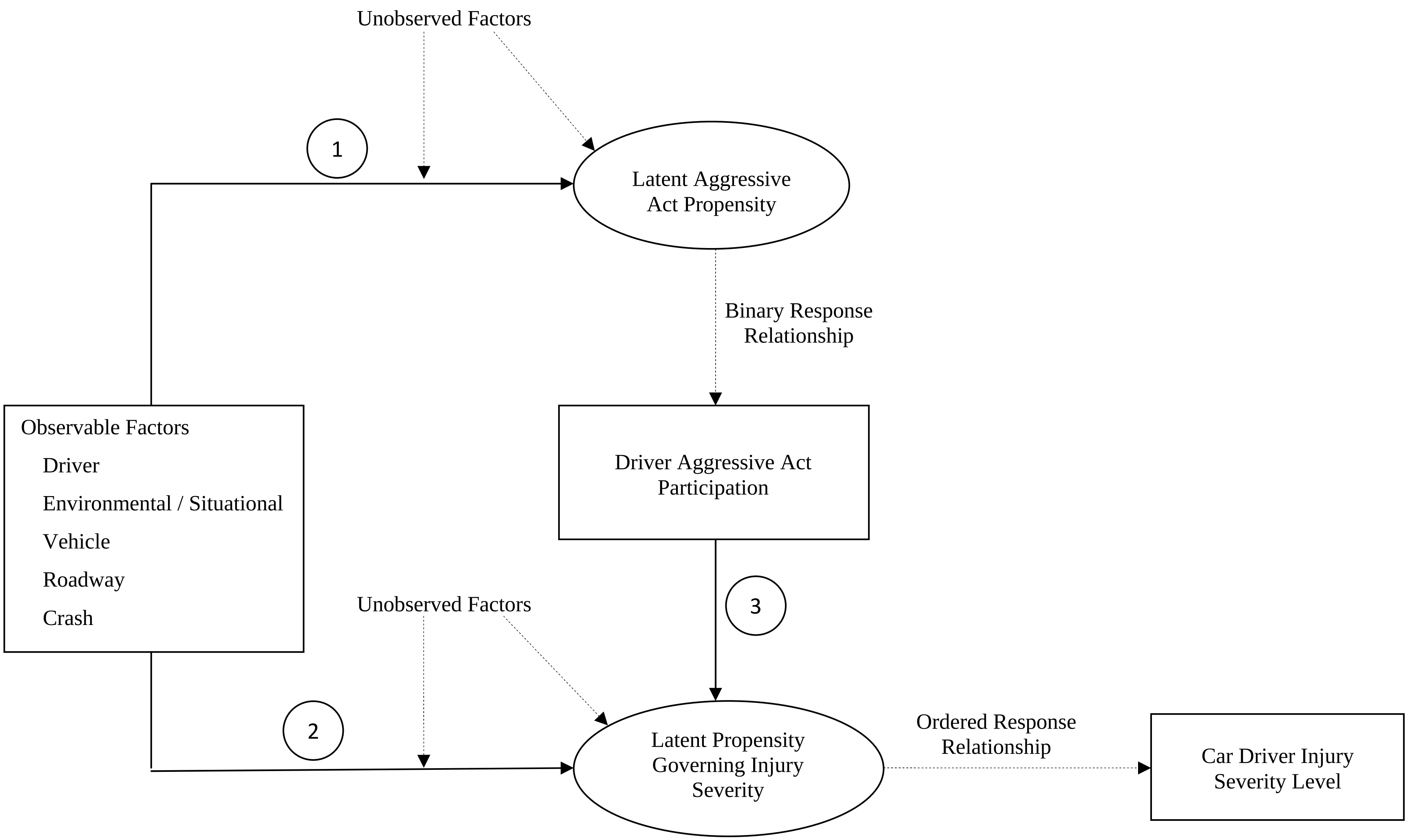

Figure 1 Conceptual Framework

Table 1 Cross Tabulation of Driver's Aggressive Behavior and Injury Severity Level

Injury Severity	Percentage of Driver Participation in Aggressive Acts	
	No	Yes
0	46.8	28.3
1	24.2	27.2
2	16.9	30.6
3	12.1	13.9

Table 2 Estimates of Aggressive Behavior Component

Variables	Coefficient	t-stats
Constant	-4.5039	9.73
Driver Characteristics		
Male driver (Base is female)	0.6795	3.59
Age of the driver (Base is age >65 years)		
16 or 17 years	1.8229	3.28
18-20 years	1.4194	2.72
21-65 years	1.1242	2.39
Seat belt not used	0.5462	2.15
Under the influence of alcohol	1.5031	5.18
Under the influence of alcohol*16-20 year driver	1.5549	1.76
Does not have a valid license	0.5294	2.11
Environmental/Situational Factors		
6:00 am to 9:00 am	0.3928	1.94
Rain and/or sleet	-0.7318	-1.75
Both driver and passengers aged between 16 and 20 years	0.9003	2.74
Vehicle Characteristics		
Van	-1.2622	-2.60
Non sedan*16-20 year driver	1.5666	2.44
Roadway Characteristics (Base is medium speed limit (50-90 km/h))		
Low speed (<50 km/h)	0.2595	1.26
High speed (>90 km/h)	0.5274	2.05
Number of Observations	2315	
Log-likelihood with only constant	-615.10	
Log-likelihood at convergence	-548.00	

