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The Impact of Gasoline Prices on Medical Care and Costs of Motor Vehicle Injuries

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THE IMPACT OF GASOLINE PRICES ON MEDICAL CARE AND COSTS OF MOTOR VEHICLE INJURIES

by

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ABSTRACT

Background Traffic safety has placed a tremendous economic and social burden on individuals and nations. Gasoline prices have been linked to traffic safety in the recent studies. Higher gasoline price may prompt people to reduce expenses by changing travel distance and frequency, transportation mode, or driving behaviors.

Objective This study aims to examine the relationship of gasoline prices to hospital utilization and cost for motorcycle and non-motorcycle motor vehicle injuries in the United States.

Methods Data on inpatient hospitalization for motor vehicle injuries were obtained from the 2001-2010 Nationwide Inpatient Sample, which is part of the Healthcare Costs and Utilization Project. Gasoline price data were gathered by the Federal Highway Administration. Panel feasible generalized least squares models were used to estimate the effects of inflation-adjusted gasoline prices on hospitalization rate (per 10 million population). Additionally, a conceptual system dynamic model was developed to examine the traffic safety system response to rising gasoline price, and it was used to estimate the effects of gasoline tax and transport policies on reducing motor vehicle injuries.

Results It was predicted that a $1.00 increase in the gasoline tax was associated with reducing the number of hospitalizations for non-motorcycle MVC injuries by 8,347, and lowered hospital costs by $143 million in 2014. However, the $1.00 increase in the gasoline tax was associated with increasing the number of hospitalizations for motorcycle crash injuries by 3,574, and increased hospital costs by $73 million. Also, our experiments of system dynamics modeling found that increasing passenger-miles traveled would be effective in reducing motor vehicle injuries in the long run.

Conclusion Our findings suggest that the increased hospital utilization and costs from motorcycle crash injuries after a rise in the price of gasoline partially offset reductions in non-motorcycle MVC injuries. Therefore, gasoline tax could be a policy alternative to improve traffic safety, provided that it is paired with efforts to improve motorcycle safety. The development of public transportation system could also become an attractively alternative commuting mode to reduce motor vehicle injuries.

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It seems to spend four years to prepare for the Olympic Games. Despite no gold medal, I think I have conquered myself.

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LIST OF ABBREVIATIONS

AHRQ: Agency for Healthcare Research and Quality

APICC: All-Payer Inpatient Cost/Charge Ratio

APTA: American Public Transportation Association

ARIMA: Autoregressive Integrated Moving Average

BAC: Blood Alcohol Content

CCR: Cost-to-Charge Ratio

CCS: Clinical Classifications Software

CDC: Centers for Disease Control and Prevention

CLD: Causal Loop Diagram

CPI: Consumer Price Index

ED: Emergency Department

EIA: Energy Information Administration

FARS: Fatality Analysis Reporting System

FHWA: Federal Highway Administration

GDL: Graduated Drivers License

GPICC: Group Average All-Payer Inpatient Cost/Charge Ratio

HCUP: Healthcare Cost and Utilization Project

IV: Instrument Variables

MAD: Mean Absolute Deviation

MAPE: Mean Absolute Percentage Error

MFE: Mean Percentage Error

MPG: Motor Press Guild

NHTSA: National Highway Traffic Safety Administration

NIS: Nationwide Inpatient Sample

NMCMV: Non-Motorcycle Motor Vehicle

NRMSE: Normalized Root Mean Squared Error

MVC: Motor Vehicle Crash

PDO: Property Damage Only

PFGLS: Panel Feasible Generalized Linear Squares

RMSE: Root Mean Square Error

PMT: Passenger-Miles Traveled

SD: System Dynamics

SFD: Stock-Flow Diagram

SID: State Inpatient Sample

TSE: Tracking Signal Error

VMT: Vehicle Miles Travelled

WHO: World Health Organization

CHAPTER 1 : INTRODUCTION

Traffic safety has become an important public health concern, and it was estimated that over 1.2 million people killed and 50 million people injured in the motor vehicle crashes (MVCs) each year around the world (Mohan, Tiwari, Khayesi, & Nafukho, 2006; Peden et al., 2004; World Health Organization (WHO), 2013). Consequently, these MVCs place a huge economic and social burden on the individuals and nations, including productivity loss, medical cost, property damage, and administration fees (Blincoe, Miller, Zaloshnja, & Lawrence, 2015; WHO, 2013).

In the United State, MVC was the leading death cause for the people under 44 years old (Centers for Disease Control and Prevention (CDC), 2015a), and there were over 40,000 people killed and 2.8 million people injured on average annually in the most recent two decades (National Highway Traffic Safety Administration (NHTSA), 2001, 2014). Moreover, total economic costs of MVCs reached $242 billion in 2010 comparing to 231 billion in 2000 (Blincoe et al., 2002; Blincoe et al., 2015). Although the CDC identified the large decline in MVC injury rate as one of ten great public health achievements in the first decade of the 21st century (CDC, 2011a), the U.S. still has the highest capita traffic fatality rate and has lagged behind other developed countries on reducing the number of fatalities and rate per vehicle miles traveled (VMT) (Committee for the Study of Traffic Safety Lessons from Benchmark Nations, 2011).

Economic factors have been identified as a major driver of travel behavior and traffic safety (French & Gumus, 2014; Kopits & Cropper, 2005; Law, Noland, & Evans, 2009; Longthorne, Subramanian, & Chen, 2010; Ruhm, 2004). Among them, the extreme fluctuation of gasoline price motivates the studies of its impact on MVCs in the recent years (Austin, 2008; Brand, 2009; Litman, 2008; Hedlund, 2013). Gasoline price was as high as $4 per gallon in 2008 comparing with $1.5 or less around year 2000, and it fell back to $2.2 at the beginning of 2015 (U.S. Energy Information Administration (EIA), 2015). Gasoline price directly affects the travel prices, and people could respond to expensive prices by changing trip distance and frequency, transportation mode, and driving behaviors (Austin, 2008; Chi et al., 2011; Chi, Porter, Cosby, & Levinson, 2013; Gillingham, 2011; American Public Transportation Association (APTA), 2011). It was found high gasoline prices have reduced the VMT and traffic congestion due to consideration of fuel cost (Austin, 2008; Brand, 2009; APTA, 2011). These may reduce the exposure of MVCs. On the other hand, people may start to ride a motorcycle or ride a motorcycle more frequently in response to high gasoline prices (Hedlund, 2013; Hyatt, Griffin, Rue, & McGwin, 2009; Wilson, Stimpson, & Hilsenrath, 2009). Motorcycles are usually more fuel-efficient than automobiles or trucks, but they have higher crash rate (Morris, 2009; NHTSA, 2013b; Litman, 2005).

Previous studies have examined the effect of gasoline prices on the MVCs; however, the number of existing studies is still limited. Furthermore, most of these studies focused on MVC fatalities, which was the smallest proportion among all the MVCs. Second, most previous studies found a negative effect of gasoline prices on fatalities; however, the effects actually were mixed. For instance, French & Gumus (2014) found that the inflation-adjusted gasoline prices were not significantly related to motorcycle fatality rates, while Grabowski & Morrisey (2004) have shown a significant effect using the same data sources. Third, only one previous study separated the MVC fatalities and injuries into automobile and motorcycle, which may be adversely affected by the gasoline prices (Hyatt et al., 2009). Finally, the data of MVC injuries used in previous studies were all from traffic crash records, reported by police and these data may lack important information; for example, the diagnoses of injury and medical care utilization were not reported in these records.

Therefore, the aim of this study is to expand existing literature to examine the relationship between gasoline prices and MVC injuries, especially for severe victims who admitted to inpatient departments. Accordingly, monitoring and understanding the impact of gasoline prices may provide early warning of impending changes on MVC related inpatient stays for health care providers.

The motivation for this study is provided in this chapter. Chapter 2 reviews the traffic safety and gasoline price background. Chapter 3 raises the objective and specific aims for this study. Chapter 4 contains a literature review of previous studies on gasoline prices and MVCs, along with the critique and rationale for this study. Chapter 5, 6, 7 state the methods, results and discussion for three specific aims, respectively. Finally, the findings of the above chapters are summarized in Chapter 8.

CHAPTER 2 : BACKGROUND REVIEW

Traffic Safety in the United States

In the United States, the annual number of MVC fatalities shows a relatively stable trend from 1993 to 2006, and a significant decline started from 2007 with the biggest reductions occurring from 2007 to 2009 (Figure 2-1, Table S2-1 in Appendix). In 2012, there were 33,561 MVC fatalities while fatality rates per 100,000 population and per 10 million VMT were 10.69 and 11.30 (NHTSA, 2001, 2014). At the same time, the number of MVC injuries presents a stable decline trend during the same periods (Figure 2-2, Table S2-2 in Appendix). Similarly, there were 2.36 million MVC injuries as well as 752 injuries per 100,000 population and 800 per 10 million VMT in 2012 (NHTSA, 2001, 2014).

The historic decline in the MVCs was generally contributed by the improvement of vehicle safety, road condition, initiative traffic safety policies (such as seat-belts and BAC laws) and innovative technologies (CDC, 2015; Evans, 2003, Grabowski & Morrisey, 2004; McKay, 2004; Oster & Strong, 2013). For instance, 0.08 Blood Alcohol Concentration (BAC) law was found significantly decreases the crash involvement and crash severity in the U.S. (Dang, 2008; Dee, 2001; Freeman, 2007; Wagennar, Maldonado-Molina, Ma, Tobler, & Komro, 2007). Most importantly, the large drops in fatalities in 2008 and 2009 have coincided with economic conditions in the U.S. (Longthorne et al., 2010).

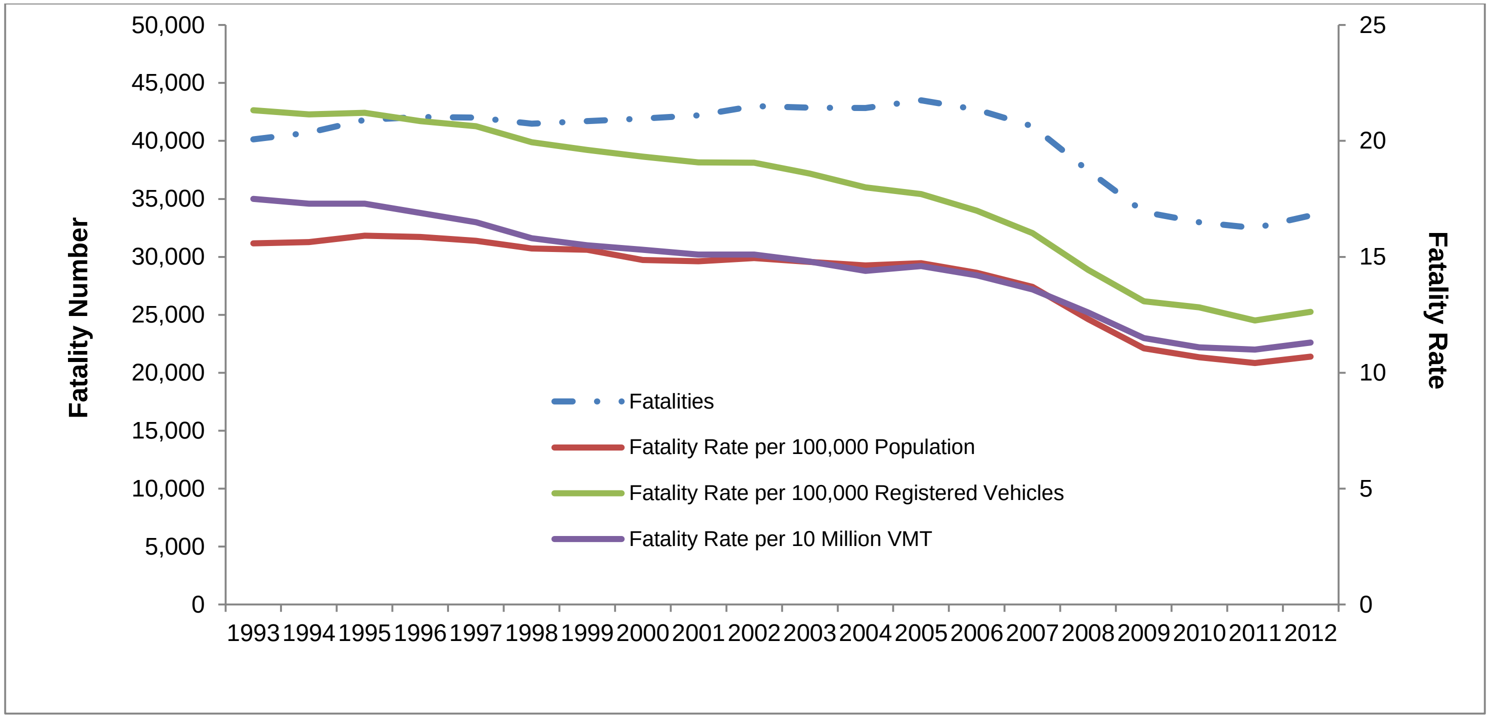

Figure 2-1: Trends of number of motor vehicle fatalities and fatality rates in the United States: 1993-2012

Source: National Highway Traffic Safety Administration.
Note: This is a dual-scaled axis graph: 1) The number of fatalities is scaled by the left axis (dashed line); 2) Three different fatality rates are scaled by the right axis, red line represents fatalities per 100,000 population, purple line represents fatalities per 10 million VMT, and green line represents fatalities per 100, 000 registered vehicles.

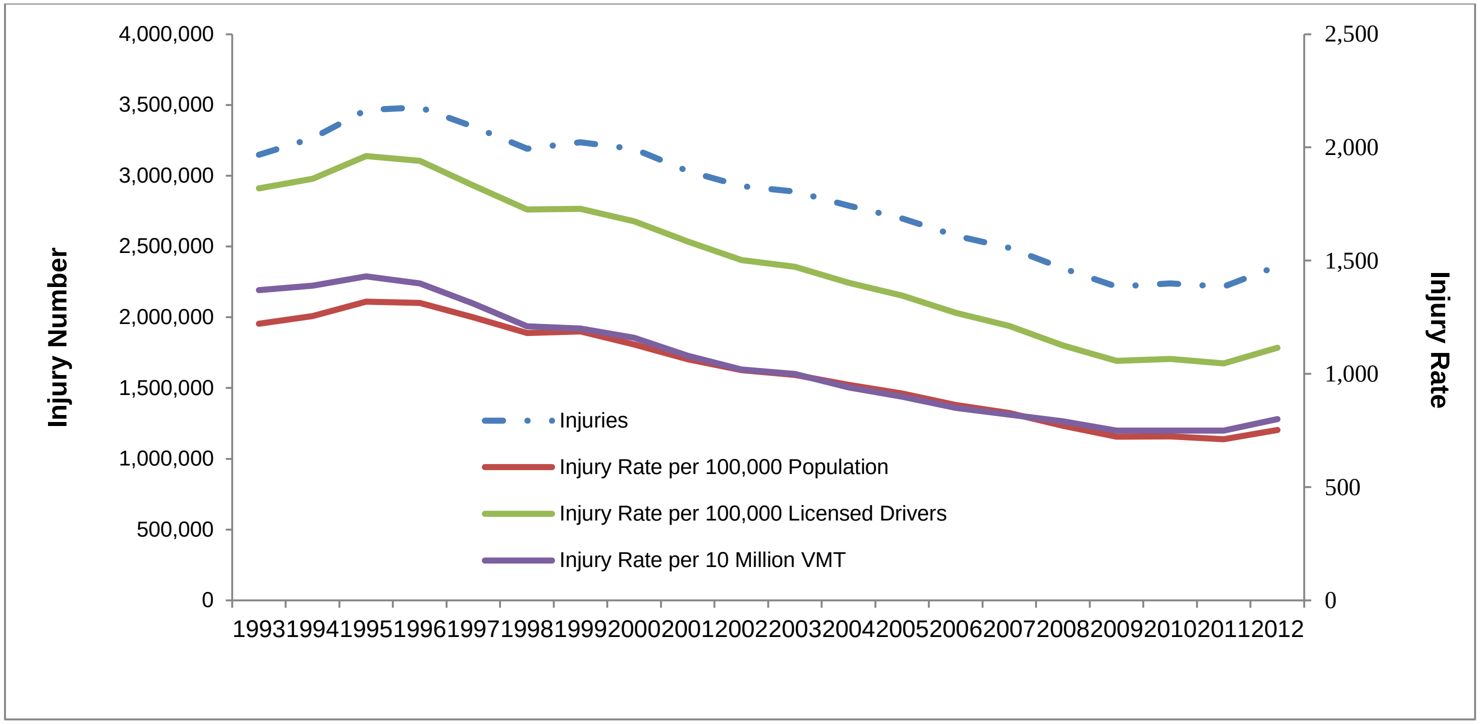

Figure 2-2: Trends of number of motor vehicle injuries and injury rates in the United States: 1993-2012

Source: National Highway Traffic Safety Administration.
Note: This is a dual-scaled axis graph: 1) The number of injuries is scaled by the left axis (dashed line); 2) Three different injury rates are scaled by the right axis, red line represents injuries per 100,000 population, purple line represents injuries per 10 million VMT, and green line represents injuries per 100, 000 registered vehicles.

Gasoline Prices and Their Influences on Traffic Safety

According to the EIA (2015), the retail price of gasoline consists of four components: the cost of crude oil, refining costs and profits, distribution and marketing costs and profits, and federal and state taxes. The fluctuations in gasoline prices were affected by combining these components. Figure 2-3 depicts the trends of gasoline prices (in 2010 dollars) in the U.S. from 1992 to 2014. Before 2004, the price of gasoline price was around $1.6, and then it kept increasing to over $3.0. In recent years, the U.S. retail gasoline prices almost followed the changes of crude oil prices (Figure 2-4), and the proportion of crude oil prices in retail prices has increased to 68% comparing with an average 56% from 2000 to 2013 (Figure 2-5). In contrast, the shares of the other three components decreased together. In fact, the price of crude oil is always determined by the global oil market, which is complex due to political, economic and culture environments (Castanias & Johnson, 1993; Deltas, 2008; Marvel, 1976). The gasoline price also presents regional differences; for example, the gasoline price in West Coast is around $0.50 higher than other regions in the U.S. (EIA, 2015).

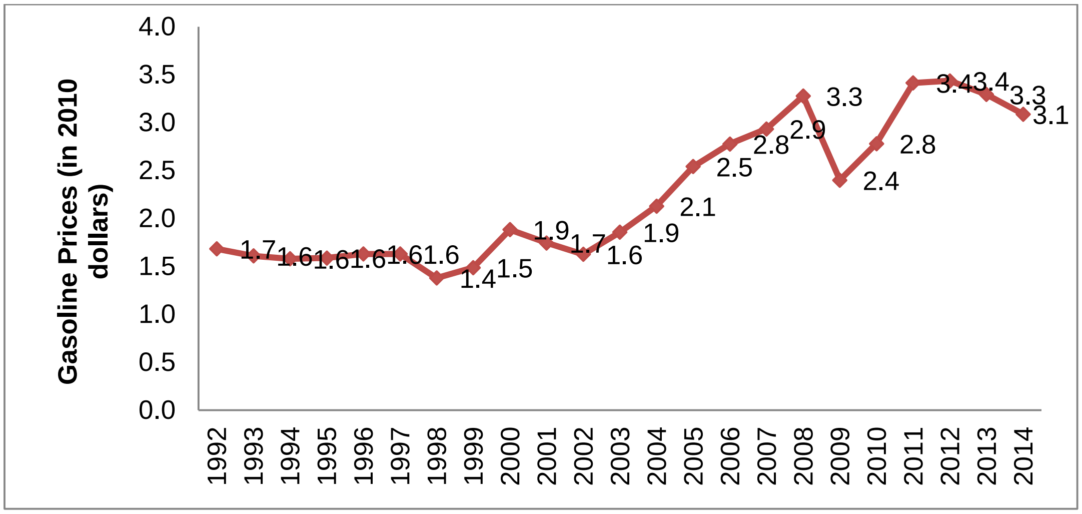

Figure 2-3: Trends of Inflation-adjusted gasoline prices in the United States: 1992-2014

Source: U.S.EIA

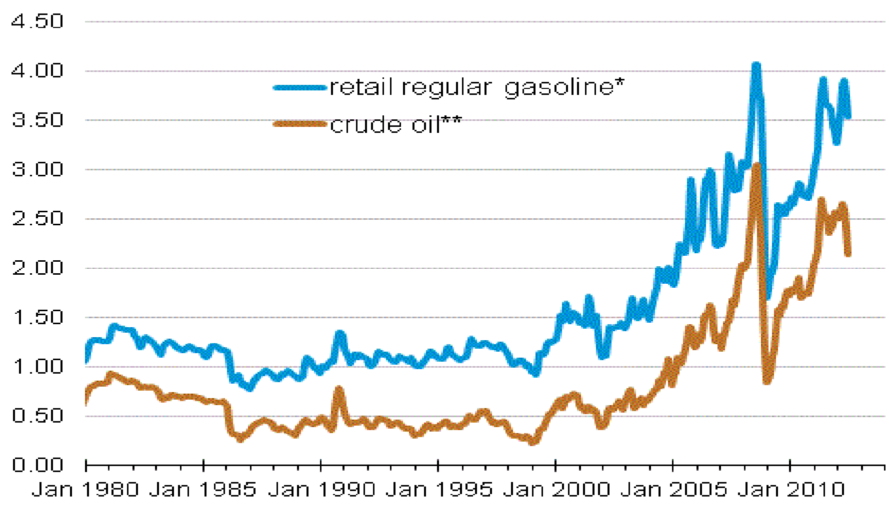

Figure 2-4: Monthly retail gasoline and crude oil prices in the United States: 1980 – 2010

Source: U.S. EIA.
Notes: *Retail prices including taxes; **Crude oil prices is the refiner average imported crude oil acquisition cost; The unit of price is one gallon, and the price are nominal without adjusting consumer price index.

