The Thesis committee for Rajesh Paleti Ravi Venkata Durga Certifies that
this is the approved version of the following thesis:

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

APPROVED BY

SUPERVISING COMMITTEE:

Supervisor: _____

Chandra R. Bhat

_____

Steven T. Waller

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

by

Rajesh Paleti Ravi Venkata Durga, B.Tech.

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2009

Dedicated to

My family

Acknowledgements

I am heartily thankful to my advisor Dr Chandra Bhat for his encouragement, guidance and support for the past year and half and without him this thesis would not be possible.

I would like to thank Naveen Eluru for his help throughout my stay at University of Texas at Austin. I would also like to thank my brother Chaitanya and my friend Vamsi for providing me support and wonderful moments to cherish throughout my life.

Finally, I am very indebted to my family for their constant support and encouragement without whom I would not be where I am today.

ABSTRACT

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

Rajesh Paleti Ravi Venkata Durga, MSE

The University of Texas at Austin, 2009

Supervisor: Chandra R. Bhat

In this study, 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 this study 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. 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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 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%).

---

[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).

In this study, we examine the effects of aggressive driving and other potential factors on the crash injury severity sustained by drivers. 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 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 this study, 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. For instance, consider the effect of age on injury severity. There is evidence in the literature that young drivers are more likely to participate in aggressive driving acts (see, for example, Agerwala *et al*., 2008, Vanlaar *et al*., 2008, and Shinar and Compton, 2004). However, assume that, after controlling for aggressive behavior, young drivers, say because of better overall health and body flexibility, are less likely to be severely injured in a crash relative to their older peers. Then, the overall effect of age on injury severity, which combines the *indirect* age effect (through aggressive driving) and the *direct* age effect, would be small because of a cancelling-out effect of the *indirect* and *direct* effects. Thus, the development of countermeasures based (purely) on a study that does not control for aggressive driving behavior and uses age as a variable in a 'reduced-form" injury severity model may underplay the need for targeted defensive driving

campaigns aimed at young drivers in the context of reducing crash injury severity. Similarly, 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 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 this study 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 data was collected between January 2005 and December 2007, and included a nationally representative sample of about 7000 crashes in the US. The data is quite unique in that a trained team of safety and human factors researchers were granted special permission from local law enforcement and emergency responders to arrive at the site of the crash immediately after it had been reported. The researchers systematically considered a variety of factors in defining whether or not the individual was driving aggressively just prior to impact, including the nature of the crash, eyewitness accounts, and interview with the occupants.

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

CHAPTER 2: EARLIER RESEARCH

In this chapter, we present earlier literature on aggressive driving behavior and driver injury severity and position the current study. Specifically, in Section 2.1, we discuss prior research on how aggressive behavior is characterized and studied. Section 2.2 provides a summary of earlier literature related to driver injury severity. In Section 2.3, we outline the objectives of the current research study in the context of earlier efforts in the safety literature.

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, a recent one being AAA Foundation for Traffic Safety's (2009) definition of "any unsafe driving behavior that is performed deliberately and with ill intention or disregard for safety". Some researchers (see, for example, Lajunen and Parker, 2001) also distinguish between instrumental aggressiveness (*i.e.*, aggressiveness that allows the driver to progress forward quickly and/or avoid frustrating obstacles, such as speeding, weaving in and out of traffic or driving on the shoulder) and hostile aggressiveness (*i.e.*, aggressiveness marked by the inability to progress forward, but as a means to potentially "feel good" by honking, tailgating, *etc*.). Further, some researchers 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.

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 that ask respondents a battery of questions regarding personal driving habits and views about driving acts such as drinking while driving, cell phone use when driving and speeding. Indicators of aggressiveness used in recent studies include one or more of (a) the 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. The personality traits include sensation-seeking behavior and the so-called big five personality factors (extraversion, neuroticism, conscientiousness, agreeableness, and openness), while the demographic and situational factors typically include age, gender, and whether respondents drove in rush hours or not. Some of the general findings from this line of research are as follows: (1) driving anger, sensation seeking nature, extraversion, neuroticism, and lower conscientiousness levels breed aggressive driving behavior, (2) aggressive drivers are less concerned about speeding, rash driving, driving inebriated and using cell phone during driving, (3)

individuals whose personalities may be characterized as emotionally less stable, less agreeable, and less open participate more often in aggressive driving behavior, (4) males, younger drivers, those with a history of traffic offences, and those who have seen close family members drive in an aggressive manner are more likely to participate in aggressive acts. However, the effectiveness of these studies in studying human behavior is limited because the respondents are prone to suppress undesirable responses to appear more social pleasing. Further, all of these studies focus on the determinants of aggressive driving behavior, but do not examine the impact of aggressive behavior on crash-related injury severity. Besides, even from the perspective of devising policies to curb aggressive driving behavior, these studies provide limited information because much of the personality traits used as determinants of aggressive driving behavior are not observed for the general population.