Table 3 Estimates of Injury Severity Component

Variables	Coefficient	t-stats
Moderating Effect of Aggressive Behavior		
Aggressive driving indicator	0.3797	2.76
Aggressive driving*(16-20) year driver	0.4602	1.68
Scale		
Aggressive drivers (t-statistic computed with respect to value of 1)	0.5978	4.81
Driver Characteristics		
Male	-0.5172	-5.54
Standard Deviation	0.7335	3.45
Seat belt not used	0.9736	3.69
Seat belt not used*Male	0.6609	1.92
Under the influence of alcohol	0.4719	2.38
Age variables (age < 21 years is base)		
21-65 years	0.2991	2.16
>65 years	0.4781	2.66
Environmental & Situational Factors		
Number of passengers (Base is 2 or more passengers)		
No passengers	0.5710	3.62
One passenger	0.3430	2.14
All passengers are young	0.3401	2.22
Traffic congestion present	-0.4059	-2.28
Rain or sleet	-0.3753	-2.37
Vehicle Characteristics (Base is pickup)		
Sedan	-2.9361	-3.22
SUV	-6.5266	-3.55
Standard Deviation	2.9536	2.14
Van	-3.2438	-3.52
Vehicle type of colliding vehicle (Base is sedan or pickup)		
Struck by an SUV	1.2592	4.50
Standard Deviation	1.1027	1.95
Struck by a van	0.6278	4.14
Roadway Characteristics		
Low speed (<50 km/h)	-0.1901	-1.82

Table 3 Estimates of Injury Severity Component (continued)

Variables	Coefficient	t-stats
Crash Characteristics		
Vehicle rolled over	0.9633	6.00
Type of collision (Base is rear-end type of crashes)		
Head on	2.2554	9.61
Sideswipe or angle	0	-
Standard Deviation	1.2342	2.88
Other	0.6388	4.93
(16-20) year driver involved in rear end crashes	0.5675	1.80
Crash with stationary object (Base is crash with another vehicle)		
Fixed object	1.1976	7.27
16 year old driver involved in a crash with fixed object	0.5510	1.32
Role of vehicle in two vehicle crashes (Base is driver strikes other vehicle)		
Driver struck by a vehicle	0.2726	2.64
Driver involved in strike and struck	0.8818	5.13
Threshold Parameters		
Threshold 1	-1.6935	-1.80
Threshold 2	-0.4354	-0.46
Threshold 3	0.9280	0.99
Number of observations	2315	
Log-likelihood with only thresholds	-2935.69	
Log-likelihood at convergence	-2670.93	

Table 4 Elasticity Effects for Driver Aggressive Behavior

Variables	Aggressive
Driver Characteristics	
Male driver (Base is female)	54.48
Age of the driver (Base is age >65 years)	
16 or 17 years	368.22
18-20 years	194.85
21-65 years	84.59
Seat belt not used	55.10
Under the influence of alcohol	285.62
Does not have a valid license	52.92
Environmental/Situational Factors	
6:00 am to 9:00 am	36.51
Rain and/or sleet	-49.11
All passengers are young	23.99
Vehicle Characteristics	
SUV	56.08
Van	-43.27
Pickup	56.04
Roadway Characteristics (Base is medium speed limit (50-90 km/h))	
Low speed (<50 km/h)	23.27
High speed (>90 km/h)	52.36

Table 5 Elasticity Effects for "Incapacitated/Fatal" Injury Category

Variables	Indirect	Direct	Total
Driver Characteristics			
Male	5.96	-26.76	-20.80
License	4.26	0.00	4.26
Seat belt not used	4.95	41.75	46.70
Under the influence of alcohol	37.44	21.05	58.49
Age variables (Base is age 16 to 17 years)			
18-20 years	-2.32	0.00	-2.32
21-65 years	-6.14	-14.23	-20.37
> 65 years	-7.40	-4.84	-12.24
Environmental & Situational Factors			
Number of young passengers (Base is driving with 2 or more passengers at-least one of whom is an adult)			
Driving alone	0.00	26.67	26.67
Driving with one young passenger	8.30	30.68	38.98
Driving with one adult passenger	0.00	16.45	16.45
Driving with 2 young passengers	8.30	16.30	24.60
Time of day and traffic conditions (Base is off peak without traffic congestion)			
6:00 am to 9:00 am and traffic congestion present	3.08	-20.45	-17.37
Evening peak traffic congestion present	0.00	-20.05	-20.05
Weather conditions (Base is normal conditions)			
Rain or sleet	-3.87	-18.19	-22.06
Vehicle Characteristics (Base is pickup)			
Sedan	-4.37	-87.00	-91.37
SUV	0.00	-99.74	-99.74
Van	-2.49	-91.25	-93.74
Vehicle type of colliding vehicle (Base is sedan or pickup)			
Struck by an SUV	0.00	52.16	52.16
Struck by a van	0.00	29.03	29.03

Table 5 Elasticity Effects for "Incapacitated/Fatal" Injury Category (continued)

Variables	Indirect	Direct	Total
Roadway Characteristics (Base is Medium Speed Limit 50-90 km/h)			
Low speed limit (<50 km/h)	1.90	-9.58	-7.68
High speed limit (>90 km/h)	4.40	0.00	4.40
Crash Attributes			
Vehicle rolled over	0.00	42.32	42.32
Type of collision (Base is rear-end type of crashes)			
Head on	0.00	64.4	64.4
Sideswipe or angle	0.00	-26.4	-26.4
Other	0.00	3.59	3.59
Crash with stationary object (Base is crash with another vehicle)			
Fixed object	0.00	50.1	50.1
Role of vehicle in two vehicle crashes (Base is driver struck by other vehicle)			
Driver in the striking vehicle	0.00	-13.46	-13.46
Driver involved in strike and struck	0.00	28.17	28.17