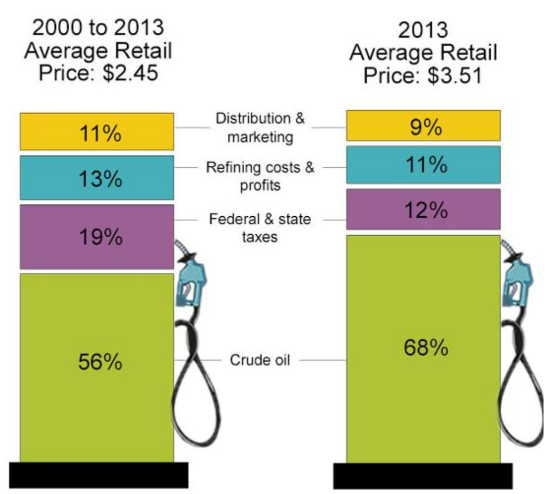

Figure 2-5: Components of gasoline prices in the United States

Source: U.S. EIA.

Federal gasoline tax has been $0.184 per gallon since October 1st, 1997. The state gasoline tax varies from $0.075 (Georgia) to $0.375 (Washington) in 2010, and about half of the states have not changed the tax rate since 2000. The total gasoline tax was around $0.39 in the U.S. (Federal Highway Administration (FHWA), 2015). In fact, gasoline taxation could be a policy alternative to reduce MVC fatalities and injuries (Leigh & Wilkinson, 1991; Leigh & Geraghty, 2008).

Gasoline prices have potentially influenced traffic safety through several ways. Figure 2-6 illustrates as a conceptual framework of gasoline price and traffic safety informed by the literature. In detail, first, the price of gasoline directly links with the consumption of gasoline from an economic perspective (Austin, 2008; Hughes, Knittel, & Sperling, 2008; Lin & Prince, 2013; Litman, 2011). According to the 2009 National Household Travel Survey (2015), it was estimated that about 40% of drivers are most concerned with the price of travel (gasoline price, fee and tolls), which ranked as the No. 1 issue when people chose to travel. It was estimated that the elasticity of gasoline demand ranged from -0.1 to -0.5, which indicated that a 10% increase in the gasoline price has resulted in gasoline consumption decreasing by 1% to 5% (Goodwin, Dargay, & Hanly, 2004). Second, the price of gasoline affects people's choices on transportation mode, and people may move to public transportation or more fuel efficient vehicles (such as motorcycles). Several previous studies have found that people shift to public transit in response to increasing gasoline prices (APTA, 2011; Austin, 2008; Gillingham, 2011). People also replace less-fuel-efficient cars with more-fuel-efficient cars or other improvements in fuel efficiency (Austin, 2008). For example, the sales and registrations of motorcycle have increased and closely tracked the changes of gasoline prices (Motorcycle Industry Council, 2010; Hedlund, 2013). However, riding a motorcycle is more dangerous than driving, and the number of motorcycle-related deaths and injuries has increased by more than 40% while total MVC fatalities and injuries decreased (NHTSA, 2001, 2013, 2014. Finally, the price of gasoline price may be related to driving behaviors. Chi et al. (2011) found that higher gasoline prices result in fewer drunk-driving crashes.

Governors Highway Safety Association published a report “Motorcyclist Traffic Fatalities by State: 2012 Preliminary Data”, and gasoline price was identified as one of reasons for changes in U.S. motorcyclist fatalities (Hedlund, 2013). In this report, it was illustrated that the motorcyclist fatalities, motorcycle registrations and gasoline prices tracked each other quite closely from national data from 1976 to 2012. The gasoline price here was inflation-adjusted, unleaded regular gasoline price for annual U.S. city average. Meanwhile, the report also suggested that continuous high gasoline prices may have encouraged some riders to use motorcycles for daily commuting instead of passenger cars because of fuel-efficiency. Although this report didn’t examine the relationships, it explored the potential impact of gasoline price on motorcyclist traffic fatalities with descriptive evidence.

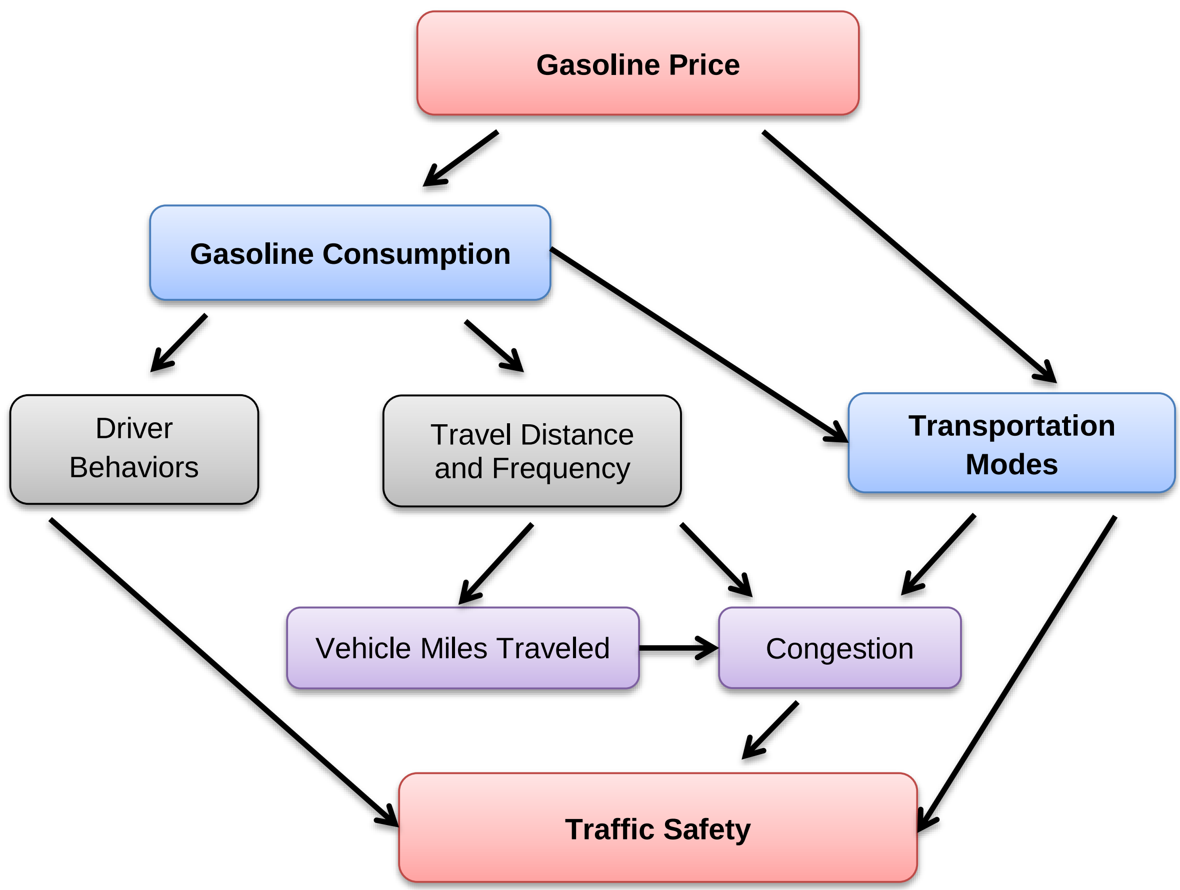

Figure 2-6: Conceptual framework of gasoline price and traffic safety

Table 2-1: Trends of gasoline prices, motorcycle sales and fatalities from 1984 to 2009

Year	Price of Gasoline ($)	Motorcycle sales (000s)	Total motorcycle fatalities	Total Motorcycle fatalities per 100,000 motorcycle registration	Fatalities from new motorcycles	New motorcycle fatality rate per 100,000 motorcycle sales
1984	2.47	550	4,431	80.9	326	59.3
1985	2.38	520	4,417	81.1	409	78.7
1986	1.82	440	4,309	81.9	355	80.7
1987	1.81	438	3,834	78.0	227	51.8
1988	1.74	310	3,492	76.2	215	69.4
1989	1.83	227	3,036	68.5	170	74.9
1990	2.00	208	3,129	73.5	203	97.6
1991	1.89	190	2,703	64.7	163	85.8
1992	1.82	186	2,291	56.4	167	89.8
1993	1.74	201	2,336	58.7	197	98.0
1994	1.70	210	2,190	58.3	183	87.1
1995	1.70	214	2,114	54.2	183	85.5
1996	1.76	228	2,046	52.8	166	72.8
1997	1.73	247	2,028	53.0	177	71.7
1998	1.47	298	2,186	56.3	219	73.5
1999	1.58	379	2,374	57.2	325	85.8
2000	1.95	471	2,783	64.0	427	90.7
2001	1.85	556	3,077	62.8	536	96.4
2002	1.71	618	3,150	62.9	484	78.3
2003	1.92	662	3,583	66.7	558	84.3
2004	2.19	725	3,827	66.3	526	72.6
2005	2.57	801	4,418	70.9	710	88.6
2006	2.79	855	4,679	70.1	799	93.5
2007	2.93	846	4,986	69.8	663	78.4
2008	3.32	888	5,060	65.3	465	52.4
2009	2.40	468	4,227	53.3	252	53.8

Source: NHTSA, EIA, Motorcycle Industry Council. Notes: Gasoline prices was adjusted to 2009 dollars.

CHAPTER 3 : OBJECTIVE AND SPECIFIC AIMS

The objective of this study was to perform a comprehensive analysis of motor vehicle injuries, and related hospital utilization and cost in response to gasoline price fluctuation in the United States. We achieved this objective by pursuing the following specific aims:

Specific Aim 1

Examine the relationships between gasoline prices and hospital utilization for motorcycle and non-motorcycle motor vehicle injuries.

Specific Aim 2

Perform the economic evaluation of gasoline taxation on hospital cost for motorcycle and non-motorcycle motor vehicle injuries.

Specific Aim 3

Estimate the effects of rising gasoline price on the traffic safety system by using a system dynamics model.

CHAPTER 4 : LITERATURE REVIEW

Gasoline prices could affect traffic safety by changing travel distance and frequency, transportation mode, driving behavior and traffic congestion; consequently, these have both positive and negative impacts on MVC fatalities and injuries. In this chapter, we searched out 16 studies directly examined the relationships of gasoline prices or taxes to MVC fatalities and injuries from 1990 to present, and summarized a detailed review for each study.

Gasoline Price and Motor Vehicle Fatality and Injury

Leigh and Wilkinson (1991) estimated the effects of gasoline prices on highway fatalities from 1976 to 1980. The authors separated gasoline price per gallon into state gasoline tax and price excluding state tax, and fatalities were defined as annual fatalities per 1,000 persons over age 15. A reduced form equation was used to examine the annual relationship of untaxed gasoline price and state gasoline tax to fatality rates by controlling inflation-adjusted income, percentage of young male and new cars, and alcohol consumption, etc. The authors found that a 10 percent increase in the gasoline tax per year would reduce fatalities by 1.8 to 2.0 percent; however, the untaxed gasoline price didn’t have a significant relationship with fatality rates, and they suggested that gasoline tax is a tool for policy makers to reduce fatalities.

This study is one of the earliest researches directly linking gasoline prices and MVC fatalities, and it found that there was a negative relationship between gasoline tax and fatalities, which implied the full gasoline price (untaxed prices plus state tax), may also have a negative impact. Furthermore, the authors suggested that increasing gasoline taxes could be a policy alternative to reduce high fatalities and additional externalities, such as air pollution and congestion. However, the authors did not report neither amount and changes of taxes nor the federal tax. Also, there was only a 4-year observation period with annual data and, thus, there may not be enough variation for analysis. Generally, this study provided a foundation for following studies on gasoline prices and traffic safety.

Grabowski and Morrisey (2004) examined the effects of gasoline prices on motor vehicle fatalities from 1983 to 2000. In this study, the gasoline price was defined for monthly regular and unleaded grade gas with federal and state taxes, and the outcomes included motor vehicle fatalities per million population and per million VMT. The control variables were the unemployment rate, per capital income and several traffic safety policy indicators (the laws regarding blood alcohol concentration, seat belt, speed limit and administrative license). Similar to the approach from Leigh & Wikinson (1991), the authors found that gasoline prices had significantly negative effects on fatalities per capita and per VMT, and a $0.01 increase in gasoline prices was significantly associated with a 0.11 percent increase in monthly fatalities per capita and 0.06 percent increase in monthly fatalities per VMT. The authors also concluded that the effect on fatalities per capita was strong in the long run, but with limited support for fatalities per VMT. Finally, the price effects on the number of MVC fatalities for different driver age groups were examined, and age 18-20 and 21-24 had significantly negative associations with gasoline prices.

Compared to Leigh & Wilkinson (1991), this study was improved in several ways: first, the observation unit was monthly fatalities at the state level and observation period was 18 years, which increased data variation; second, Grabowski & Morriesy (2004) clearly established the potential link between gasoline price and fatalities: price was related to gas consumption, consumption was related to VMT, and VMT was related to fatalities; third, this study added two analysis dimensions: effective period (short/long run) and age-specific fatalities. However, VMT data used here was annual data to calculate monthly adjusted rates, which may bias the results because travel usually has a seasonal trend.

Leigh and Geraghty (2008) applied a simulation-based partial equilibrium model to assess the MVC fatalities in different gasoline price increase scenarios for one year. This study used annually average gasoline price per gallon (including tax) for all grades (data from EIA) and annual vehicle crash deaths (data from CDC). Based on the data of 2003, it was predicted that there would be 997 fewer deaths in one year in response to a 10 percent increase in gasoline price; 1,994 fewer in response to a 20 percent increase; and 4,984 fewer in response to a 50 percent increase. Additionally, the authors also extended this effect to reducing pollution deaths by reducing air pollution with increasing gasoline prices. The authors mentioned that less air pollution through increasing gasoline price and taxes would potentially be associated with fewer MVC deaths due to greater visibility and less congestion.

In brief, this study provided new evidence of a negative relationship between gasoline price and MVC fatalities by using different analyses compared with previous studies. In fact, the predicted decrease in fatalities was a little larger than the estimation in Leigh & Wilkinson (1991). The strength of this study was that it applied an innovative simulation method and included the air pollution perspective, yet, the number of fewer fatalities seemed to be more sensitive to the demand price elasticity from previous research.

Hyatt et al. (2009) also estimated the effect of gasoline prices on motorcycle crashes, and they extended the effects to motorcycle and passenger car fatalities and injuries from 1992 to 2007. The outcome of this study was the rate of all the occupants in an injured or fatal crash (per population and per registered vehicles). The gasoline price as a predictor was categorized into four groups ($1.00-1.49, $1.50-1.99, $2.00-2.49, and

$2.5+), and unemployment rate and per capita income were covariate variables. Autoregressive Integrated Moving Average (ARIMA) regressions estimated that higher gasoline prices were significantly associated with higher number of motorcycle fatalities per population, and a lower number of personal vehicle injury and fatality per population. However, there was no association between motorcycle injury rates (per population) and motorcycle fatalities rates (per register motorcycles).

This study first examined and compared the separate effects of gasoline price on motorcycles and passenger cars. However, the authors believed that the number of registered vehicles was the most appropriate to measure the injury and mortality rate because the population remained relatively stable, and the increase of motorcycle registration was higher than motorcycle VMT from 1996 to 2005. In fact, consist with the research period (1992-2007), the number of registered motorcycles increased 75% and the number of motorcycle VMT increased 124%, as well as the number of motorcycle fatalities increased 116% (NHTSA, 2000; 2011). Thus, it can be argued that the rate for motorcycle registration may not be most appropriate.

Chi, Cosby, Quddus, Gilbert, & Levinson (2010) extended the effect of gasoline prices to total motor vehicle crashes by adding injury and property-damage-only (PDO) crashes. The PDO crashes counted in this study were defined as those with property losses of more than $500. The crash data came from Mississippi Highway Patrol from April 2004 to December 2008, and gasoline price was retrieved from EIA. Poisson-gamma regression models were used to estimate the effects and the outcome of crash number was also stratified by age, gender and race. The authors found that a 1 percent increase in inflation-adjusted gasoline prices was associated with 0.25 percent decrease in total motor vehicle crash per million VMT, and the price had different effects by age, gender and race in short and intermediate time periods.

The study improved upon previous studies by estimating the effects on total motor vehicle crashes and stratifying by race and gender. However, the outcome was the number of MV crashes and related rate, which may not be comparable with prior literature using the number of fatalities and injuries. Moreover, the gasoline price was averaged across all Gulf Coast States rather other specifically the state of Mississippi, and this may cause over- or under-estimate.

Chi et al. (2011) focused on the relationship between gasoline prices and drunk-driving crashes. This study used the same data and analytical frame with Chi et al. (2010), and it narrowed the outcome to be the number of total drunk-driving related crashes (including fatal, injury and PDO crashes). The results from negative binomial regression models showed that higher gasoline prices were associated with a bigger effect on reducing PDO drunk-driving crashes and higher alcohol consumption was associated with a larger effect on reducing fatal and injured drunk-driving crashes.

This study was the first one to link gasoline prices with a specific driving behavior. Yet, it has the similar limitation with Chi et al. (2010) on gasoline price data; furthermore, the authors also mentioned the issue of small data size.

Morrisey and Grabowski (2011) focused on motor vehicle fatalities of young adult (15-24 years old) in the U.S., and examined the effect of gasoline prices combining with beer taxes and Graduated Drivers License (GDL) programs. Annual state data of all motor vehicle fatalities from 1985 to 2006 were obtained from the Fatality Analysis Reporting System (FARS), and regular grade unleaded gasoline prices (including taxes) adjusted to 2006 dollars were from EIA and the Federal Highway Administration. The authors found that a 10 percent increase in inflation-adjusted gasoline prices was associated with 6.7 percent reduction on fatalities for 15-17 young adult, 3.2 percent reduction for 18-20, and 3.7 percent reduction for 21-24. The analyses were stratified by the above three age groups with day time (day and night), gender (male and female), and location (urban and rural).

This study was the first study to specifically link gasoline prices with motor vehicle fatalities for young adults, and it implied the younger people may be more likely to be affected by gasoline prices. Compared with gasoline prices, the results indicated beer taxes had a smaller impact on fatality and the GDL program had higher effect.