A few aggressive driving studies have used traffic crash reports filed by police officers that record the officer's judgment of 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; see Shinar and Compton, 2004 and Cook *et al.*, 2005). A couple of recent studies have also used observations at an intersection to record such characteristics as changing lanes, gap acceptance, and acceleration/deceleration rates to declare an act as being aggressive (see 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. The important findings from these studies include the following: (1) presence of long queues at intersections, driving during the rush hours, presence of heavy vehicles and pedestrians in the nearby surroundings, and duration of red light contribute to driver aggressiveness, (2) women and people older than 45 years are less likely to drive aggressively, and (3) younger drivers driving an SUV are more likely to participate in aggressive acts. But, again, 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 Injury Severity Studies

The crash injury severity of drivers has been extensively studied in the safety literature. Most of the recent injury severity studies have used 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"). A comprehensive review of different discrete variable studies of crash-related injury severity is provided in Eluru and Bhat (2007). In this chapter, we limit our review of injury severity studies to those very recent discrete choice studies that have not been listed in Eluru and Bhat, or are directly relevant to the aggressiveness-injury severity context of the current research effort.

Islam and Mannering (2006) analyzed the moderating effect of driver gender and age on the influence of other injury severity determinants using segmented multinomial logit models for male and female drivers for three age groups (16 to 24 years, 25 to 64 years, 65 and above). They found that there are significant differences in the factors, and the magnitudes of the influence of factors, affecting injury severity levels based on gender and age. Awadzi *et al*., (2008) similarly estimated a multinomial logit model with three injury levels (no injury, injury, and fatality) to examine the effect of various restraint and situational factors on injury severity of younger (35-54) and older adults (65 and above). The study found increased risk of fatal injury for older drivers if the point of impact on the vehicle is on the front passenger side or the passenger side behind the driver. Gray *et al*., (2008) studied the effect of factors determining injury severity for young drivers in London, using an ordered-response model structure. Among other things, the study found inconsistent results in the effect of age using a crash sample only from London and a crash sample from the entire of Great Britain. The London sample suggested that drivers aged 17 to 22 years are likely to be seriously injured in traffic

crashes relative to drivers aged 23 to 25 years, while the Great Britain sample indicated that those between 17-19 years incurred the least severe injuries. Very recently, Malyshkina and Mannering (2009) applied a markov-switching multinomial logit model that takes the form of a latent segmentation model with two unobserved states of injury severity.

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 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 crash-related injury severity determinants, it is indeed surprising that only one recent study has considered aggressive driving along with other factors.

In the current research effort, we bring the two streams of earlier work (those on aggressive driving and those on injury severity) together to capture both the *indirect* and *direct* effects of exogenous variables on injury severity. 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 or those that do not wear seat belts. 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. Similarly, aggressive driving-related crashes are likely to involve more impact energy, and therefore not wearing seat belts when involved in such crashes can be particularly deadly. The above two instances are examples of the impact of aggressive driving behavior being moderated by the <u>observed</u> characteristics of "being young" and

"not wearing a seat belt". 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 <u>unobserved</u> 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 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 William, 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.

CHAPTER 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. As identified earlier, these may include driving anger, sensation seeking nature, extraversion, neuroticism, agreeableness, openness, conscientiousness, and emotional state on the trip on which crash the occurred. These 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 3.1 presents the conceptual framework, with this latent aggressive driving act propensity toward the top of the figure. This propensity is a function of easily 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 (see bottom part of the figure) aggressiveness act participation prior to the crash. 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.