Chi, McClure, & Brown (2012) moved to use the data for Alabama State from 1999 to 2009, and the number of total crashes was obtained from the Alabama CARE system, and average gasoline prices for the Gulf Coast region were used from EIA. Similar with his previous two studies (Chi et al., 2010; Chi et al., 2011), the negative binomial regressions estimated that a 1 percent increase in inflation-adjusted gasoline price was related to a 0.21 percent decrease in monthly total MV crashes per 100,000 persons. However, the effects of gasoline price varied among different demographic groups.

This study added evidence to the relationship between gasoline price and traffic safety. However, it only focused on Alabama State, which is not representative enough due to small crash numbers and mostly rural areas.

Chi et al. (2013a) reexamined the relationship between gasoline prices and motor vehicle crash from a time-geography perspective for Mississippi. Comparing with the first author previous studies (Chi et al., 2010; Chi et al., 2011; Chi et al., 2012), the analysis was improved by using gasoline prices specifically for Mississippi, extending data to December 2010. The authors estimated that 1 percent increase in inflation-adjusted gasoline price was related a 0.10 percent decrease at a 9-month lag, 0.16 percent decrease at 12-month lag and 0.12 percent decrease at 18-month lag.

Chi, Quddus, Huang, & Levinson (2013b) added an urban-rural comparison perspective to examine gasoline price effects on the crash number from Minnesota State from 1998 to 2007. Random-effect negative binominal models were used to measure the gasoline price effect, and the results indicated that a 10 percent increase in gasoline price would be related to a 4.1 percent decrease in rural areas compared with a 2.8 percent decrease in urban areas. Also, the effects of gasoline prices in both rural and urban areas decreased for PDO, fatal and injury crashes sequentially.

Burke and Nishitateno (2015) published a study of gasoline prices and motor vehicle crash fatalities by using data for 144 countries from 1991 to 2010. They used country's oil reserves and the yearly international crude oil prices as instrument variables (IV), and they found 10 percent increase in gasoline price may reduce fatalities from 3 to 6 percent around the world. The application of IV established the causality relationship between gasoline price and fatalities.

Chi, Brown, Zhang and Zheng (2015) explored the time of gasoline prices' effect on traffic safety. The authors used 2004 to 2012 Mississippi motor vehicle crash data, and the outcomes were the number of non-fatal crashes, and the statistical methods are the BATS model and negative binomial regression. Their findings include a positive associations between the price of gasoline and the number of non-fatal crashes. Most importantly, they emphasized that the changing gasoline prices would take 9 to 10 months to be effective. This study is creative to consider how long the price of gasoline would take to affect the traffic safety. However, the generalization due to data limitation might be a major limitation of this study.

Gasoline Price and Motorcycle Fatality and Injury

Wilson et al. (2009) explored the relationship between gasoline prices and motorcycle fatalities. The authors described that gasoline price per gallon for all grades

(EIA data) sharply increased from 1998 to 2007. Particularly, the number of motorcycle fatalities (FARS data) closely tracked the changes of gasoline prices. Autoregressive integrated moving average regression were used to estimate the relationship between weekly gasoline price and motorcycle fatalities from 1990 to 2007 nationwide by controlling climate, and they found that a one dollar increase of gasoline price was associated with over 1,500 more motorcycle fatalities.

This study specifically focused on the number of motorcycle fatalities, and had a positive relationship with gasoline prices, which was an inverse relationship compared with total motor vehicle crash fatalities in previous studies. Moreover, this study provided a different perspective to evaluate the impact of increasing gasoline prices, and emphasized its negative effect - encouraging people to use a more fuel efficient transportation mode (such as motorcycle) but more dangerous, consequently, the crash risk was increased. However, some unobserved factors such as personal transportation preference and the effect of helmet laws were not considered in this study.

Hyatt et al. (2009) also estimated the effect of gasoline prices on motorcycle crashes, and they extended the effects to motorcycle injuries and personal vehicle fatalities and injuries from 1992 to 2007. The outcome in this study was the rate of all the occupants in an injured or fatal crash (per population and per registered vehicles). The gasoline price as a predictor was categories into four groups ($1.00-1.49, $1.50-1.99, $2.00-2.49, and $2.5+), and unemployment rate and per capita income were covariate variables. ARIMA regressions estimated that higher gasoline prices were significantly associated with higher numbers of motorcycle fatality per population. However, there was no association between motorcycle injury rate (per population) and motorcycle fatalities rate (per register motorcycles).

French and Gumus (2014) focused on the economic activities (including gasoline prices) and motorcycle fatalities in the U.S. Data on motorcycle fatalities came from 1988-2010 FARS at annual state level. Gasoline price was defined as annual average regular grade unleaded gasoline prices inclusive of federal and state taxes from EIA and FHWA. However, the authors found that there were not significant associations between inflation-adjusted gasoline prices and motorcycle fatalities rate after controlling unemployment rate, inflation-adjusted income per capita, and other motorcycle related measures (such as motorcycle registration per capita) and traffic safety policies (BAC limit and administrative license revocation). The coefficients implied gasoline prices had negative impact on motorcycle fatality rate, which was contradicted with previous studies.

Zhu, Wilson, & Stimpson (2014) used 2002-2011 California crash data, and examined the relationships between gasoline prices and motorcycle injuries, which were categorized into fatal, severe and minor injuries. Crash injury data were obtained from California's Statewide Integrated Traffic Records System, and monthly gasoline price of California for all grades including tax provided by EIA. The results showed gasoline prices were highly correlated with three types of injuries, and ARIMA regressions estimated that 800 fatalities and 10,290 non-fatal injuries resulted from gasoline price increase during the study period. Comparing to previous studies, this article was the first to examine severe and minor injuries and it also suggested that increasing gasoline prices lead to more riders, especially inexperienced riders, on the road resulting in more motorcycle injuries.

Gasoline Tax and Motor Vehicle Fatalities and Injuries

Leigh and Wilkinson (1991) estimated the effects of state gasoline taxes on fatalities from 1976 to 1980. Highway fatalities were defined as annual fatalities per 1,000 persons over age 15. A reduced form equation was used to examine the annual relationship between state gasoline tax and fatality rates by controlling inflation-adjusted income, percentage of young male and new cars, and alcohol consumption etc.. The authors found that a 10 percent increase in the gasoline tax per year would reduce fatalities by 1.8 to 2.0 percent, and they suggested that gasoline taxation is a tool for policy makers to reduce fatalities.

Grabowski & Morrisey (2006) used state-year data for 48 states from 1982 to 2000 to examine the effect of state gasoline tax on motor vehicle fatalities. It was found that $0.01 increase in state gasoline taxes was associated with 0.45 percent decrease in fatalities per capita and 0.42 percent decrease in fatalities per VMT. The authors suggested that the tax can reduce motor vehicle fatalities, and this effect was sustained over time.

Table 4-1: Summary of literature on gasoline price and traffic safety

Articles	Study Sample	Study Period	Outcomes	Main Findings
Leigh & Wilkinson (1991)	National (U.S.)	1976-1980	Fatalities per 1,000 persons age 15 or more	A 10 percent increase in the gasoline tax per year would reduce fatalities by 1.8 to 2.0 percent; and it suggested that higher gasoline tax was an alternative policy to reduce highway fatalities.
Grabowski & Morrisey (2004)	National (U.S.)	1983-2000	Fatalities per capita and per VMT	A 10 percent increase in the gasoline prices decreased fatalities by 2.3 percent over a 2-year period; and it indicated that the lower gasoline price was the important reason for the stability of motor vehicle fatality rate in the 1980s and 1990s.
Grabowski & Morrisey (2006)	48 States (U.S.)	1982-2000	Fatalities per capita and per VMT	A 10 percent increase in the gasoline tax indicated a 0.6 percent decrease in fatality rate, and it suggested that tax effect would sustained over time on reduce the fatalities.
Leigh & Geraghty (2008)	National (U.S.)	2003	Number of fatalities	997 fewer deaths one year in response to 10 percent increase in gasoline price; 1,994 fewer in response to 20 percent increase; and 4,984 fewer in response to 50 percent increase.
Wilson, Stimpson & Hilsenrath (2009)	National (U.S.)	1990-2007	Number of Motorcycle fatalities	One dollar increase of gasoline price was associated with over 1,500 more motorcycle fatalities.
Hyatt et al. (2009)	National (U.S.)	1992 - 2007	Motorcycle injury and fatality rate; automobile injury and fatality rate	Higher gasoline prices were significantly associated with a higher number of motorcycle fatalities and injuries per population; however, there was no association between motorcycle injuries per registered motorcycle and motorcycle fatalities per registered motorcycle.
Morrisey & Grabowski (2011)	National (U.S.)	1985 - 2006	Number of total fatalities and driver fatalities	A 10 percent increase in inflation-adjusted gasoline prices was associated with 6.7 percent reduction on fatalities for 15-17 young adult, 3.2 percent reduction for 18-20, and 3.7 percent reduction for 21-24.
Chi et al. (2010)	Mississippi (U.S.)	2004/04-2008/12	Number of motor vehicle crashes	1 percent increase in inflation-adjusted gasoline price was associated with 0.25 percent decrease in total MVCs per million VMT.

Table 4-1: Summary of literature on gasoline price and traffic safety (cont'd)

Articles	Study Sample	Study Period	Outcomes	Main Findings
Chi et al. (2011)	Mississippi (U.S.)	2004/04-2008/12	Number of drunk-driving crashes	Bigger effects on reducing fatal and injured drunk-driving crashes.
Chi et al. (2012)	Alabama (U.S.)	1999-2009	Number of motor vehicle crashes	1 percent increase in inflation-adjusted gasoline price was related to 0.21 percent decrease in monthly total MVC per 100,000 persons.
Chi et al. (2013a)	Mississippi (U.S.)	2004/04-2010/12	Number of motor vehicle crashes	1 percent increase in inflation-adjusted gasoline price was related to a 0.10 percent decrease at a 9-month lag, 0.16 percent decrease at 12-month lag and 0.12 percent decrease at 18-month lag.
Chi et al. (2013b)	Minnesota (U.S.)	1998-2007	Number of motor vehicle crashes	10 percent increase in gasoline price would be related to a 4.1 percent decrease in rural areas comparing with 2.8 percent decrease in urban areas.
Chi et al. (2015)	Mississippi (U.S.)	2004-2012	Number of all crashes rather than fatal crashes	Gasoline prices had a positive impact on crashes by 9 to 10 months after price changing.
Burke & Nishitateno (2014)	144 countries	1991-2010	Road deaths per 100,000 population	10 percent increase in gasoline price may orderly reduce fatalities from 3 percent to 6 percent around the world.
French & Gumus (2014)	National (U.S.)	1988-2010	Motorcycle fatalities per 100,000 people	The coefficients implied gasoline prices had negative impact on motorcycle fatality rate, but not significant.
Zhu et al. (2014)	California (U.S.)	2002-2011	Number of fatal, severe and minor motorcycle injuries	It was estimated that 800 fatalities and 10,290 non-fatal injuries resulted from gasoline price increase during the study period.

Application of System Dynamics in Traffic Safety

Studies have traditionally examined the motor vehicle crash risk attributable to road users, vehicles or environment separately. Moreover, most of these studies have taken a “road-user” approach, in which motor vehicle crashes are presumed to be associated only with human errors (Larsson, Dekker, & Tingvall, 2010; Muhlrad & Lassarre, 2005; Peden et al., 2004). In contrast, the WHO encourages researchers to use a complex systems approach to study road safety issues and factors associated with crash involvement other than human error, which may include vehicle, road and environmental factors (Peden et al., 2004).

Systems dynamics (SD) is defined as a computer-aided approach to model and facilitate analysis of system behaviors over time (Homer & Hirsch, 2006; Meadows, 2008; McClure et al., 2014). SD modeling has a number of advantages over traditional regression-based modeling. These advantages include permitting dynamic and non-linear analyses, examining the interaction and feedback mechanisms between the variables, predicting the long-term impact of different policy strategies and scenarios, and incorporating a large number of interrelationships between variables that ultimately shape outcomes (Meadows, 2008; Goh & Love, 2012; Sterman, 2000).

SD modeling has been widely used to understand road safety issues (Abbas & Bell, 1994; Fiorello, Fermi, & Bielanska, 2010; Minami & Madnick, 2010; Egilmez& Tatari, 2012; Young, Sobhani, Lenne, & Sarvi, 2014), and it has been used to assess performance of traffic systems and to simulate driver behaviors. Sterman (2000) constructed an SD model to explain why road-building programs are unlikely to alleviate traffic congestion. Friedman (2006) used an SD model to evaluate the effect of road conditions on crash incidence. Another study constructed an SD model to simulate driver behavior in relation to law enforcement, traffic monitoring, and education for the Emirate of Abu Dhabi (Mehmood, 2010). A recent study by Goh and Love (2012) utilized SD models to analyze whether subsidization of car safety technologies would decrease motor vehicle crashes.

Summary of Literature

To sum up, most previous studies suggested a negative relationship between gasoline prices and motor vehicle crash fatalities and injuries. However, there are several controversies and gaps due to various data, methods and measures. First, most of these studies focused on MVC fatalities, which is the smallest proportion among all the MVCs. Second, about one third of these studies are from Chi and his colleagues, and the authors used the number of crashes as outcomes compared with other studies using number of fatalities and injuries. They may not be comparable. Third, only one study (Hyatt et al., 2009) stratified between passenger cars and motorcycles, because it has been found that the gasoline price has had opposite effects; however, it is unclear which effect was larger. Fourth, the gasoline price has regional differences, and it may have different impacts in different regions, Chi and his colleagues used data from Alabama and Mississippi; however, these states share a small proportion of total U.S. fatalities, which may not be generalized. Finally, only one study used simulation to set different scenarios for gasoline price increases (Leigh & Geraghty, 2008), and all others applied traditional statistical analyses, which may ignore non-linear and feedback relationships among the measures.

Rationale

This study extends and improves upon the existing literature: 1) Measure improvement: Medical records provide an evidence-based measure for injuries, and they also can reflect medical care needs and costs. 2) Representativeness improvement: Extend previous studies to a comprehensive study to cover more states in the United

States. 3) Method improvement: Add the application of a system dynamic approach, which has several advantages comparing with statistical regressions.

CHAPTER 5 : SPECIFIC AIM 1- THE RELATIONSHIP BETWEEN THE PRICE OF GASOLINE AND INPATIENT HOSPITALIZATION OF MOTOR VEHICLE INJURIES

Methods

Data Sources

Data on inpatient hospitalization of motor vehicle injuries were obtained from the 2001-2010 Nationwide Inpatient Sample (NIS) database as part of the Healthcare Cost and Utilization Project (HCUP), sponsored by the Agency for Healthcare Research and Quality (AHRQ) (*HCUP Databases*, 2015). The NIS is a nationally representative patient-level hospitalization database, and it is also the largest publicly available all-payer hospital inpatient database in the U.S. (*HCUP Databases*, 2015).

The NIS was created by sampling 20% of hospitals drawn from the HCUP State Inpatient Databases (SIDs), which HCUP participating states provide inpatient discharge records from all community, non-rehabilitation hospitals (excluding long-term acute-care hospitals) within the their states (*HCUP Databases*, 2015). The strata include region, urban or rural location, teaching status, ownership and bed size. In 2010, the NIS data have contained 1,051 hospitals located in 45 states with 7.8 million unweight and 39 million weighted inpatient discharge records (*HCUP Introduction to the HCUP Nationwide Inpatient Sample*, 2012).

The NIS data elements include both clinical and non-clinical information for hospitalized patients, such as diagnoses, treatment procedures, disposition status, patient demographics, and expected source of payment and total charges (*HCUP Databases*, 2015). Furthermore, the HCUP provides cost-to-charge ratios at the hospital or state peer group level, which can be used to estimate the health care service cost or hospital received payment (*HCUP Cost-to-Charge Ratio Files*, 2015).

Based on the design and data elements above, the NIS can be used to estimate national and regional trends in inpatient utilization, and quality, especially for health service charge and costs (*HCUP Trend Weights for 2001-2010 HCUP NIS Data*, 2015). The strength of this large sample enables analysis of rare conditions using NIS. Prior to 2012, data can be linked with the American Hospital Association Annual Survey Database to combine more information (HCUP Databases, 2015). The NIS has been broadly used to analyze hospitalization issues in the U.S., especially for utilization and economic burden.

Data on prices of gasoline were reported by the Federal Highway Administration (FHWA), which were the sum of retail regular gasoline prices (excluding taxes) from the U.S. Energy Information Administration (EIA) and federal and state taxes (excluding local and sale taxes) from the FHWA (FHWA, 2015). The EIA collects prices for regular, medium and premium grade gasoline by telephone every Monday from a sample of self-serve retail gasoline outlets in the U.S (EIA, 2015). EIA price data were compiled using weighted average prices at city, state, regional and national levels based on the number of pumps, sales volume, grades and geographic areas. The FHWA collected federal and state tax rates for motor fuel and added these taxes into EIA price data to retrieve monthly retail prices at regular, medium and premium grades for 50 states (District of Columbia was excluded because of non-disclosure) (FHWA, 2015). Although EIA provides the annual, monthly, and weekly retail gasoline price data for national, regional and several states (14 states), its definition of states in each region is not consistent with NIS's (EIA, 2015). Therefore, FHWA data were chosen in this study other than EIA.

In addition, data on climate (including precipitation and temperature) were derived from National Climatic Data Center, U.S. Department of Commerce, population from U.S. Bureau of the Census, unemployment rate from U.S. Bureau of Labor Statistics, and income per capita from U.S. Bureau of Economic Analysis. All above data were linked by region-month to create a new dataset for the analysis in this study.

Study Sample

This study focused on inpatient hospitalization for motorcycle and non-motorcycle motor vehicle (NMCMV) injuries. Motorcycle injuries were defined as the rider (motorcyclist) and passenger on a motorcycle; NMCMV injuries include driver and passenger in a motor vehicle other than motorcycle. Other types of motor vehicle injuries (e.g. rider of animal, pedestrian and other specified persons etc.) were excluded from this study because these types of transportation were not directly related to gasoline consumption.

A motor vehicle subgroup of NIS was identified through two steps. First, all motor vehicle injuries were identified by E codes (Motor vehicle traffic accidents: E810 to E819; Table S5-1 in Appendix) (CDC, 2011b). Prior to 2003 in the NIS, E codes were mixed with other diagnosis codes, and E codes have separate E codes variables as a secondary diagnosis since 2003. Second, the fourth digit of E codes was used to define victim types: non-motorcycle motor vehicle (0-driver and 1-passenger) and motorcycle (2-rider and 3-passenger), all the person type categories can be found in Table S5-2 (Appendix).

Since the NIS design only allows national and regional estimation, the observation unit was aggregate region monthly data in this study. The region definition can be found in Figure 5-1 (Table S5-3 in Appendix). The state of Florida in South region was excluded from this study due to the unavailability of admission month data from

2001 to 2010. Annual Florida data were checked to have similar trends with all other data in the South region. It was estimated there were a total of 2,415,029 (95% CI, 2,220,393-2,609,665) inpatient hospitalizations for motor vehicle injuries from 2001 to 2010: 1) Northeast region accounted for 20.0% of the total sample (392, 958; 95% CI, 316,599-469,318); 2) Midwest region accounted for 21.3% (419,022; 95% CI, 361,545-476,498); 3) South region accounted for 35.8% (703,969; 95% CI, 593,328-814,610); and 4) West region accounted for 22.9% (450,697; 95% CI, 378,506-522,888).

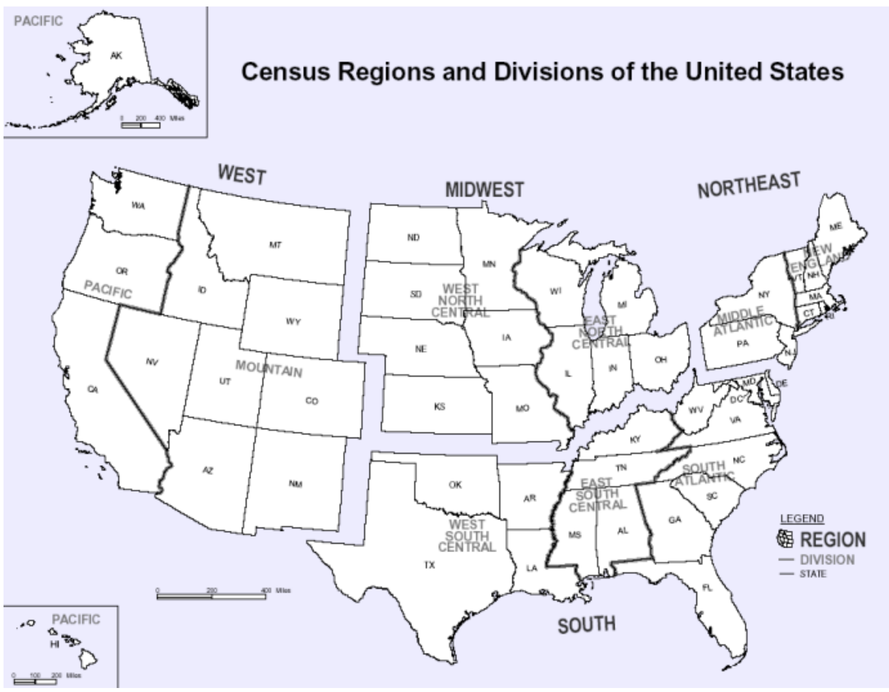

Figure 5-1: The U.S. Census Region

Source: U.S. Bureau of Census

Measures

The number of MVC inpatient hospitalizations refers to aggregate individual MVC injuries admitted to inpatient treatment for each month and each region, and this number was stratified by victim types (motorcycle and non-motorcycle motor vehicle).

Correspondingly, the NMCMV and motorcycle hospitalization rates (per 10 million population) were calculated by the aggregate numbers dividing annual region population.

Monthly gasoline price was defined as regular gasoline price per gallon including federal and state taxes in each region, which was the average price of the states in each region. All prices are adjusted to 2010 dollars using the Consumer Price Index (CPI).

Income per capita was the annual income per capita on average for states in each region, and it is also adjusted to 2010 dollars using the CPI. Unemployment rate was the monthly percentage of unemployed people in total labor force, and it was seasonal adjusted and on average of states in each region. In the previous studies, income and unemployment rate were found to be correlated with traffic safety, and they were usually included at covariates (Grabowski & Morrisey, 2004; Hyatt et al., 2009). We also measured climate data, which may affect the risk of a MVC (French & Gumus, 2014; Wilson et al., 2009). Temperature was monthly average temperature for the states in the region, and the precipitation was the monthly average level in inches. The descriptive statistics of these variables can be found in the Table 5-1.

The demographic characteristics of crash victims include occupant type (driver/ rider and passenger), gender (male and female), age (<16, 16-20, 21-29, 30-44, 45-64, and 65 and more years old), race/ethnicity (Non-Hispanic white, Black, Hispanic and others), and median household income for patient’s zip code. There were four quartiles for median household, and higher number of quartile represents higher median income; the range may vary in accordance with the economic development, for instance, the 2008 median income quartiles were defined as: 1st Quartile was from $1 to $38,999; 2nd Quartile was from $39,000 to $47,999; 3rd Quartile was from $48,000 to $62,999; and 4th Quartile was $63,000 and more (*HCUP Databases*, 2015).

Table 5-1: Descriptive statistics of the variables

Variables	Obs.	Mean	Std. Dev.	Min	Max
Monthly non-motorcycle motor vehicle related inpatient admission (per 10 million population)	480	489	97	295	828
Monthly motorcycle-related inpatient admission (per 10 million population)	480	92.21	53.78	3	206
Monthly inflation-adjusted gasoline price ($ per gallon)	480	2.35	0.59	1.23	4.09
Monthly precipitation (inch)	480	3.06	1.6	0.51	11.8
Monthly temperature (degree F)	480	51.61	16.67	15.52	81.16
Monthly unemployment rate (%)	480	5.68	1.56	3.42	9.38
Annual inflation-adjusted income per capita ($000s)	480	39.75	3.28	35.68	47.03

Statistical Analysis

We observed 4 regions from 2001 to 2010, and there were 480 region-month observations. We first describe the trends of annual hospitalization per 10 million population for motorcycle and non-motorcycle motor vehicle injuries, and their percentages of all MVC inpatient hospitalizations and inflation adjusted gasoline prices over time. Second, the demographic characteristics of inpatients for crash victims were summarized and compared; chi-square tests were used to assess differences between NMCMV and motorcycle injuries. Lastly, panel feasible generalized least squares (PFGLS) models were used to examine the relationship of inflation-adjusted gasoline prices to NMCMV and motorcycle hospitalizations per 10 million population. PFGLS was chosen because 1) Generalized linear squares models are generally more efficient than having a dummy variable for each entity (Cameron & Trivedi, 2010; Dobson & Barnett, 2008; Liang & Zeger, 1986); 2) Data with 4 region and 120 months were a typical long panel data format (Large T, Small N). Comparing with panel data with large N and Small T, long panel data may encounter several issues similar to time series data (Baltagi, 2008; Cameron & Trivedi, 2010).

Before the regression, we first checked the stationarity by using the Levin-Lin-Chu (LLC) unit-root test (Hadri, 2000; Levin, Lin, & Chu, 2002), and we also checked co-integration and serial correlation (Torres-Reyna, 2013). The test results showed that the month-region NMCMV and motorcycle hospitalization rates were stationary with no co-integration. However, serial correlation existed. Therefore, a panel specific first-order autoregressive process (AR(1)) was used, which allows each group to have errors that follow a different AR(1). Finally, PFGLS models with heteroskedastic and correlated error structure were used to examine the coefficients. Statistical analyses were performed by Stata 13.0 (Stata Corp, College Station, TX).

Results

Table 5-2 presented inflation-adjusted gasoline prices, annual weighted numbers and rates for motor vehicle inpatient hospitalizations. The inflation-adjusted gasoline price was $1.63 in 2002, then it doubled to be $3.20 in 2008, even the price was over $ 4.0 in several states (e.g., California). There was a significant decrease for gasoline price in 2009, which may be affected by the world oil market; however, it rose to $2.73 in 2010. At the same time, it was estimated that there were 1,653,641 (95%CI, 1,516,264 - 1,791,019) NMCMV and 313,005 (95%CI, 285,896 - 340,113) motorcycle inpatient hospitalizations in the 4 regions (South region excluded Florida) from 2001 to 2010. Annual average NMCMV and motorcycle hospitalization rates were 5,933 and 1,117 per 10 million population, respectively. In general, the number and rate of motorcycle inpatient hospitalizations generally continually increased over time. In 2010, about 39,608 motorcycle crash victims were admitted to inpatient care comparing to about 22,412 in 2001. Also, the hospitalization rate per 10 million population reached 1,363 in 2010 from 834 in 2001. In contrast, the NMCMV inpatient number and rate declined from 2003 (194, 321 and 7,115 per 10 million population) to 2009 (141,570 and 4,914 per 10 million population) every single year, while inflation-adjusted gasoline increased during this period.

As illustrated in Figure 5-2, the annual correlation coefficient between inflation-adjusted gasoline prices and motorcycle-related MVC inpatient hospitalizations as a percentage of all MVC inpatient hospitalizations was 0.88. When the gasoline price declined in 2009, the motorcycle MVC percentage also declined, then it rose again with increasing gasoline prices in 2010. In particular, there was a 60% increase in motorcycle MVC (9.8% in 2001 vs 15.7% in 2010). In addition, the annual correlation coefficient between inflation-adjusted gasoline prices and the percentage of NMCMV in total MVC inpatient hospitalization was -0.74, while this percentage had a decreasing trend which gasoline price increased. The NMCMV percentage decreased from 72% in 2001 to 64% in 2010.

Table 5-3 summarized and compared the demographic characteristics between NMCMV and motorcycle crash victims. In general, driver or rider, middle age (30 to 64 years old), male, and Non-Hispanic White shared more NMCMV and motorcycle injuries; however, motorcycle injuries seemed to be more concentrated in these groups. It was estimated that 69.4% (95%CI, 68.8-69.9%) were drivers of motor vehicle other than motorcycle and 93.2% (95%CI, 92.9-93.5%) were motorcycle riders. In terms of age, over 60% of motorcycle injuries were between 30 and 64 years old, and younger (15-20 years old) and older (65+ years old) patients shared higher proportions for NMCMV comparing with motorcycle. For median household income, it was almost equally distributed in four quartiles for NMCMV; however, higher median household incomes at the patient's zip code level had a higher percentage of motorcycle inpatient hospitalization. All chi-square tests reported significant differences of patient characteristics between NMCMV and motorcycle inpatient hospitalizations. Although the state of Florida was excluded from this study sample, we also described the same trends and characteristics with Table 5-2 and 5-3 (Table S5-4 and S5-5 in Appendix).

Table 5-4 presented a set of regression results from the PFGLS models, which estimated the effect of changing inflation-adjusted gasoline prices on NMCMV and motorcycle hospitalization rates per 10 million population. For NMCMV hospitalization rate, Model 1 estimated the effect of gasoline price after controlling precipitation, temperature, unemployment rate, inflation-adjusted income per capita and panel-specific AR1 and excluding region-, year-, and month-fixed effects. Model 2 added the year- and month- fixed effects, and Model 3 added region-fixed effect based on Model 2. The coefficients of gasoline prices indicated a negative impact on NMCMV hospitalization rate. According to Model 2, it was estimated that a 1 dollar increase in monthly average inflation-adjusted gasoline prices was associated with about 23 more NMCMV inpatient hospitalization per 10 million population adjusting for confounding factors. Similarly, the coefficients from Model 4, 5, and 6 implied a positive relationship between inflation-adjusted gasoline prices with motorcycle hospitalization rates; a 1 dollar increase in gasoline prices resulted in 10 more motorcycle inpatient hospitalizations per 10 million population. Also, compared to the non-significant relationship of control variables in the NMCMV models, precipitation has significantly negative effects on motorcycle hospitalization rates, while temperature showed significantly positive effects. The effects of the unemployment rate and income per capita were not statistically significant after controlling region- and year-fixed effects.

Table 5-2: Weighted numbers, hospitalization rate per 10 million population by year and crash victim type: NIS, 2001 – 2010

	Gasoline price [a]	Motor vehicle [b]			Non-motorcycle motor vehicle			Motorcycle		
Year	$	N	95%CI	Rate	N	95%CI	Rate	N	95%CI	Rate
2001	1.73	228,380	191,360 - 265,400	8,502	164,572	136,973 - 192,171	6,127	22,412	18,705 - 26,119	834
2002	1.63	236,835	196,915 - 276,754	8,741	168,296	138,892 - 197,699	6,212	23,059	19,065 - 27,053	851
2003	1.79	273,404	222,806 - 324,003	10,011	194,321	158,131 - 230,510	7,115	30,107	24,127 - 36,087	1,102
2004	2.08	266,806	218,276 - 315,336	9,688	187,946	152,937 - 222,954	6,825	32,303	26,066 - 38,540	1,173
2005	2.46	246,595	204,339 - 288,850	8,881	171,782	141,608 - 201,957	6,186	30,252	24,817 - 35,686	1,089
2006	2.71	245,466	201,385 - 289,546	8,760	168,241	137,675 - 198,806	6,004	33,015	26,758 - 39,272	1,178
2007	2.86	219,594	177,318 - 261,870	7,763	144,805	116,882 - 172,727	5,119	32,520	25,923 - 39,117	1,150
2008	3.20	225,296	183,319 - 267,273	7,889	149,777	121,344 - 178,210	5,245	35,715	28,378 - 43,052	1,251
2009	2.32	219,542	180,193 - 258,891	7,620	141,570	115,936 - 167,204	4,914	34,013	27,392 - 40,635	1,181
2010	2.73	253,112	207,047 - 299,177	8,713	162,333	132,742 - 191,924	5,588	39,608	31,811 - 47,406	1,363
Total/ Mean	1.73	2,415,029	2,220,393 - 2,609,665	8,657	1,653,641	1,516,264 - 1,791,019	5,933	313,005	285,896 - 340,113	1,117

Notes: a. Gasoline price was the average price of the states except Florida; b. Motor vehicle includes all injured occupants defined by E code 810.0-819.9. Florida was excluded.

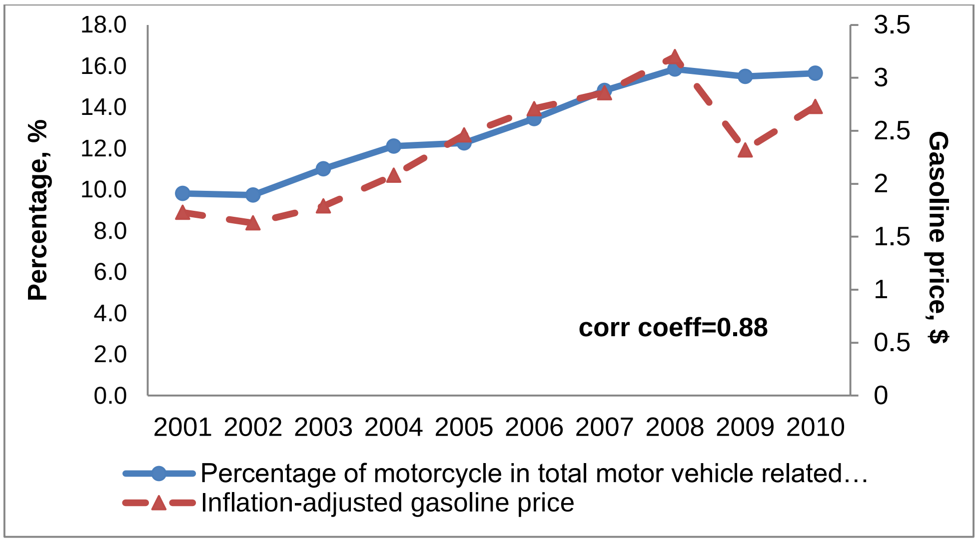

Figure 5-2: Inflation-adjusted gasoline prices and percentages of motorcycle-related inpatient admissions out of all motor vehicle crash inpatient hospitalizations, NIS 2001-2010

Notes: Florida was excluded.
corr coeff: Correlation coefficient.

Table 5-3: Demographic characteristics of inpatients for crash victims by vehicle mode, NIS 2001-2010

	Non-Motorcycle Motor Vehicle Inpatient Hospitalization				Motorcycle Inpatient Hospitalization				
	N	**95% CI**	**%**	**95% CI**	**N**	**95% CI**	**%**	**95% CI**	**P-value**
Occupant Type									
Driver/Rider	1,146,900	1,049,605 - 1,244,194	69.4	68.8 - 69.9	291,755	266,726 - 316,783	93.2	92.9 - 93.5	<0.001
Passenger	506,741	465,186 - 548,297	30.6	30.1 - 31.2	21,250	19212 - 23287	6.8	6.5 - 7.1	
Age									
<15	81,458	70,931 - 91,985	4.9	4.4 - 5.5	6,514	5,774 - 7,255	2.1	1.9 - 2.3	<0.001
15-20	246,764	223,299 - 270,229	15	14.7 - 15.3	23,392	21,269 - 25,514	7.5	7.2 - 7.8	
21-29	315,908	286,125 - 345,690	19.2	18.8 - 19.5	62,229	56,543 - 67,914	20.0	19.4 - 20.6	
30-44	359,211	326,530 - 391,892	21.8	21.4 - 22.2	101,383	92336 - 110430	32.5	32.0 - 33.1	
45-64	371,429	341,381 - 401,478	22.5	22.2 - 22.8	107,084	97463 - 116705	34.4	33.6 - 35.1	
65+	275,067	256,805 - 293,329	16.7	16.2 - 17.2	11,172	10,058 - 12,287	3.6	3.4 - 3.8	
Gender									
Male	908,040	829,159 - 986,921	55.2	54.9 - 55.6	271,081	247750 - 294412	87.5	87.1 - 87.8	<0.001
Female	736,662	678,393 - 794,930	44.8	44.4 - 45.1	38,846	35,287 - 42,404	12.5	12.2 - 12.9	
Race/Ethnicity									
White	856,739	772,069 - 941,408	68.5	66.3 - 70.7	193,295	173849 - 212741	79.7	77.8 - 81.5	<0.001
Black	144,775	123,915 - 165,634	11.6	10.4 - 12.9	19,759	16,788 - 22,730	8.2	7.2 - 9.2	
Hispanic	162,752	135,906 - 189,598	13	11.3 - 14.9	18,874	15,310 - 22,439	7.8	6.6 - 9.2	
Other	86,056	74,137 - 97,975	6.9	6.2 - 7.7	10,510	8,843 - 12,176	4.3	3.7 - 5.0	
Median Household Income for Patient's Zip Code									
1st Quartile	387,999	344,953 - 431,045	24.2	22.5 – 26.0	60,211	53,138 - 67,284	19.8	18.3 - 21.4	<0.001
2nd Quartile	411,304	374,932 - 447,676	25.7	24.6 - 26.7	74,765	67,517 - 82,014	24.6	23.5 - 25.7	
3rd Quartile	393,405	356,650 - 430,159	24.5	23.6 - 25.5	82,708	74,828 - 90,588	27.2	26.2 - 28.2	
4th Quartile	410,918	362,868 - 458,967	25.6	23.6 - 27.8	86,408	76,975 - 95,840	28.4	26.4 - 30.5	

Notes: Florida was excluded.

Table 5-4: Estimations of PFGLS models for non-motorcycle motor vehicle and motorcycle hospitalization rates per 10 million population, 2001-2010

Independent Variables	Monthly Non-Motorcycle Motor Vehicle Inpatient Hospitalization Rate			Monthly Motorcycle-related Inpatient Hospitalization Rate		
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Monthly inflation-adjusted gasoline price ($ per gallon)	-43.63***	-23.27*	-21.90*	9.96**	9.54**	10.16**
	(11.88)	(9.03)	(9.21)	(2.92)	(3.55)	(3.90)
Monthly precipitation (inch)	0.32	-1.00	-1.94	-3.66***	-3.21***	-3.10***
	(1.62)	(1.36)	(1.29)	(0.53)	(0.54)	(0.55)
Monthly temperature (degree F)	1.10***	0.34	-0.53	1.94***	2.10***	2.18***
	(0.30)	(0.50)	(0.50)	(0.20)	(0.22)	(0.22)
Monthly unemployment rate (%)	-1.86	-4.25	-8.03	3.91**	4.26**	4.94
	(5.58)	(7.43)	(7.87)	(1.25)	(1.12)	(3.01)
Annual inflation-adjusted income per capita ($1,000)	4.92*	6.72***	-26.23	2.39***	1.93	0.78
	(1.91)	(1.86)	(16.69)	(0.49)	(1.81)	(3.93)
Region-fixed effects	NO	NO	YES	NO	YES	YES
Month-fixed effects	NO	YES	YES	YES	YES	YES
Year-fixed effects	NO	YES	YES	NO	NO	YES
Pane-specific AR1	YES	YES	YES	YES	YES	YES

Notes: Standard errors are presented in parentheses. Florida was excluded.

Discussion

Results from our study show a significant relationship between inflation-adjusted gasoline prices and motor vehicle injury hospitalization in the U.S. (excluding Florida); however, it was found that gasoline prices have adverse impacts on motorcycle and non-motorcycle motor vehicle injuries. It was estimated that a $1.00 increase in inflation-adjusted gasoline price was associated with 23 fewer non-motorcycle motor vehicle injury hospitalizations per 10 million population, but 10 more motorcycle injury hospitalizations per 10 million population at the same time. Furthermore, we also predicted hospitalization rates assuming that the gasoline price had remained $1.73 (in 2010 dollars). This suggests that over 48,576 non-motorcycle motor vehicle hospitalizations would have been avoided, but over 20,000 motorcycle hospitalizations would have occurred. Also, motorcycle crash victims were more likely to be the riders, middle-aged, female, and non-Hispanic white comparing to non-motorcycle motor vehicle ones.

This study extended previous studies of gasoline price and motor vehicle fatalities, and it indicated that gasoline price had substantial impact on severe motor vehicle injuries. In the literature, the outcomes were either motor vehicle fatalities or total crash and injury, but they didn’t differentiate the injury severity for the victims. In fact, the severity of injury usually is an important measure to assess the need of medical care and the quality of life. Based on the estimation of our study (Table S5-3 in Appendix) and NHTSA’s public data (Table S2-2 in Appendix), about 10% of motor vehicle injuries were admitted to inpatient care from 2001 to 2010. Our study of motor vehicle injury hospitalization highlighted the importance of the impact of gasoline price on traffic safety and associated medical care provision.