12

Overall, the estimation phase entails two independent equations – one for estimating the determinants of driver aggressiveness act participation (labeled as "1" in Figure 3.1) and the second for estimating the determinants of injury severity (labeled as "2" and "3" in Figure 3.1). 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 3.1 cannot be explicitly used. However, one can use the determinants of aggressive act participation (the relationship labeled "1" in Figure 3.1) 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 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 study. The equations for aggressive act participation and injury severity are:

13

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

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

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 mth 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 those who partake in aggressive acts just before a crash may be 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 $Var(\xi_q) = \pi_q = \exp(\gamma.a_q)$. The exponential form guarantees that the variance is positive. The variance for drivers who do not participate in an aggressive act is normalized to zero for identification.

The reader will note that there is no reason to believe that the unobserved factors that impact aggressive act propensity also influence injury severity propensity. Thus, 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 terms. 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 study, 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:

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

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:

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

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

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

The first component corresponds to a random-coefficients binary logit model, while the second corresponds to a random-coefficients heteroscedastic ordered response logit

16

model. The log-likelihood function then corresponds to separate components for these two models. The multidimensional integrals may be evaluated\d 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:

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

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

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

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

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

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

17

$$P(y_q = k) = [1 - P(a_q = 1)] \cdot [P(y_q = k) | (a_q = 0)] + [P(a_q = 1)] \cdot [P(y_q = k) | (a_q = 1)] \qquad (8)$$

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.
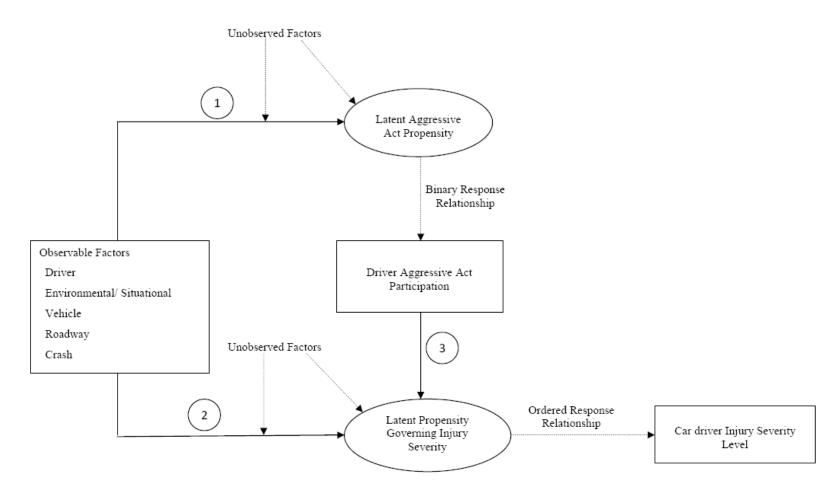
Figure 3.1 Conceptual Framework

CHAPTER 4: THE DATA

In Chapter 3, the methodology used in the current study to analyze aggressive driving behavior and its implications for driver injury severity was presented. In this chapter, the focus is on the data source used for the analysis. Specifically, we provide details of the data collection procedure and highlighting the richness of this data in comparison to other crash databases.

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. The data is particularly suited for the current study because substantial effort was expended on understanding the pre-crash events that led to the crash. 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.[2] 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

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 decision to go to a crash site (once informed of a crash) was based on a multistage sampling process based on targeting crashes in each combination of geographic location, time-of-day, and day of week in the same proportion as the number of crashes coded in the National Automotive Sampling System (NASS) – Crashworthiness Data System (CDS) in the previous year for that combination of geographic location, time-of-day, and day of week. 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:

---

[2] 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.

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 sample included in the data base after considering the above criteria was weighted to make it nationally representative. 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. The complete details of the sampling plan, the data collection procedure, weighting scheme, and compilation methods are available in NHTSA (2008).

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 crashes. The sample for analysis was obtained after several cleaning and screening steps for

consistency and removing crash observations with missing information. However, the resulting crash sample had a substantial under-representation of aggressive act participations and overrepresentation of the no-injury severity category compared to the nationally representative crash population for 1-2 vehicle collisions without non-commercial vehicles, as implied by the weighted version of the NMVCCS sample. To match the dependent variable proportions from our empirical sample to the nationally representative crash population, we deleted observations corresponding to the no-injury severity category and implemented other sampling procedure techniques.[3] The final sample proportions were almost identical to the nationally representative population implied by the weighted version of the NMVCCS.

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 4.1. 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

---

[3] 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.

acts, and accommodate the *indirect* effects (through aggressive act participation) and *direct* effects of exogenous factors on driver injury severity.