Moreover, our study was the first to use the same data source to estimate the effects on both motorcycle and non-motorcycle motor vehicle injuries, thus increasing their comparability. Most previous studies did not separate motorcycle from non-motorcycle collisions or injuries. However, several studies on gasoline prices and motorcycles have found a positive relationship (Hyatt et al., 2009; Wilson et al., 2009; Zhu et al., 2015). Although the number of overall motor vehicle fatalities has decreased by about 20% in the first decade of the 21st century, motorcycle safety issues have attracted more attention from policy makers. According to the NHTSA (2013), motorcyclist fatalities increased every year from 1994 to 2008; in 2008, 5,312 motorcyclist fatalities accounted for 14% of all motor vehicle deaths. Our findings provide support that rising gasoline prices contributed to the increase of motorcycle injury hospitalizations. Similar to motorcycle fatalities, motorcycle injury hospitalizations almost doubled from 2001 to 2010.

One interpretation of the negative relationship between gasoline price and non-motorcycle motor vehicle injuries is that high gasoline prices might incentivize people to drive less and, consequently, reduce their injury exposure risk. In 2008, gasoline prices reached over $3.00 per gallon, and the VMT for automobiles and trucks declined after continuously increasing over the prior two decades. Several studies reported a negative gasoline price elasticity on gas consumption or VMT. VMT per vehicle decreased 10% from 12,600 miles in 2001 to 11,400 miles in 2010 annually. Hughes et al. (2006) computed that the price elasticity of gasoline prices was between -0.034 to -0.077, which means that the usage of gasoline declined between 0.34 percent and 0.77 percent if gasoline prices increased 10 percent. The Congressional Budget Office reported that a 10 percent increase of the gasoline price would reduce VMT by 1.1 to 1.5 percent (Austin, 2008). Also, previous studies mentioned people may drive slowly in response to high gasoline prices, increasing driving safety (Leigh & Wilkinson, 1991), and gasoline prices may have a disproportionate effect of reducing non-motorcycle motor vehicle injuries among young adults. Our results showed that people under 20 years old shared 17% of total NMCMV injury hospitalizations in 2010 compared to over 21% in 2001. However, several traffic safety policies, especially targeted toward teen drivers, have been implemented during the same period, and it is unclear whether this decline was related to rising gasoline prices.

Furthermore, high gasoline prices may encourage people to shift from private cars to alternative transportations modes in order to reduce travel costs. For example, people may take public transportation (such as buses and subways), which may also reduce the probability of injuries. Lane (2010) found that increasing gasoline prices was significantly associated with increased amount of transit ridership in nine major U.S. cities, especially for more car-dependent cities. The American Public Transportation Association (2011) estimated an additional 670 million passenger trips per year when regular gasoline price reached $4 per gallon.

On the contrary, people may substitute private cars with motorcycles by either purchasing motorcycles or riding them more frequently. Hedlund (2013) reported the number of motorcycle registration has tracked closely to gasoline price changes since 1972. One of the attractions of a motorcycle is its fuel economy; average fuel economy of motorcycles was about 43.54 Motor Press Guild (MPG), which almost doubled the passenger cars' MPG (U.S. Department of Energy, 2015). In other words, a motorcycle can travel over 43 miles by consuming one gallon gasoline on average while a passenger car can travel about 23 miles per gallon. Moreover, a motorcycle usually costs less than a passenger car. According to the Motorcycle Industry Council (2010), the average price for an on-highway motorcycle was $5,612 in 2009, while the average transaction price of a passenger car was almost $30,000 (Healey, 2013). Nevertheless, riding a motorcycle has a substantially higher risk of injury. For example, NHTSA (2013) reported that motorcyclists were over 26 times more likely to die than passenger car occupants for every mile travelled.

In addition, increasing road congestion problems may also attract more people to ride motorcycles as a way to save travel time. For example, lane splitting for motorcyclists is allowed in California. At the same time, a large number of riders may not be properly trained or experienced in riding motorcycles. The pioneering study on motorcycle safety by Hurt and colleagues based on 900 in-depth crash investigations of motorcycle riders found that 92% of riders involved in crashes were self-taught or had learned to ride from friends and family (Hurt, Quellet and Thom, 1981). The above factors may work in concert with rising gasoline prices to substantially increase people's incentives to consider motorcycling as a reasonable alternative to driving.

Besides the evidence for the effect of gasoline prices on reducing motor vehicle fatalities, severe injuries and overall crashes found in previous studies along with this study, high gasoline prices are also linked to several positive externalities, such as reducing air pollution from less gas consumption and reducing congestion from the decrease in VMT.

To sum up, in the first decade of the 21st century, the significant increase of inflation-adjusted gasoline prices has had a negative relationship with severe motor vehicle injuries in the U.S. However, this impact on overall motor vehicle injuries has been mitigated by the positive relationship between gasoline prices and motorcycling. More attention should be paid to motorcycle safety with increasing gasoline prices.

There are several limitations for this study. First, the state of Florida was excluded from this study because admission month was missing from the data. Because the NIS is not a state-representative sample, this exclusion may affect the results. However, it is not reasonable to impute the data due to limited information and a traffic safety culture that may be specific to Florida. For instance, motorcycle injuries all show a strong seasonal pattern in all other regions or states, e.g., higher injuries in summer and lower in winter. However, Florida shows a different pattern, which may be related to warm weather. Second, the NIS did not provide information related to the car and crash, such as type of car, alcohol involvement or drug involvement, appropriate equipment used, and other factors which may affect the severity of injury. Third, we excluded other types of injured persons in a motor vehicle crash, because they may not be directly related to gasoline use such as horse riders, pedestrian and other specified persons, etc. Finally, we have no data on individual motivations to ride motorcycles (e.g., riding for leisure or commuting), and thus it is not possible to determine the extent to which rising gasoline prices result in changing patterns of commuting or non-commuting trips.

CHAPTER 6 : SPECIFIC AIM 2 – GASOLINE PRICES, TAXATION AND HOSPITAL COST FOR MOTOR VEHICLE INJURIES

Methods

The HCUP NIS data from 2001 to 2010 were analyzed for this specific aim, which has been described in Specific Aim 1. Specific Aim 2 also used the same study sample with Specific Aim 1, and this aim focused on medical outcomes of MVC injuries and associated hospital cost.

Measures

According to the HCUP Clinical Classifications Software (CCS), the principle injury diagnoses were categorized: 1) Crushing injury or internal injury; 2) Fracture of lower limb; 3) Fracture of neck of femur (hip); 4) Fracture of upper limb; 5) Intracranial injury; 6) Joint disorders and dislocations, trauma-related; 7) Open woods of extremities; 8) Open wound of head, neck and trunk; 9) Other fractures; 10) Skull fractures; 11) Spinal cord injury; 12) Sprains and strains; and 13) other diagnoses.

Primary payers included Medicare, Medicaid, private, self-pay, no charge and others. Other payers include charity care, CHAMPUS/TRICARE, worker's compensation, and Indian Health Services.

Disposition of status represented the destination of patients after inpatient admissions, and it consisted of routine discharge, transfer to short-term hospital, other transfers (skilled nursing facility, intermediate care and another type of facility), home health care, left against medical advice, died in hospital and discharged alive, destination unknown.

Length of stay was a count variable measured by number of days. If a patient was discharged in the same day as the admission day, length of stay was coded to be 0.

Total charge for individual inpatient hospitalization was provided by SID, but edited by HCUP depending on the data source and year. Generally, the total charges did not include professional fees and non-covered charges, and the range of total charges was between $25 to $1.0 million from 1998 to 2006, and between $100 and $1.5 million from 2007 to 2010 (*HCUP Databases*, 2015). In fact, the total charge value was not actual health service cost or the payment hospital received for this case, which should be considered using cost-to-charge ratios (CCRs). HCUP provides CCRs every year from 2001, constructed using all-payer, inpatient cost and charge information from the detailed reports by hospitals to the Centers for Medicare and Medicaid Services. There were two types of CCRs provided: 1) the all-payer inpatient cost/charge ratio (APICC) is hospital-specific, all-payer inpatient CCR; 2) the group average all-payer inpatient cost/charge ratio (GAPICC) is a weighted average for the hospitals in the group (defined by state, urban/rural, investor-owned/other, and number of beds), using the proportion of group beds as the weight for each hospital. The total cost was estimated by multiplying total charge and relevant CCR. A mix of CCRs was used in this study as recommended by HCUP, and we use APICC first, and then use GAPICC when APICC was not available. For missing total charge and CCR, we do the listwise deletion. The mean of the total cost was estimated by averaging total cost for all possible cases.

Gasoline tax included both federal and state taxes per gallon; the tax rate can be found in Appendix Table S6-3. Federal taxes have been 18.4 cents tax per gallon gasoline since 1997, and the average state tax was about 24 cents per gallons (FHWA, 2015). In this aim, we define the gasoline tax as the sum of federal and state taxes, which is also inflation adjusted by the CPI to 2010 dollars.

Statistical Analysis

We analyzed motor vehicle-related inpatients' diagnosis, payer and disposition and related hospital stays and cost and stratified by motorcycle and non-motorcycle motor vehicle crash victims. Chi-square tests were used to analyze the differences between non-motorcycle motor vehicle and motorcycle inpatient hospitalizations. Then, based on the estimated effects of gasoline prices on motor vehicle hospitalization rate from Specific Aims 1, we predicted the number of motorcycle and non-motorcycle vehicle hospitalization by multiplying the coefficient and number of population. Finally, the total cost of crash hospitalization was calculated by multiplying the estimated number and mean of total cost per case. Statistical analyses were performed by Stata 13.0 (Stata Corp, College Station, TX).

Results

Table 6-1 presents the injury diagnosis, primary payer and disposition status for motorcycle and NMCMV hospitalizations, and Table 6-2 describes the average length of stay and hospital cost for above categories. It was estimated that the mean of length of stay was 5.5 days (95%CI, 5.20-5.90 days) for NMCMV and 6.2 days (95%CI, 6.02-6.42 days) for motorcycle hospitalization, and mean hospital cost was $17,105 (95%CI, $16,458-$17,752) for NMCMV and $20,452 (95%CI, $19,630-$21,274) for motorcycles. Motorcycle crash victims have had a longer stay and higher cost than NMCMV on average.

Intracranial injury, other fractures, fracture of lower lib, and crushing injury or internal injury were the most common principle injury diagnoses for NMCMV injuries, and they accounted for 17.8% (95%CI, 17.0-18.6%), 17.7% (95%CI,17.3-18.2%), 13.3% (95%CI, 12.9-13.6%) and 12.3% (95%CI, 12.0-12.6%), respectively. Correspondingly, the average costs per case were $21,019, $16,378, $20,531 and $21,178 for intracranial injury, other fractures, fracture of lower lib, and crushing injury or internal injury, respectively. At the same time, the most common principle diagnosis was fracture of the lower limb, which accounted for 27.5% (95%CI, 27.0-28.1%) of motorcycle hospitalizations, and its average cost was about $20,588 (95%CI, $19,701 - $21,476) with 6.0 days stay (95%CI, 5,8-6.2 days). Number of motorcycle hospitalizations doubled that of NMCMV for fractures of lower and upper limb. Total cost of spinal cord injury averaged $63,323 (95% CI, $58,782-$67,864) for motorcycle patients and $51,040 (95% CI, $48,882-$53,198) for NMCMV patients, which was the most severe injury.

In terms of primary payer, about 65% (95%CI, 63.4-66.3%) and 15% (95%CI, 13.9-16.1%) of motorcycle patients were paid by private payers and individuals, respectively. Medicare and Medicaid payment accounted for about 12% of motorcycle hospitalizations. For NMCMV, private and self-pay accounted for a lower percentage while Medicare and Medicaid accounted for a higher proportion compared to motorcycle payers. Medicaid paid on average $21,280 (95%CI, $20,215-$22,346) for NMCMV and $27,803 (95% CI, $26, 035-$29,572) for motorcycle injuries, which were higher than payments from other payers.

For disposition of patients, about 73% of NMCMV and motorcycle injured patients were discharged as routine; however, motorcycles had higher proportions on disposition of home health care and short-term hospital. The chi-square tests reported there were significant differences between NMCMV and motorcycle victims for principal injury diagnosis, primary payer and disposition status.

From the coefficients in specific aim 1, we used model 2 and model 4 because they had the smallest standard errors in predicting the impact of gasoline prices. If the inflation-adjusted gasoline price were assumed to stay at $1.73 (2001 gasoline price in 2010 dollars) for the years 2002 and 2010, we predicted that rising gasoline prices were associated with 48,576 less NMCMV and 20,786 more motorcycle hospitalizations. By multiplying the average inpatient costs ($17,105 NMCMV and $20,452 motorcycle per case), these findings suggest that the rise in gasoline prices after 2001 resulted in about $831 million in inpatient cost savings from decreasing NMCMV injuries. However, we predict that total costs increased by over $425 million due to increasing inpatient admissions for motorcycle injury (Figure 6-1). We also used results from the multivariate regression modeling to predict the impact of an increase in the gasoline tax. These results predict that a $1 increase in gasoline taxes would lead to 8,347 fewer NMCMV hospitalizations resulting in $143 million in hospital cost savings. Increased hospitalizations from motorcycle injuries would partially offset these savings. However. a $1 increase in gasoline taxes is predicted to result in 3,574 additional motorcycle-related hospitalizations accounting for more than $73 million in hospital costs (Figure 6-2).

Table 6-1: Number of principle injury diagnosis, primary payer and disposition status for non-motorcycle motor vehicle and motorcycle inpatient hospitalization: NIS, 2001-2010

	Non-motorcycle motor vehicle inpatient hospitalization				Motorcycle inpatient hospitalization				
	N	95% CI	%	95% CI	N	95% CI	%	95% CI	p-value
Principle Injury Diagnosis									
Crushing injury or internal injury	203,027	184,099 - 221,954	12.3	12 - 12.6	36,207	32,728 - 39,685	11.6	11.2 - 11.9	<0.001
Fracture of lower limb	219,271	199,927 - 238,615	13.3	12.9 - 13.6	86,136	79,039 - 93,233	27.5	27 - 28.1	
Fracture of neck of femur (hip)	27,651	25,107 - 30,195	1.7	1.6 - 1.7	5,605	5,008 - 6,201	1.8	1.7 - 1.9	
Fracture of upper limb	108,562	99,505 - 117,618	6.6	6.4 - 6.7	39,095	35,763 - 42,428	12.5	12.1 - 12.9	
Intracranial injury	294,476	262,003 - 326,949	17.8	17 - 18.6	47,864	42,473 - 53,255	15.3	14.6 - 16	
Joint disorders and dislocations, trauma-related	18,560	16,947 - 20,173	1.1	1.1 - 1.2	4,683	4,188 - 5,178	1.5	1.4 - 1.6	
Open woods of extremities	25,300	23,005 - 27,595	1.5	1.5 - 1.6	10,508	9,527 - 11,490	3.4	3.2 - 3.5	
Open wound of head, neck, and trunk	46,212	41,776 - 50,648	2.8	2.7 - 2.9	4,082	3,650 - 4,514	1.3	1.2 - 1.4	
Other fractures	292,323	266,581 - 318,066	17.7	17.3 - 18.1	39,493	35,647 - 43,340	12.6	12.2 - 13	
Skull fractures	61,983	55,593 - 68,373	3.8	3.6 - 3.9	9,740	8,651 - 10,830	3.1	3 - 3.3	
Spinal cord injury	25,475	22,449 - 28,501	1.5	1.5 - 1.6	3,897	3,343 - 4,452	1.3	1.1 - 1.4	
Sprains and strains	24,863	22,443 - 27,283	1.5	1.4 - 1.6	2,215	1,957 - 2,473	0.7	0.6 -0 .8	
Other diagnoses	305,939	285,651 - 326,226	18.5	17.7 - 19.4	23,479	21,707 - 25,251	7.5	7.1 - 8	
Primary Payer									
Medicare	131,069	120,193 - 141,946	8.0	7.6 - 8.5	13,169	11,735 - 14,602	4.2	3.9 - 4.5	<0.001
Medicaid	178,828	157,994 - 199,663	10.9	10.1 - 11.8	24,598	21,473 - 27,722	7.9	7.2 - 8.6	
Private	948,313	861,599 - 1,035,027	57.9	56 - 59.8	201,825	184,114 - 219,536	64.9	63.4 - 66.3	
Self-pay	230,228	204,038 - 256,418	14.1	13 - 15.2	46,605	41,490 - 51,720	15.0	13.9 - 16.1	
No Charge	5,626	3,728 - 7,525	0.3	0.3 - 0.5	1,417	936 - 1,897	0.5	0.3 - 0.6	
Other payers	143,797	124,516 - 163,079	8.8	7.9 - 9.7	23,601	20,025 - 27,177	7.6	6.7 - 8.5	
Disposition of Patient									
Routine	1,196,942	1,097,122 - 1,296,762	72.5	71.7 - 73.4	227,683	208,794 - 246,572	72.9	71.8 - 73.9	<0.001
Short-term hospital	48,498	44,211 - 52,785	2.9	2.7 - 3.2	10,799	9,328 - 12,270	3.5	3.1 - 3.9	
Other facilities	234,944	212,494 - 257,394	14.2	13.7 - 14.8	38,264	33,639 - 42,890	12.3	11.5 - 13	
Home health care	111,093	99,073 - 123,112	6.7	6.3 - 7.2	25,784	22,726 - 28,843	8.3	7.6 - 8.9	
Against medical advice	16,055	14,423 - 17,688	1.0	0.9 - 1.0	2,364	2,023 - 2,706	0.8	0.7 - 0.9	
Died in hospital	41,674	36,433 - 46,915	2.5	2.4 - 2.7	7,362	6,367 - 8,357	2.4	2.2 - 2.5	
Alive but unknown	864	488 - 1,241	0.1	0 - 0.1	212	76 - 348	0.1	0 - 0.1	

Notes: Florida was excluded.

Table 6-2: Average of length of stay and hospital cost per case for non-motorcycle motor vehicle and motorcycle inpatient hospitalization: NIS, 2001-2010

	Non-motorcycle motor vehicle inpatient hospitalization				Motorcycle inpatient hospitalization			
	Length of Stay		Hospital Cost		Length of Stay		Hospital Cost	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Principle Injury Diagnosis								
Crushing injury or internal injury	6.8	6.6 - 7.0	21,178	20,347 - 22,009	7.0	6.7 - 7.3	22,122	20,855 - 23,389
Fracture of lower limb	6.4	6.2 - 6.6	20,531	19,818 - 21,244	6.0	5.8 - 6.2	20,588	19,701 - 21,476
Fracture of neck of femur (hip)	8.2	7.9 - 8.6	25,834	24,650 - 27,018	7.7	7.0 - 8.3	27,041	24,503 - 29,579
Fracture of upper limb	4.3	4.2 - 4.5	14,324	13,807 - 14,842	3.8	3.7 – 4.0	14,066	13,476 - 14,657
Intracranial injury	6.4	6.0 - 6.8	21,019	19,936 - 22,102	8.1	7.7 - 8.5	28,000	26,586 - 29,414
Joint disorders and dislocations; trauma-related	4.0	3.8 - 4.2	13,010	12,214 - 13,806	3.8	3.5 - 4.1	12,377	11,407 - 13,347
Open woods of extremities	4.8	4.5 - 5.1	14,499	13,692 - 15,306	6.1	5.6 - 6.7	18,369	16,858 - 19,881
Open wound of head; neck; and trunk	2.4	2.3 - 2.5	8,923	8,511 - 9,335	2.9	2.6 - 3.3	10,275	9,026 - 11,524
Other fractures	5.7	5.5 - 5.8	16,378	15,748 - 17,008	6.2	6.0 - 6.5	20,126	18,847 - 21,405
Skull fractures	4.4	4.2 - 4.5	15,417	14,819 - 16,016	4.7	4.4 - 5.1	17,290	15,891 - 18,689
Spinal cord injury	13.8	13.1 - 14.4	51,040	48,882 - 53,198	16.0	14.6 - 17.4	63,323	58,782 - 67,864
Sprains and strains	2.3	2.1 - 2.4	6,327	6,019 - 6,635	2.8	2.3 - 3.3	9,708	8,481 - 10,936
Other diagnoses	3.7	3.5 - 3.8	9,197	8,863 - 9,530	4.8	4.5 - 5.2	10,767	10,178 - 11,356
Primary Payer								
Medicare	6.3	6.1 - 6.6	17,536	16,553 - 18,518	6.9	6.5 - 7.3	21,087	19,553 - 22,620
Medicaid	6.8	6.5 - 7.2	21,280	20,215 - 22,346	8.6	8.1 - 9.1	27,803	26,035 - 29,572
Private	5.4	5.2 - 5.5	16,779	16,118 - 17,440	5.9	5.7 - 6.1	20,054	19,188 - 20,920
Self-pay	4.5	4.2 - 4.7	14,485	13,668 - 15,302	5.5	5.1 - 5.8	17,691	16,615 - 18,768
No Charge	4.5	4.0 - 5.1	14,782	12,821 - 16,742	5.2	4.5 - 5.8	18,449	15,289 - 21,609
Other payers	5.6	5.3 - 6.0	17,916	16,984 - 18,849	6.2	5.9 - 6.5	21,569	20,180 - 22,958
Disposition of Patient								
Routine	3.8	3.6 - 3.9	11,589	11,144 - 12,035	4.3	4.1 - 4.4	13,568	13,031 - 14,104
Short-term hospital	6.5	6.0 - 7.0	25,672	23,704 - 27,639	6.9	6.1 - 7.7	30,454	28,122 - 32,785
Other facilities	12.7	12.2 - 13.1	38,095	36,488 - 39,702	15.5	14.8 - 16.1	52,609	50,181 - 55,037
Home health care	8.4	8.1 - 8.6	21,800	20,930 - 22,671	9.0	8.7 - 9.4	25,505	24,302 - 26,708
Against medical advice	2.4	2.1 - 2.6	8,670	8,145 - 9,195	3.6	3.0 - 4.1	12,695	10,954 - 14,435
Died in hospital	6.1	5.8 - 6.4	34,979	33,568 - 36,391	4.6	4.2 – 5.0	34,603	32,423 - 36,782
Alive but unknown	7.5	6.0 - 8.9	37,141	28,314 - 45,968	8.8	5.2 - 12.4	40,433	24,216 - 56,651

Notes: Florida was excluded.

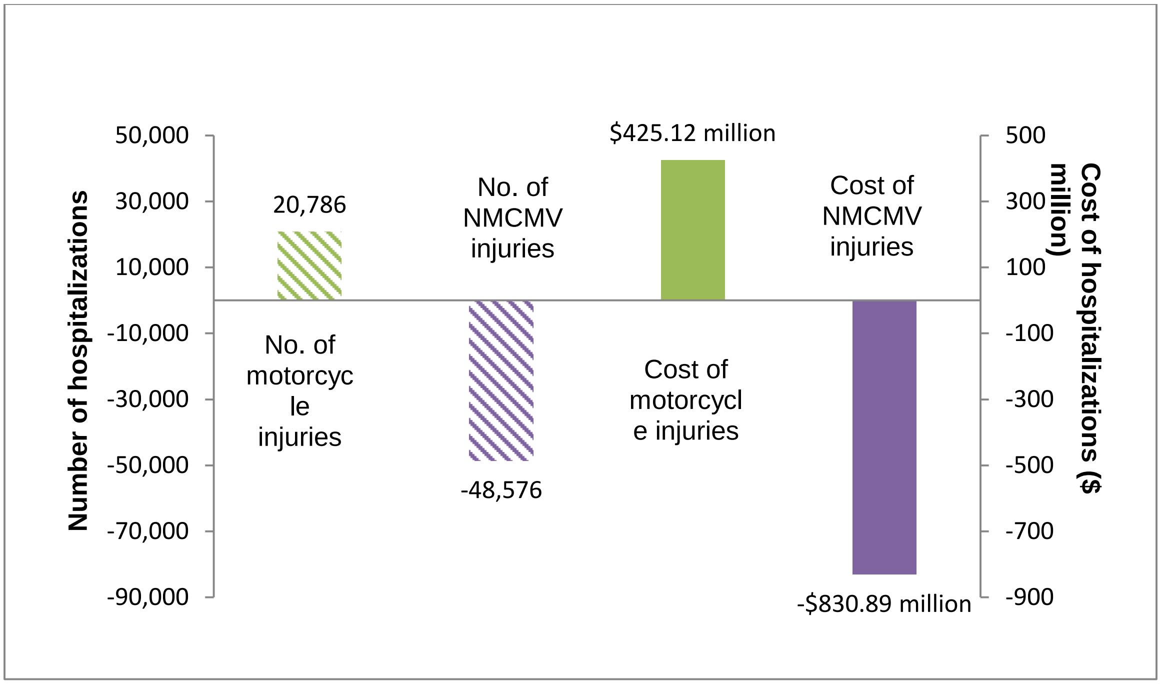

Figure 6-1: Predicted impact of gasoline price increase on the utilization and cost of hospitalizations for motorcycle and non-motorcycle motor vehicle by assuming 2001 gasoline price: NIS, 2001-2010

Notes: Inflation-adjusted gasoline price in 2001 was $1.73. NMCVM: non-motorcycle motor vehicle. Florida was excluded.

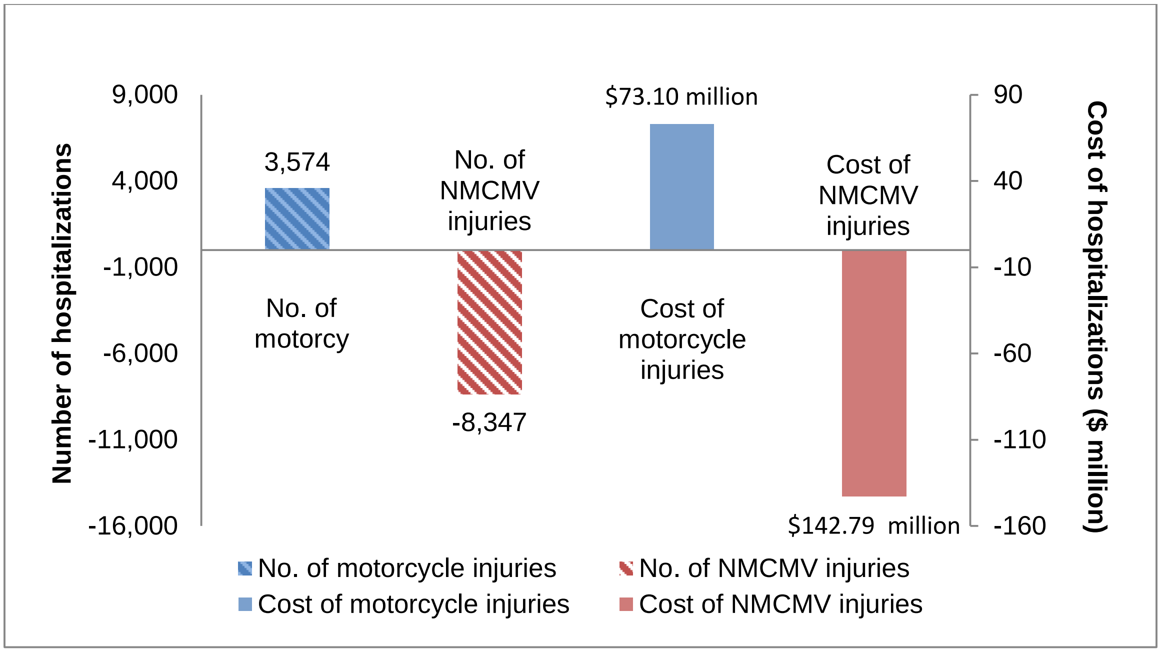

Figure 6-2: Predicted impact of increasing gasoline tax by $1.00 on the numbers and costs for non-motor vehicle and motorcycle hospitalizations in 2014

Notes: NMCVM: non-motorcycle motor vehicle**.** Florida was excluded.

Discussion

Our results show that inpatient care from motorcycle injuries were usually more costly than non-motorcycle motor vehicle injuries, and potentially increased the economic burden for private insurers and individuals. The benefits of rising gasoline prices on reducing non-motorcycle motor vehicle hospitalizations and cost was offset over 40% by increasing motorcycle admissions. Similarly, it was predicted that a $1.00 increase in gasoline tax would decrease hospital costs by about $143 million from over 8,000 fewer non-motorcycle motor vehicle hospitalizations. Meanwhile, it would increase costs by about $73 million associated with about 3,600 more motorcycle hospitalizations. Overall, increasing gasoline taxes will have a positive impact on reducing inpatient utilization and cost, but it will be offset by the rising motorcycle injuries.

The gasoline tax is an important policy tool to increase government revenues and to control negative externalities such as vehicle emission (Li et al, 2012; Litman, 2014). Gasoline tax could also be a policy alternative to improve traffic safety, as it was associated with the reduction of MVC fatalities and injuries in this study and in the literature. Clearly, the U.S. almost has the lowest gasoline tax among industrialized countries; however, it has highest fatalities and injuries rate per capita. Recent proposals to increase the federal gasoline tax have failed in Congress, and some states have decreased gasoline taxes (Cohen, 2015). The International Monetary Fund has suggested that the United States should have a $1.40 gasoline tax per gallon to lessen the environmental impact of burning gasoline, however it may be possible that a higher gasoline tax would hurt the U.S. economy, especially for low income families (Laskoski, 2013).

The gasoline taxes consist of federal and state taxes. The federal tax has been $0.184 per gallon since 1997, and the weighted average state tax is around $0.20

(Appendix Table S6.1) (FHWA, 2015). These taxes accounted for 19% of retail gasoline prices from 2001 to 2013, and this percentage has been decreasing due to a stable tax and rising gasoline prices (EIA, 2014). However, other countries charge over ten times this amount. For example, the gasoline tax rate was $4.40 per gallon in Belgium, $4.06 in Italy and $2.83 in Japan (FHWA, 2015).

Our findings are consistent with previous literature that the increase of gasoline taxes is associated with overall decreases in motor vehicle injuries and fatalities (Grabowski & Morrisey, 2006; Leight & Wilkinson, 1991). However, we found there may be a significant increase in severe motorcycle injuries along with higher hospital costs when retail gasoline prices increase. Wilson et al (2009) estimated that over 1,500 additional motorcycle fatalities would occur annually for each dollar increase in gasoline prices in the U.S., and Zhu et al (2014) estimated that 800 fatalities and 10,290 non-fatal injuries resulted from gasoline price increases in California from 2002 to 2010.

With high gasoline prices, more attention should be given to increasing motorcycle safety. Substitution toward motorcycling in response to rising gasoline prices would be expected to increase crashes due to the substantially higher risk of injury from riding. Helmet laws and more training for motorcyclists may help to achieve these goals. Helmets have been proved to effectively reduce injury severity, particular for trauma brain injuries (Houston & Richardson, 2007; Lin & Kraus, 2009). Currently, only 19 states and D.C. have universal helmet laws, 28 states have helmet laws for teens, and 3 states (Illinois, Iowa and New Hampshire) have no helmet law at all (Insurance Institute for Highway Safety, 2015).

NHTSA reports that about two in every five fatally injured motorcyclists were involved in single vehicle collisions (NHTSA, 2007). This suggests that a large number of riders may not be properly trained or experienced in riding motorcycles. The pioneering study on motorcycle safety by Hurt and colleagues based on 900 in-depth crash investigations of motorcycle riders found that 92% of riders involved in crashes were self-taught or had learned to ride from friends and family (Hurt et al, 1981). Furthermore, one-third of riders in crashes had taken no evasive actions to avoid the collision, and a large proportion of the evasive actions that were used were determined to have been inappropriate (e.g., not using both front and rear brakes) (Hurt et al, 1981).

There are no restrictions on the type of motorcycle that may be purchased by adult riders in the U.S. Only Florida and Organ has mandatory training requirements for new motorcycle riders. About 60% of states will waive one or more testing requirements if a rider completes a rider education course. This situation contrasts with licensing in the European Union, for example, where motorcycle licenses are graduated based on motorcycle power, age and years of experience (European Commission, 2013). Therefore, there are few legal barriers limiting motorcycle power-to-weight ratios or mandating basic skills training for inexperienced riders in the U.S.

A possible policy-based solution to increasing the safety of motorcycling for new riders may be incentivizing them to take formal training on riding motorcycles. Although most states will waive some testing requirements if riders have taken a training course, there is substantial variation in the administration, content and length of training programs—and their effectiveness in decreasing crash rates—across states (Daniello, Gabler, & Mehta, 2009; French, Gumus, & Homer, 2009). However, there have been substantial efforts by organizations such as the Motorcycle Safety Foundation to provide standardized training programs across the country (Motorcycle Safety Foundation, 2004).

CHAPTER 7 : SPECIFIC AIM 3 - A SYSTEM DYNAMICS FRAMEWORK OF THE TRAFFIC SAFETY SYSTEM RESPONSE TO RISING GASOLINE PRICES

Systems dynamics is defined as a computer-aided approach to model and facilitate analysis of system behaviors over time (Homer & Hirsch, 2006; Meadows, 2008; McClure et al., 2014). SD modeling has been used to assess performance of traffic systems and to simulate driver behaviors. The advantages of SD approach include permitting dynamic and non-linear analyses, examining the interaction and feedback mechanisms between the variables, predicting the long-term impact of different policy strategies and scenarios, and incorporating a large number of interrelationships between variables that ultimately shape outcomes (Meadows, 2008; Goh & Love, 2012).

To our knowledge, no study has used an SD approach to studying the gasoline prices and traffic safety. Thus, this chapter was an exploratory study, and we emphasized the adverse effects of rising gasoline price on the motorcycle and non-motorcycle motor vehicle travel behaviors. Notably, we introduced public transportation choice as a substitution of the motor vehicle, and this made the model dynamic and similar to the “real world”.

Methods

A conceptual system dynamics model was developed to examine the traffic safety system response to rising gasoline price. We created a causal loop diagram (CLD) to capture the major feedbacks among gasoline prices, travel behaviors and traffic injuries, informed by the literature. A stock-flow diagram (SFD) was constructed to convert these dynamic processes in the CLD to quantitative expressions. Vensim PLE (Ventana System, Inc., Harvard, MA) was used to build and simulate the SD model.

Model Description

A CLD of the traffic safety system response to rising gasoline prices was illustrated in Figure 7-1 to define the variables in this system along with their causal pathways.

Model Boundary The model of this study focused on gasoline price directly affecting travel behavior by shifting transportation modes and adjusting travel miles (distance and frequency), and the incidence of motor vehicle injury was decided by the exposure of travel mode and miles. We didn't consider other factors because some of them have been controlled when calculating the relationships between gasoline price and driving, as well as their inconsistent and complex associations with driving and injury. The three most common transport modes included the non-motorcycle motor vehicle (automobile and truck), motorcycle and public transportation. It was assumed that a motorcycle could substitute for a non-motorcycle motor vehicle, and taking public transportation with increasing passenger-miles could substitute for non-motorcycle motor vehicle miles.

Model Elements The variables of this model included population, retail regular gasoline prices increase or gasoline tax increase, registration numbers of non-motorcycle motor vehicle (abbreviated as vehicle) and motorcycle (MC), miles traveled of motorcycle, vehicle and public transportation, and motorcycle and motor vehicle injury incidence rate (per million miles) and related injury numbers, as well as congestion and highway capacity. Two policy intervention options were gasoline tax and transport policies in this CLD.

Loop Construction The relationships or loops among the model elements were constructed based on previous studies (Austin, 2008; Brand, 2009; Chi et al, 2013a;

Grabowski & Morrisey, 2004; Litman, 2008). In brief, rising gasoline prices affect traffic crash injuries by reassigning the travel mode and miles within a dynamic system.

- The growth of population increased the demand of both vehicles and motorcycles. However, the increase of gasoline price could mitigate the increase of vehicles by encouraging shifting toward a fuel-efficient motorcycle for daily commuting (Chi et al., 2013a; Wen, Chiou, & Huang, 2012). Hedlund (2013) found that motorcycle registration numbers and inflation-adjusted gasoline prices were highly correlated from 1972 to 2012. Therefore, the link was marked negative between gasoline price increase and vehicle numbers, and marked positive between gasoline price increase and motorcycle numbers.
- High gasoline prices could cause people to drive less. It was found that there was a negative relationship between gasoline price and fuel consumption or vehicle miles traveled (Austin, 2008; Brons, Nijkamp, Pels, & Rietveld, 2008; Goodwin et al., 2004; Hughes et al., 2008).
- People may take public transit in response to rising gasoline price instead of driving a vehicle. Previous studies found a positive relationship between gasoline prices and transit ridership (APTA, 2011; Stimpson, Wilson, Araz, & Pagan, 2014). Thus, it was assumed that the increase of passenger-miles traveled (PMT) equaled to the decrease of VMT. At the same time, congestion avoidance also can cause the substitution between PMT and VMT.
- Number of motor vehicle injuries was aggregated by vehicle and motorcycle injuries, and a mile traveled by vehicle and motorcycle led to differences in crash risk (NHTSA, 2013). We assume zero crash risk for mass transit.

- Fuel tax increases retail gasoline prices, and transport policies such as investment on infrastructure and improvement of transit services can attract more mass transit usage besides higher gasoline prices.

Feedback Loops Three balancing feedback loops were summarized in this system listed below. Plus and minus signs represented cocurrent and countercurrent flows, respectively.

Feedback Loop 1: + Motorcycle (MC) # → + MC VMT → + MC injury # → - Motorcycle (MC) #

Feedback Loop 2: + Passenger-miles traveled (PMT) → - Veh VMT → + Congestion → + Passenger-miles traveled (PMT)

Feedback Loop 3: + Passenger-miles traveled (PMT) → - Veh VMT → + Veh injury # → + Motor vehicle injury # → + Passenger-miles traveled (PMT)

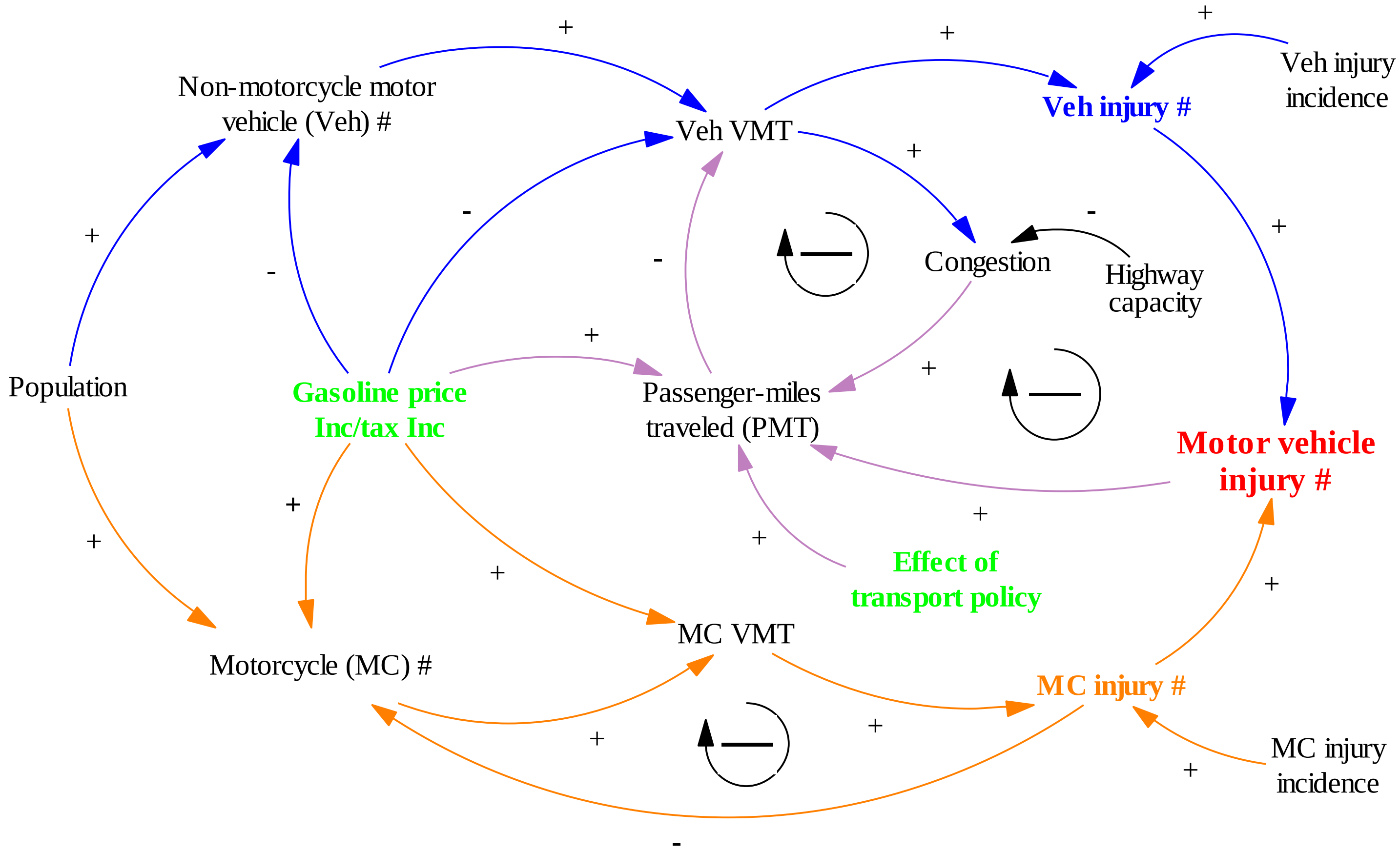

Figure 7-1: Causal loop diagram of traffic safety system response to rising gasoline price

Notes: **Blue arrows** represent non-motorcycle motor vehicle related loops; **orange arrows** represent motorcycle related loops; **purple arrows** represent public transit related loops**.** **Green variables** are intervention variables; blue, orange and red are the injury-related variables.+: increase; -: decrease;  :balancing feedback loop.