Table 4.1 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

CHAPTER 5: EMPIRICAL RESULTS

In the preceding chapter, the data source employed for the empirical analysis of aggressive behavior and driver injury severity was discussed. The current chapter discusses the empirical results for the study framework outlined in Section 3. In particular, the chapter provides details of the empirical results of two independent models – one for estimating the determinants of driver aggressiveness act participation and the second for estimating the determinants of injury severity. Further, elasticity effects are also presented.

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).

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 variable and combining variables when their effects were not significantly different. The 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.

The results of the aggressive participation act component and the injury severity component are presented in Tables 5.1 and 5.2, respectively, and are discussed in turn below.

5.2 Estimation Results

5.2.1 Aggressive Driving Behavior Component

The coefficients in Table 5.1 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.

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 (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, McNight and McNight, 2003), or because of an exaggerated sense of how good their driving skills are (William *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

27

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 5.1. 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 <u>strict no-young adult</u> 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 5.1, 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 5.2 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 Chapter 1 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

31

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 5.2 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 any 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 Chapter 1 of the thesis, 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 5.2). We disentangle these two separate effects in the current research effort, 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 5.2 provide the "direct" effects of these variables. Earlier research that co-mingles these two effects artificially inflates the estimate of the impacts of these two variables, as hypothesized earlier in Chapter 1. Thus, they run the danger of inflating the effectiveness of strict law enforcement campaigns alone to curb seat belt non-use and drinking while driving.

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 5.2) 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 5.2 regarding the number/age of passengers, when combined with the results from Table 5.2, 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. Again, it is important to note that these are the "*direct*" effects.

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 5.2 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 kmph). Once again, though, this is only the *direct* effect. The net effect of speed limit on injury severity will need to consider both the *indirect* effects through the aggressiveness driving behavior variable and the *direct* effect.

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.

36

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. 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 the chi-squared statistic with three degrees of freedom at any level of significance.

5.3 Elasticity Effects

The parameters on the exogenous factors in Tables 5.1 and 5.2 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.

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 5.3 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 5.3 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 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 5.3 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. 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

39

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 5.4 provides the elasticity effects 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

40

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).

Table 5.1 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	

42

Table 5.2 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 5.2 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 5.3 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 5.4 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 5.4 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

CHAPTER 6: CONCLUSIONS

In this study, 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. 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 this study 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 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. <u>First</u>, 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

49

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 *et al.*, 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

51

this. However, as indicated in NCHRP (2007), there is no documented empirical evidence of the detrimental effects of strict passenger restrictions. <u>Fifth</u>, 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.

REFERENCES

AAA Foundation for Traffic Safety. (2009) Aggressive driving: Research update. AAA Foundation for Traffic Safety, Washington, D.C. Available at: http://www.aaafoundation.org/pdf/AggressiveDrivingResearchUpdate2009.pdf

Agerwala, S.M., A. Votta, B. Hogan, J. Yannocone, S. Samuels and S. Chifriller (2008) Aggressive driving in young motorists. *International Journal of Humanity and Social Sciences*, 2(3), 182-185.

Arnett, J.J., C.E. Irwin, Jr and B.L. Halpern-Felsher (2002) Developmental sources of crash risk in young drivers. *Injury Prevention,* 8(Supplement 2), ii17-ii23.

Awadzi, K.D., S. Classen, A. Hall, R.P. Duncan and C.W. Garvan (2008) Predictors of injury among younger and older adults in fatal motor vehicle crashes. *Accident Analysis and Prevention*, 40, 1804-1810.

Basar, G., and C.R. Bhat (2004) A parameterized consideration set model for airport choice: An application to the San Francisco Bay area. *Transportation Research Part B,* 38(10), 889-904.

Beck, K.H., J.L. Hartos, and B.G. Simons-Morton (2002) Teen driving risk: The promise of parental influence and public policy. *Health Education and Behavior*, 29, 71-82.

Beck, K.H., M.Q. Wang and M.M. Mitchell (2006) Concerns, dispositions and behaviors of aggressive drivers: What do self-identified aggressive drivers believe about traffic safety? *Journal of Safety Research*, 37, 159-165.

Benfield, J.A., W.J. Szlemko and P.A. Bell (2007) Driver personality and anthropomorphic attributions of vehicle personality relate to reported aggressive driving tendencies. *Personality and Individual Differences,* 42, 247-258.