Stock-Flow Diagram

After identifying the elements and their relationships in above CLD, an SFD was established to analyze the dynamic flows in mathematical expressions (Figure 7-2). There were eight stock variables as follows:

- Population was the annual U.S. population, and it was assumed that population increase with constant growth rate.
- Non-motorcycle motor vehicle number (Veh #) was the total registration number of automobile and trucks in the U.S. It was assumed vehicles flowed in the vehicle stock based on population increase and initial vehicle prevalence (Initial Veh per capita). At the same time, people may substitute vehicles with motorcycles or public transportation in response to rising gasoline price. The flow out of the vehicle (Veh decrease) was measured by the stock of vehicle and vehicle gas elasticity. Elasticity is the measurement in the relative change between two variables. A positive elasticity occurs when two variables both increase or both decrease as they change. A negative elasticity occurs when one variable increases and the other decreases. A relationship is said to be inelastic when one variable changes and the other has little or no change.
- Motorcycle number (Motorcycle #) was the total registration number of motorcycle in the U.S. Similar to vehicle number, it was also determined by initial registration rate (per capita) and population size and gasoline price increase, as well as that people are assumed to quit riding a motorcycle after severe injuries.
- Veh VMT was the miles traveled by automobile and trucks. Veh VMT increase with more vehicles, and the reduction of Veh VMT came from people driving less due to high gasoline prices and substitution of passenger-miles traveled.

- Motorcycle VMT was the miles traveled by motorcycle. Besides assuming that more motorcycles lead to more motorcycle VMT, rising gasoline price caused people to ride motorcycles more frequently. However, motorcycle crashes usually caused severe injury and certain proportion injured people (MC quite rate) may not ride motorcycle for certain time after the injuries.
- Passenger-miles traveled (PMT) increased with rising gasoline price and effect of transport policies and effect of congestion.
- Highway capacity was measured by the national freeway miles in the U.S., which multiply the increase rate due to road construction.
- Motor vehicle (MV) injury number was accumulated number of motorcycle and vehicle injuries.

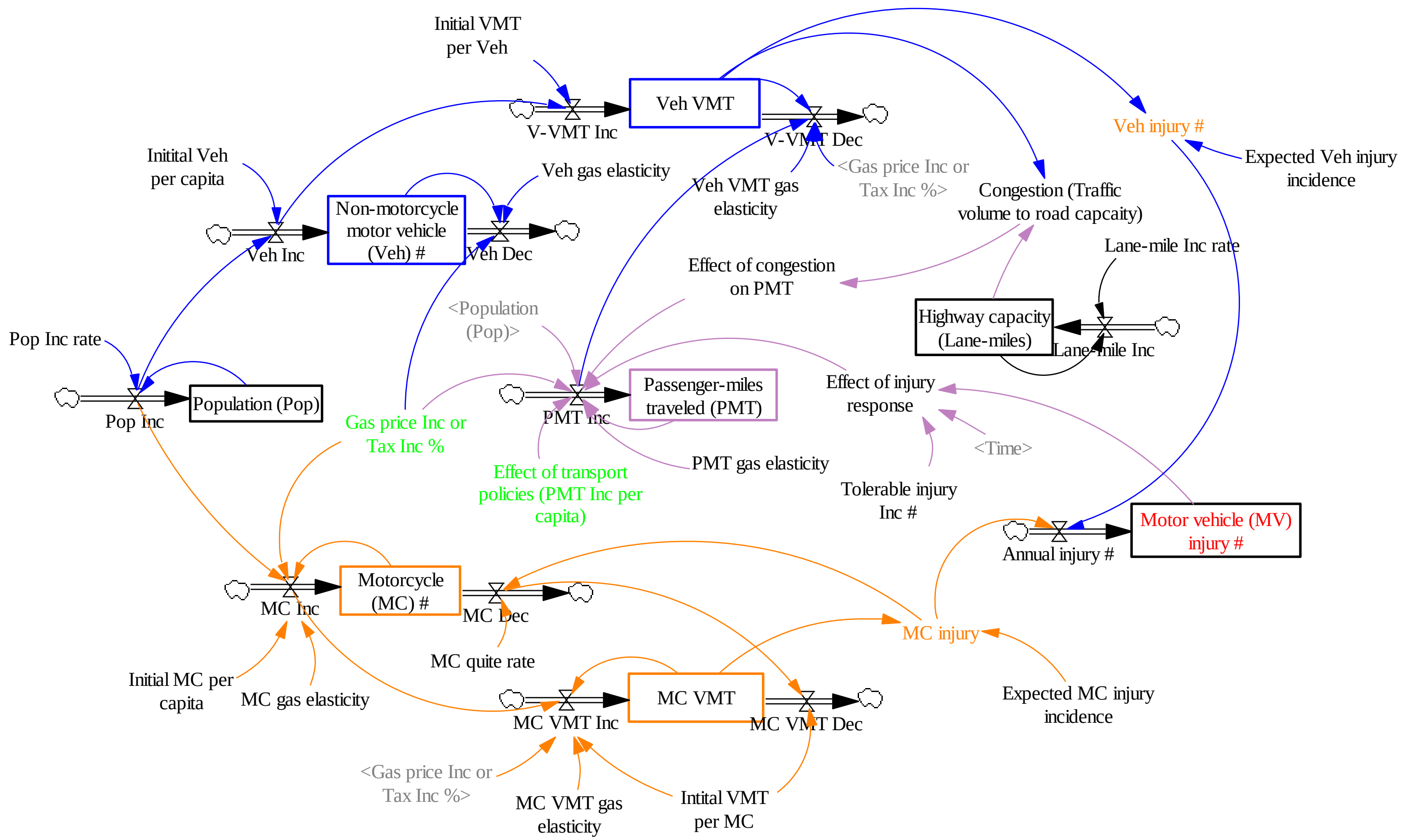

Figure 7-2: Stock-flow diagram of traffic safety system response to rising gasoline price

Notes: **Blue arrows** represent non-motorcycle motor vehicle related loops; **orange arrows** represent motorcycle related loops; **purple arrows** represent public transit related loops. **Green variables** are intervention variables; blue, orange and red are the injury-related variables.

Simulation Experiments and Policy Analyses

A system dynamics model of the traffic safety system response to rising gasoline prices was developed above. We estimated parameter values based on publicly available data and the results of previous studies from 2001 to 2010, and simulated the effects of gasoline tax increases and transport policies on the number of motorcycle, non-motorcycle motor vehicle injuries from 2011 to 2010, respectively.

Data Sources and Parameter Estimation

We observed annual stock variables at the national level, and the initial year was defined as 2001, which was consistent with data in specific aims 1 and 2. First, data on population came from the U.S. Bureau of the Census, and population showed a linear increase over ten years. Second, the initial number of motorcycle and non-motorcycle motor vehicle and their related miles traveled were obtained from the FHWA, as well as highway capacity measured by the national freeways lane-miles. Third, passenger-miles traveled were retrieved from the U.S. Department of Transportation. Fourth, the elasticities were obtained from estimation in previous studies (Austin, 2008; Gillingham, 2011; Yanma-Tuzel & Ozbay, 2011; Currie & Phung, 2007), and we picked their values based on using similar study periods or similar results in more than one studies. Fourth, motorcycle quit rate was estimated for patients who died as inpatients, or patients discharged to home health care and short- or other facilities using data from the Nationwide Inpatient Sample. All the values and equations of other variables can be found in Table 7-1 and Table S7-1.

Table 7-1: Parameter estimation

Parameters	Unit	Initial Value/Value	Sources
Population (Pop)	Person	284,968,955*	U.S. Bureau of the Census
Non-motorcycle motor vehicle (Veh) #	Vehicle	229,678,778*	U.S. Department of Transportation, Federal Highway Administration
Motorcycle (MC) #	Vehicle	4,903,056*	National Highway Traffic Safety Administration
Veh VMT	Million miles	2,778,908*	U.S. Department of Transportation, Federal Highway Administration
MC VMT	Million miles	9,639*	National Highway Traffic Safety Administration
Passenger miles traveled (PMT)	Million miles	46,508*	U.S. Department of Transportation, Federal Transit Administration
Highway capacity (Lane-miles)	Mile	546,259*	U.S. Department of Transportation, Federal Highway Administration
Pop Inc rate	No Unit	0.0092	U.S. Bureau of the Census
Initital Veh per capita	Vehicle	0.8060	U.S. Bureau of the Census; U.S. Department of Transportation, Federal Highway Administration
Initial VMT per Veh	Million miles	0.0121	U.S. Department of Transportation, Federal Highway Administration
Initial VMT per MC	Million miles	0.0020	U.S. Department of Transportation, Federal Highway Administration
Initial MC per capita	Vehicle	0.0172	U.S. Bureau of the Census; National Highway Traffic Safety Administration
Expected MC injury incidence	Persons per million miles	2.46	Calibration by optimization process in Vensim
Expected NMCMV injury incidence	Person per million miles	0.0653	Calibration by optimization process in Vensim
MC quite rate	No Unit	0.024	Nationwide Inpatient Sample
Tolerable injury Inc #	Person	400	U.S. Department of Transportation, Federal Transit Administration
MC gas elasticity	No Unit	0.0057	Calibration by optimization process in Vensim
Veh gas elasticity	No Unit	-0.0015	Gillingham (2011)
Veh VMT gas elasticity	No Unit	-0.002	Austion (2008)
MC VMT gas elasticity	No Unit	0.0053	Calibration by optimization process in Vensim
PMT gas elasticity	No Unit	0.0012	Yanma-Tuzel & Ozbay (2011); Currie & Phung (1992)

*Initial value, defined as the start value in 2001

Model Calibration and Validation

To calibrate the model, we used an optimization process in Vensim on the parameters *Motorcycle gasoline elasticity, Motorcycle VMT gasoline elasticity, and Expected motorcycle injury incidence, Expected non-motorcycle motor vehicle injury incidence* by using observed values of numbers of *Motorcycle, Motorcycle VMT, Motorcycle injury, NMCMV injury* and *NMCMV VMT* from 2001 to 2010 (Figure 7-3).

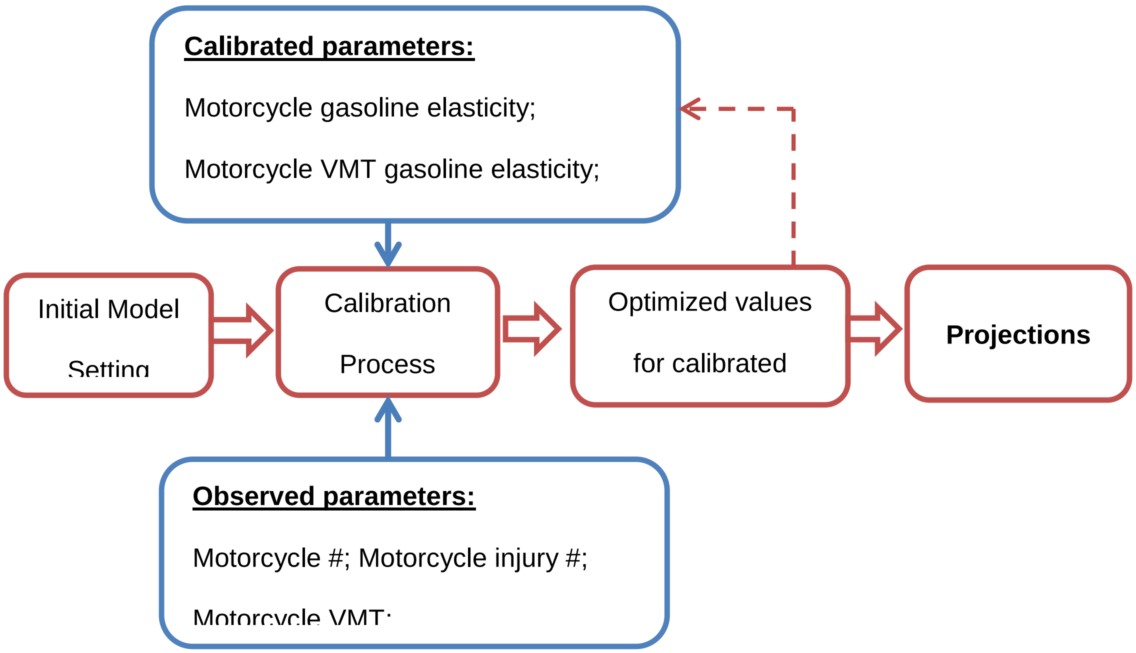

Figure 7-3: Flowchart of model calibration

To validate our model, we compared the observed data from the NIS with estimated data from SD model for motorcycle and non-motorcycle motor vehicle injuries from 2001 to 2010. Table 7-2 listed the observed and estimated values over time, and the errors were calculated based on the difference between observed and estimated values. Then, several accuracy measures were calculated in Table 7-3. The mean absolute deviation (MAD) was 11,760 for non-motorcycle motor vehicle injuries and 4,724 for motorcycle injuries, correspondingly, the TSEs were -0.04 and 1.83. Generally, the estimated numbers of SD model we developed fit the actual numbers statistically well with the aforementioned statistical performance measures.

Table 7-2: Model validation

	Non-motorcycle motor vehicle injuries			Motorcycle injuries		
Year	Observed No.	Estimated No.	Error	Observed No.	Estimated No.	Error
2001	181,426	186,465	-5,039	24,861	23,712	1,149
2002	188,638	190,701	-2,063	26,364	22,113	4,251
2003	211,547	186,978	24,569	34,025	25,839	8,186
2004	210,167	183,119	27,048	37,547	30,177	7,370
2005	178,139	177,617	522	31,865	36,540	-4,675
2006	181,943	175,927	6,016	36,876	40,169	-3,293
2007	163,186	175,543	-12,357	38,724	42,629	-3,905
2008	162,501	173,026	-10,525	40,301	47,726	-7,425
2009	155,025	184,058	-29,033	38,145	35,535	2,610
2010	180,267	179,836	431	45,917	41,545	4,372

Table 7-3: Measuring accuracy

Measures	Non-motorcycle motor vehicle	Motorcycle
Root mean square error (RMSE)	15,836	5,193
Normalized root mean squared error (NRMSE)	0.28	0.25
Mean Absolute Deviation (MAD)	11,760	4,724
Tracking Signal Error (TSE)	-0.04	1.83
Mean Percentage Error (MFE)	-0.83%	2.87%
Mean Absolute Percentage Error (MAPE)	6.50%	13.29%

Scenario Setting

The design for the experimentation includes two different policy scenarios. Baseline was assumed that no increase in gasoline tax and passenger-miles traveled from 2011 to 2020. The gasoline price from 2011 to 2014 has been published by the EIA, and these actual gasoline prices at baseline were used for 2011 ($3.42 in 2010 dollars), 2012 ($3.44 in 2010 dollars), 2013 ($3.29 in 2010 dollars), and 2014 ($3.09 in 2010 dollars). The rest of years were assumed to be $3.09 the same as 2014. In terms of

PMT per capita, it was assumed to equal to 172 miles from 2011 to 2020 the same as 2010.

Policy 1: **Increasing gasoline tax**

- Scenario 1: A $0.1 increase in gasoline tax in 2014
- Scenario 2: A $0.5 increase in gasoline tax in 2014
- Scenario 3: A $1.0 increase in gasoline tax in 2014

Policy 2: **Increasing passenger-miles traveled (PMT) by improving transportation policies**

- Scenario 4: A 10 miles increase in PMT per capita every year
- Scenario 5: A 50 miles increase in PMT per capita every year
- Scenario 6: A 100 miles increase in PMT per capita every year

Results

Results of 10 year-simulations for each policy option are presented in the following figures.

Policy 1: Increase Gasoline Tax

Figure 7-4 illustrates the effects of increasing gasoline tax at three levels on reducing non-motorcycle motor vehicle injuries. At baseline of 2014, the estimated number of non-motorcycle motor vehicle injuries was 181,593, and it would decrease associated with the increase of gasoline tax. If gasoline tax increased $1.0, the number of non-motorcycle motor vehicle injuries would be 170,638, a 6% (10,955) decrease. This result was similar to the estimation in Aim 2. Similarly, a $0.1 and $0.5 increase in gasoline tax were associated with 1,084 and 5,495 decrease in the number of non-motorcycle motor vehicle injuries, respectively.

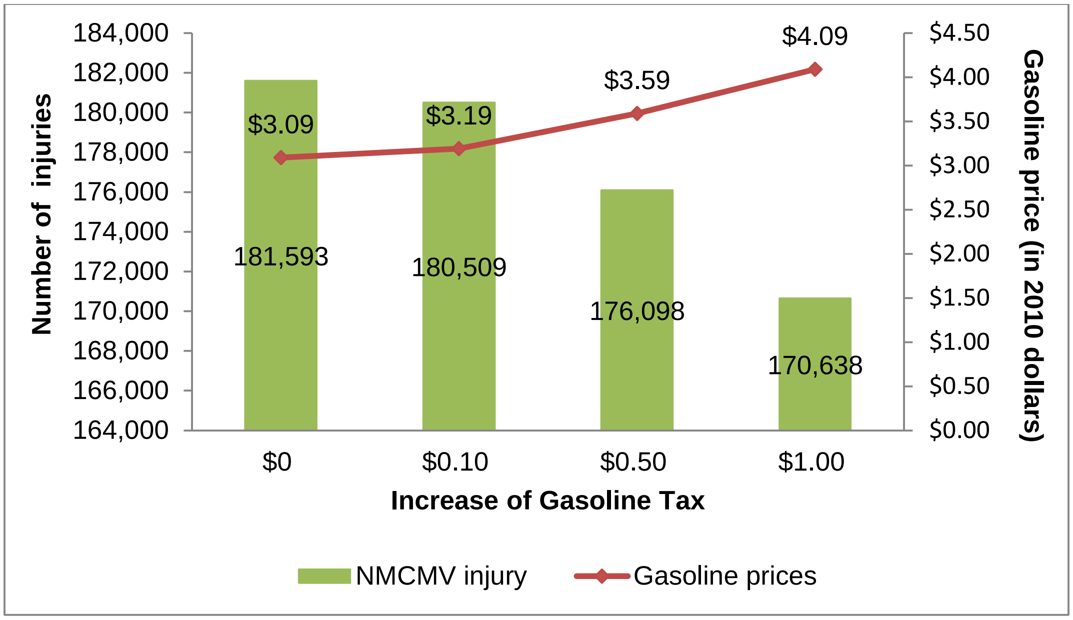

Figure 7-4: The effect of gasoline tax increase on number of non-motorcycle motor vehicle injuries in 2014

Notes: Baseline – No increase in gasoline tax and passenger-miles traveled. NMCMV: Non-motorcycle motor vehicle.