Bhat, C.R. (2001) Quasi-random maximum simulated likelihood estimation of the mixed multinomial logit model. *Transportation Research Part B*, 35, 677-693.

Bhat, C.R. (2003) Simulation estimation of mixed discrete choice models using randomized and scrambled Halton sequences, *Transportation Research Part B*, 37(9), 837-855.

Bhat, C.R., S. Sen, and N. Eluru (2008) The impact of demographics, built environment attributes, vehicle characteristics, and gasoline prices on household vehicle holdings and use. *Transportation Research Part B,* 43(1), 1-18.

Chamberlain, G. (1980) Analysis of covariance with qualitative data. *Review of Economic Studies*, 47, 225-238.

Chen, L.H., S.P. Baker, E.R. Braver and G. Li (2000) Carrying passengers as a risk factor for crashes fatal to 16- and 17-year-old drivers. *Journal of the American Medical Association*, 283(12), 1578-1582.

Cohen, A., and L. Einav (2003) The effects of mandatory seat belt laws on driving behavior and traffic fatalities. The *Review of Economics and Statistics*, 85(4), 828-843.

Cook, L.J., S. Knight and L.M. Olson (2005) A comparison of DUI and aggressive crashes. *Journal of Safety Research*, 36, 491-493.

Cosslett, S. (1981) Maximum likelihood estimator for choice based samples. *Econometrica*, 9, 1289-1316.

Dahlen, E.R., and R.P. White (2006) The big five factors, sensation seeking, and driving anger in the prediction of unsafe driving. *Personality and Individual Differences*, 41, 903-915.

Eluru, N., and C.R. Bhat (2007) A joint econometric analysis of seat belt use and crash-related injury severity. *Accident Analysis and Prevention*, 39(5), 1037-1049.

Ferguson, S.A., and A. F. Williams (2002) Awareness of zero tolerance laws in three states. *Journal of Safety Research*, 33, 293-299.

Galovski, T.E., and E.B. Blanchard (2002) The effectiveness of a brief psychological intervention on court-referred and self-referred drivers. *Behaviour Research and Therapy*, 40(12), 1385-1402.

Giedd, J. (2004) Adolescent brain development: vulnerabilities and opportunities. *Annals of the New York Academy of Science*, 1021, 77-85.

Gray, C.R., M.A. Quddus and A. Evans (2008) Injury severity analysis of accidents involving young male drivers in Great Britain. *Journal of Safety Research*, 39, 483-495.

Hamdar, S.H., H.S. Mahmassani and R.B. Chen (2008) Aggressiveness propensity index for driving behavior at signalized intersections. *Accident Analysis and Prevention*, 40(1), 315–326.

Islam, S., and F. Mannering (2006) Driver aging and its effect on male and female single-vehicle accident injuries: Some additional evidence. *Journal of Safety Research*, 37, 267-276.

Jasanoff, S. (1998) The political science of risk perception. *Reliability Engineering and System Safety*, 59, 91-99.

Kaysi, I.A., and A.S. Abbany (2007) Modeling aggressive driver behavior at unsignalized intersections. *Accident Analysis and Prevention*, 39(4), 671-678.

Kim, K., L. Nitz, J. Richardson, and L. Li (1994) Personal and behavioral predictors of automobile crash and injury severity. *Accident Analysis and Prevention*, 27(4), 469-481.

Lajunen, T., and D. Parker (2001) Are aggressive people aggressive drivers? A study of relationship between self-reported general aggressiveness, driving anger and aggressive driving. *Accident Analysis and Prevention*, 33(2), 243-255.

Malyshkina, N.V., and F. Mannering (2009) Markov switching multinomial logit model: an application to accident-injury severities. *Accident Analysis and Prevention*, 41(4), 829–838.

Manski, C.F., and S.R. Lerman (1977) The estimation of choice probabilities from choice based samples, *Econometrica*, 46, 1977-1988.

McKnight, A.J., and A.S. McKnight (2003) Young novice drivers: Careless or clueless. *Accident Analysis and Prevention*, 35, 921-925.

Millar, M. (2007) The influence of public self-consciousness and anger on aggressive driving. *Personality and Individual Differences*, 43, 2116-2126.

Millman, R.P. (2005) Excessive sleepiness in adolescents and young adults: Causes, consequences, and treatment strategies. *Pediatrics*, 115(6), 1774-1786.

National Cooperative Highway Research Program (NCHRP) (2007) Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: A Guide for Reducing Collisions Involving Young Drivers. Report 500, Volume 19, Transportation Research Board, Washington, D.C.

National Highway Traffic Safety Administration (NHTSA) (2007). Traffic safety fact sheet, 2007. Publication DOT HS 810993, National Center for Statistics and Analysis, National Highway Traffic Safety Administration. Available at: http://www-nrd.nhtsa.dot.gov/Pubs/810993.PDF

National Highway Traffic Safety Administration (NHTSA) (2008) National motor vehicle crash causation study: A report to Congress. Publication DOT HS 811059, U.S. Department of Transportation, National Highway Traffic Safety Administration. Available at: http://www-nrd.nhtsa.dot.gov/Pubs/811059.PDF

National Highway Traffic Safety Administration (NHTSA) (2009) Countermeasures that work: A highway safety countermeasure guide for state highway safety offices. Fourth edition. Publication DOT HS 811081, U.S. Department of Transportation, National Highway Traffic Safety Administration.

Nevarez, A., M.A. Abdel-Aty, X. Wang and J. Santos (2009) Large scale injury severity analysis for arterial roads: Modeling scheme and contributing factors. Presented at the 88th Transportation Research Board Annual Meeting, Washington DC.

O' Donnell, C. J., and D. H. Connor (1996) Predicting the severity of motor vehicle accident injuries using models of ordered multiple choice. *Accident Analysis and Prevention*, 28 (6), 739-753.

Parker, D., T. Lajunen, and H. Summala (2002) Anger and aggression among drivers in three European countries. *Accident Analysis and Prevention*, 34, 229-236.

Preusser, D.F., and W.A. Leaf (2003) Provisional license. *Journal of Safety Research*, 34(1), 45-49.

Shinar, D., and R. Compton (2004) Aggressive driving: an observational study of driver, vehicle

and situational variables. *Accident Analysis and Prevention*, 36, 429-437.

Simons-Morton, B.G., N. Lerner and J. Singer (2005) The observed effects of teenage passengers on the risky driving behavior of teenage drivers. *Accident Analysis and Prevention*, 37(6), 973-982.

Simons-Morton, B., M.C. Ouimet, and R.F. Catalano (2008) Parenting and the young driver problem. *American Journal of Preventive Medicine*, 35(3S), S294-S303.

Srinivasan, K.K. (2002) Injury severity analysis with variable and correlated thresholds: Ordered mixed logit formulation. *Transportation Research Record*, 1784, 132-142.

Tasca, L. (2000) A review of the literature on aggressive driving research. Aggressive Driving Issues Conference, sponsored by the Ministry of Transportation of Ontario, Canada, in cooperation with the Transportation Research Board. Available at: http://www.aggressive.drivers.com/papers/tasca/tasca.pdf

Vanlaar, W., H. Simpson, D. Mayhew and R. Robertson (2008) Aggressive driving: A survey of attitudes, opinions and behaviors. *Journal of Safety Research*, 39, 375-381.

Williams, A.F. (2000) Graduated licensing in the United States. Proceedings of the 65th Road Safety Congress, Around the World in 2 1/2 days: Lessons for the UK? Royal Society for the Prevention of Accidents, Plymouth, England.

Williams, A.F. (2003) Teenage drivers: Patterns of risk. *Journal of Safety Research* 34(1), 5-15.

Williams, A.F., N.N. Paek and A.K. Lund (1995) Factors that drivers say motivate safe driving practices. *Journal of Safety Research*, 26, 119-124.

Wolfson, A.R., and M.A. Carskadon (2003) Understanding adolescents' sleep patterns and school performance: A critical appraisal. *Sleep Medicine Review*, 7(6), 491-506.

VITA

Rajesh Paleti Ravi Venkata Durga was born in Eluru, India. After finishing his schooling in New Generation Junior College in Hyderabad, he joined Indian Institute of Technology, Kharagpur. He graduated with the degree of Bachelor of Technology (Honors) in civil engineering in the year 2008. He then joined University of Texas at Austin for pursuing graduate studies in the field of transportation engineering under the guidance of Dr Chandra Bhat. He is continuing his graduate study for a PhD under Dr Bhat.

Permanent Address: 302, Ganapathi homes, Lane besides Hanuman Temple, Phanigiri colony, New Maruthi Nagar, Chaitanyapuri, Hyderabad -500060

This thesis was typed by the author.