On the other hand, the increase of gasoline tax has a positive impact on motorcycle injuries. In the same three scenarios, the number of motorcycle injuries would increase by 1,448, 7,337, and 14,625 comparing to baseline, respectively (Figure 7-5). This estimated result of $1 increase was significantly higher than the prediction in Aim 2. As checked the model, we found the expected motorcycle injury incidence caused potentially overestimation. From 2001 to 2010, annual motorcycle injury incidence varied from 1.81 to 3.71 motorcycle crash injuries per million VMT. By using the model calibration, the expected motorcycle injury incidence was assigned to be 2.46 per million VMT.

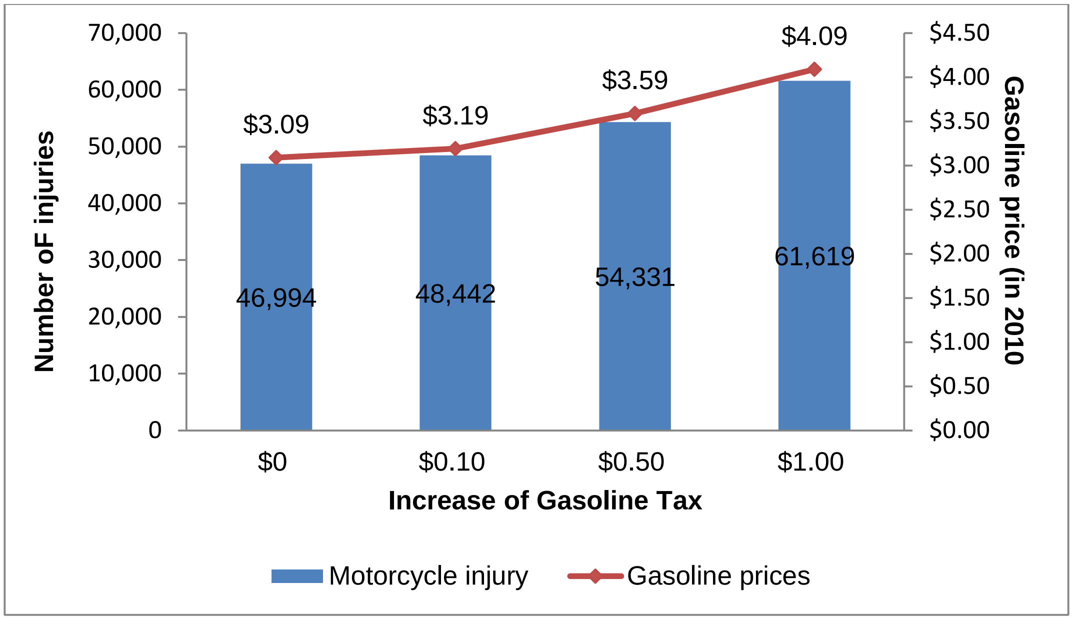

Figure 7-5: The effect of gasoline tax increase on number of motorcycle injuries in 2014

Notes: Baseline – No increase in gasoline tax and passenger-miles traveled. NMCMV: Non-motorcycle motor vehicle.

Policy 2: Increase Passenger-Miles Traveled

The effect of transport policies is to encourage people to use more public transportation instead of vehicle miles traveled, and it mainly affects the VMT and vehicle injuries. In Figure 7-6, the scenarios show the increase of PMT has slowed down the rise of vehicle injuries. Current, the annual passenger-miles traveled per capita was around 170 miles. In scenario 4, we assumed PMT per capita would increase 10 miles every year, it would reach 272 miles per capita in 2020. A total number of non-motorcycle motor vehicle injuries would decrease 1,130 averagely per year. In scenario 5, the assumption of a 50 PMT per capita increase every year, the number of non-motorcycle motor vehicle injuries would be flat comparing with the increasing trend in the baseline. Finally, when 100 PMT increase per capita (Scenario 6), the number of non-motorcycle motor vehicle injuries would decrease. In this model, we assumed that people riding a motorcycle has no response to high gasoline price to transfer to public transportation; thus, this policy was no effect on motorcycle injuries in this study.

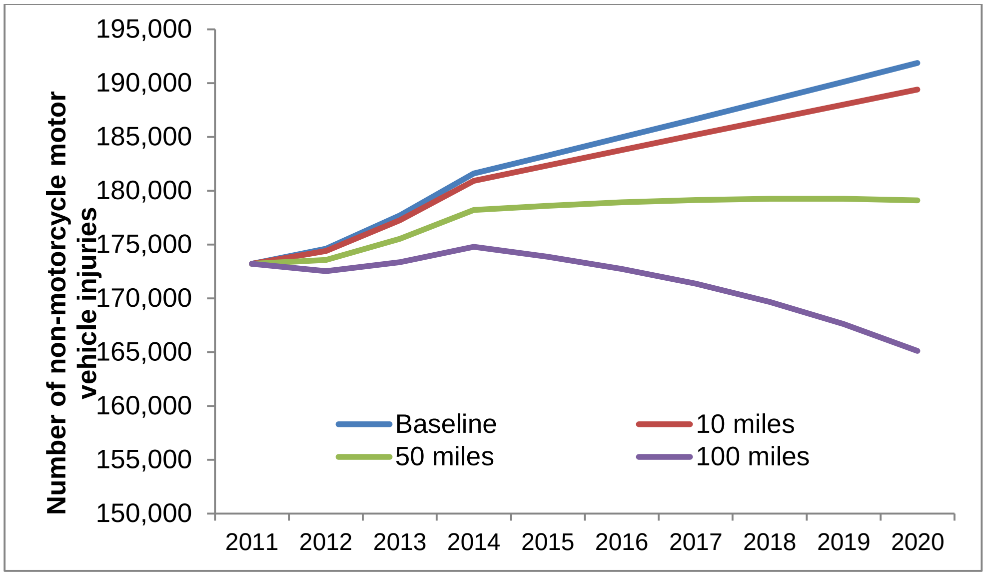

Figure 7-6: The effect of transport policies on number of non-motorcycle motor vehicle injuries from 2011 to 2020

Notes: Baseline – No increase of passenger-mile travel (PMT) per capita; S4 –A 10 miles PMT increase per capita; S5 – A 50 miles PMT increase per capita; S6 – A 100 miles PMT increase per capita.

Discussion

We constructed a conceptual system dynamics model for the traffic safety system response to rising gasoline price and estimated the effects of gasoline tax increase and transport policies on motor vehicle injuries. Our experiments found that increasing passenger-miles traveled was effective in reducing motor vehicle injuries, and increasing gasoline tax would decline non-motorcycle motor vehicle injuries, but this decrease would be attenuated by a significant increase of motorcycle injuries.

Compared to prior studies, this study made a comprehensive analysis of gasoline prices and traffic crash injuries by applying an SD approach. We linked rising gasoline price and the magnitude of motor vehicle injuries by the number of motor vehicle registrations and their VMT. We studied commuting modes by motorcycle, non-motorcycle motor vehicle, and public transportation, which provided a realistic context. The SD approach also allows policy simulation experiments, and we set up different potential scenarios to simulate the effect of policies.

The increase of gasoline tax could reduce vehicle VMT, and increasing gasoline taxes may have benefits in the short-term. However, in response to high gasoline prices, more people may shift to ride motorcycles as a preferred daily commuting mode, potentially increasing the injury risk.

Public transportation policies of improving transit system infrastructure, using appropriate fares and increasing supply adequacy, can reduce the total number of motor vehicle crashes by potentially moving people to safer public transit and fewer drivers on the road. Annual transit ridership has increased by about 420 million passengers, while 86% transit agencies report ridership increases in 2011 (APTA, 2011). Despite this increase, it is still a small proportion compared to a decline of 90 billion VMT (NHTSA, 2014; APTA, 2011). One study evaluated the impact of public transportation policies on traffic safety considerations using an SD model, and its simulation results showed that larger subsidy of public transportation leads to greater decreases in number of crashes; however, a small subsidy was not effective within a six-month period (Goh & Love, 2012). Another study concluded that an increasing share of mass transit miles traveled per capita was associated with reduced motor vehicle fatalities (Stimpson et al., 2014). Moreover, multiple factors may influence the use of public transportation, including public investment, unemployment rates, route availability and cost per trip (Liu et al., 2010).

The results were estimated based on model boundary, model assumptions and available data used in this analysis, and they were influenced by the model specification.

They should be interpreted within the context of several limitations. First, this model didn't consider any other traffic safety policies, such as driving under the influence, motorcycle helmet laws, and distracted driving laws. These laws may have a disproportionate impact on reducing the injuries. Second, most SD models are unable to account for uncertainty and variability, and a lack of data may limit model construction. In this model, we used an expected motor vehicle crash incidence for motorcycle and non-motorcycle motor vehicle; however, the crash incidence may vary significant for motorcycle riders over time. For example, people may ride motorcycle more frequently when the weather would be warmer in certain years. In this study, we didn't add other control variables due to the consistence with non-motorcycle motor vehicle injuries. In future, more measures need to be identified affecting motorcycle crash injuries.

CHAPTER 8 : DISCUSSION AND CONCLUSION

This study first explored the relationship between gasoline prices and hospital utilization and costs for motor vehicle injuries by using an inpatient sample. Our results show that the rising price of gasoline has had a substantial effect on hospitalizations for MVC injuries. The benefits of higher gasoline prices from 2001 to 2010 in reducing hospitalizations and associated costs among non-motorcycle MVC drivers and passengers was estimated to be partially offset by increasing hospitalizations and costs among motorcycle MVC victims. Additionally, inpatient care for those with motorcycle MVC injuries was usually more costly and more likely to increase those individuals' financial burden than it was for those with non-motorcycle MVC injuries. Overall, increasing gasoline taxes will reduce hospital utilization and cost, but that reduction will be offset by an increase in motorcycle MVC injuries.

Our estimation found rising gasoline prices since 2001 were associated with a reduction of $831 million in inpatient costs from having over 48,000 fewer non-motorcycle motor vehicle hospitalizations. At the same time, the increase in gasoline prices also was associated with an additional $425 million in inpatient costs from having 21,000 more motorcycle-related hospitalizations. It was predicted that a $1.00 increase in gasoline taxes would be associated with an overall 4,774 reduction in motor vehicle hospitalizations with savings of $111 million in inpatient costs for the U.S. (excluding Florida) in 2014.

We also constructed a conceptual system dynamics model for the traffic safety system response to rising gasoline price, and estimated the effects of gasoline tax increases and passenger-miles traveled increase on motor vehicle injuries. Our simulation found that increasing passenger-miles traveled was more effective in reducing motor vehicle injuries compared to increasing gasoline taxes in the long run.

Our findings suggest that higher gasoline taxes could reduce motor vehicle injuries and associated hospital utilization and costs. However, this positive effect was significantly mitigated by increasing incentives for people to substitute toward motorcycling as a transportation mode. The effect of gasoline prices on overall roadway fatalities is mixed. For example, high gasoline prices might influence people to use other alternative transportation, such as walking, bicycles, carpools, buses and subways, etc. Other literature demonstrates a negative association between driving and gasoline prices. In the context of high gasoline prices, the decline in MVC injuries may be seen as the result of a reduction of VMT and an increase in public transportation ridership. VMT per vehicle decreased 10% over the study period, from 12,600 miles annually in 2001 to 11,400 miles in 2010. However, substitution toward motorcycling in response to rising gasoline prices would be expected to increase crashes due to the substantially higher risk of injury from riding. More policies such as universal helmet laws and mandated training should be emphasized to improve motorcycle safety. Most importantly, public transportation investment is a promising option to encourage safe commuting in an environment of rising gasoline prices.

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APPENDIX

Table S2-1: Number of motor vehicle fatalities and fatality rates in the United States: 1993-2012

Year	Fatalities	Resident Population (Thousands)	Fatality Rate per 100,000 Population	Licensed Drivers (Thousands)	Fatality Rate per 100,000 Licensed Drivers	Registered Motor Vehicles (Thousands)	Fatality Rate per 100,000 Registered Vehicles	Vehicle Miles Traveled (Billions)	Fatality Rate per 10 Million VMT
1993	40,150	257,783	15.58	173,149	23.19	188,350	21.32	2,296	17.50
1994	40,716	260,327	15.64	175,403	23.21	192,497	21.15	2,358	17.30
1995	41,817	262,803	15.91	176,628	23.68	197,065	21.22	2,423	17.30
1996	42,065	265,229	15.86	179,539	23.43	201,631	20.86	2,484	16.90
1997	42,013	267,784	15.69	182,709	22.99	203,568	20.64	2,552	16.50
1998	41,501	270,248	15.36	184,861	22.45	208,076	19.95	2,628	15.80
1999	41,717	272,691	15.30	187,170	22.29	212,685	19.61	2,690	15.50
2000	41,945	282,162	14.87	190,625	22.00	217,028	19.33	2,747	15.30
2001	42,196	284,969	14.81	191,276	22.06	221,230	19.07	2,796	15.10
2002	43,005	287,625	14.95	194,602	22.10	225,685	19.06	2,856	15.10
2003	42,884	290,108	14.78	196,166	21.86	230,633	18.59	2,890	14.80
2004	42,836	292,805	14.63	198,889	21.54	237,949	18.00	2,965	14.40
2005	43,510	295,517	14.72	200,549	21.70	245,628	17.71	2,989	14.60
2006	42,708	298,380	14.31	202,810	21.06	251,415	16.99	3,014	14.20
2007	41,259	301,231	13.70	205,742	20.05	257,472	16.02	3,031	13.60
2008	37,423	304,094	12.31	208,321	17.96	259,360	14.43	2,977	12.60
2009	33,883	306,772	11.05	209,618	16.16	258,958	13.08	2,957	11.50
2010	32,999	309,326	10.67	210,115	15.71	257,312	12.82	2,967	11.10
2011	32,479	311,588	10.42	211,875	15.33	265,043	12.25	2,950	11.00
2012	33,561	313,914	10.69	211,815	15.84	265,647	12.63	2,969	11.30

Source: National Highway Traffic Safety Administration.

Table S2-2: Number of motor vehicle injuries and injury rates in the United States: 1993-2012

Year	Injured	Resident Population (Thousands)	Injury Rate per 100,000 Population	Licensed Drivers (Thousands)	Injury Rate per 100,000 Licensed Drivers	Registered Motor Vehicles (Thousands)	Injury Rate per 100,000 Registered Vehicles	Vehicle Miles Traveled (Billions)	Injury Rate per 10 Million VMT
1993	3,149,000	257,783	1,222	173,149	1,819	188,350	1,672	2,296	1,370
1994	3,266,000	260,327	1,255	175,403	1,862	192,497	1,697	2,358	1,390
1995	3,465,000	262,803	1,319	176,628	1,962	197,065	1,758	2,423	1,430
1996	3,483,000	265,229	1,313	179,539	1,940	201,631	1,728	2,486	1,400
1997	3,348,000	267,784	1,250	182,709	1,832	203,568	1,644	2,562	1,310
1998	3,192,000	270,248	1,181	184,980	1,726	208,076	1,534	2,632	1,210
1999	3,236,000	272,691	1,187	187,170	1,729	212,685	1,522	2,691	1,200
2000	3,189,000	282,224	1,130	190,625	1,673	217,028	1,469	2,747	1,160
2001	3,033,000	284,969	1,064	191,276	1,585	221,230	1,371	2,796	1,080
2002	2,926,000	287,625	1,017	194,602	1,503	225,685	1,296	2,856	1,020
2003	2,889,000	290,108	996	196,166	1,473	230,633	1,252	2,890	1,000
2004	2,788,000	292,805	952	198,889	1,402	237,949	1,172	2,965	940
2005	2,699,000	295,517	913	200,549	1,346	245,628	1,099	2,989	900
2006	2,575,000	298,380	863	202,810	1,269	251,415	1,024	3,014	850
2007	2,491,000	301,231	827	205,742	1,211	257,472	967	3,031	820
2008	2,346,000	304,094	771	208,321	1,126	259,360	904	2,977	790
2009	2,217,000	306,772	723	209,618	1,058	258,958	856	2,957	750
2010	2,239,000	309,350	724	210,115	1,066	260,252	860	2,967	750
2011	2,217,000	311,588	712	211,875	1,046	265,043	836	2,950	750
2012	2,362,000	313,914	752	211,815	1,115	265,647	889	2,969	800

Source: National Highway Traffic Safety Administration.

Table S5-1: Definition of ICD-9 E codes

E codes	Definition
E810	Motor vehicle traffic accident involving collision with train
E811	Motor vehicle traffic accident involving re-entrant collision with another
E812	Other motor vehicle traffic accident involving collision with motor vehicle
E813	Motor vehicle traffic accident involving collision with other vehicle
E814	Motor vehicle traffic accident involving collision with pedestrian
E815	Other motor vehicle traffic accident involving collision on the highway
E816	Motor vehicle traffic accident due to loss of control without collision on the
E817	Noncollision motor vehicle traffic accident while boarding or alighting
E818	Other noncollision motor vehicle traffic accident
E819	Motor vehicle traffic accident of unspecified nature

Source: Centers for Disease Control and Prevention.

Table S5-2: Definition of the fourth digit of E codes

Fourth Digit	Definition
0	Driver of motor vehicle other than motorcycle
1	Passenger in motor vehicle other than motorcycle
2	Motorcyclist
3	Passenger on motorcycle
4	Occupant of streetcar
5	Rider of animal; occupant of animal-drawn vehicle
6	Pedal cyclist
7	Pedestrian
8	Other specified person
9	Unspecified person

Source: Centers for Disease Control and Prevention.

Table S5-3: All states by region

Region	States
Northeast	Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
Midwest	Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, *North Dakota*, Ohio, South Dakota, Wisconsin.
South	*Alabama*, Arkansas, *Delaware*, *District of Columbia*, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia.
West	Alaska, Arizona, California, Colorado, Hawaii, *Idaho*, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming.

Source: Healthcare Cost and Utilization Project, Nationwide Inpatient Sample.
Notes: States/areas in italics do not participate in HCUP and New Hampshire participates in HCUP, but did not provide data in time for the 2010 NIS.

Table S5-4: Weighted numbers, hospitalization rates per 10 million population by year and motor vehicle type: NIS, 2001 – 2010

	Motor vehicle inpatient admission			Non-motorcycle motor vehicle inpatient admission			Motorcycle inpatient admission		
Year	N	95%CI	Rate	N	95%CI	Rate	N	95%CI	Rate
2001	252,526	211,365 - 293,687	8,862	181,426	151,092 - 211,760	6,367	24,861	20,631 - 29,090	872
2002	266,743	222,641 - 310,846	9,274	188,638	156,679 - 220,597	6,558	26,364	21,802 - 30,925	917
2003	301,398	248,026 - 354,770	10,389	211,547	174,139 - 248,955	7,292	34,025	27,409 - 40,642	1,173
2004	301,949	248,869 - 355,028	10,312	210,167	172,746 - 247,589	7,178	37,547	30,416 - 44,679	1,282
2005	256,790	214,137 - 299,444	8,690	178,139	147,711 - 208,568	6,028	31,865	26,353 - 37,378	1,078
2006	268,025	221,701 - 314,348	8,983	181,943	150,148 - 213,738	6,098	36,876	30,142 - 43,611	1,236
2007	251,749	203,069 - 300,429	8,357	163,186	132,441 - 193,930	5,417	38,724	30,414 - 47,034	1,286
2008	248,488	203,285 - 293,690	8,171	162,501	132,869 - 192,134	5,344	40,301	32,122 - 48,480	1,325
2009	242,312	200,761 - 283,863	7,899	155,025	128,273 - 181,776	5,053	38,145	30,986 - 45,304	1,243
2010	285,670	234,957 - 336,382	9,235	180,267	148,612 - 211,923	5,827	45,917	37,020 - 54,814	1,484

Source: Healthcare Cost and Utilization Project, Nationwide Inpatient Sample (NIS).
Notes: CI: Confidence interval.

Table S5-5: Demographic characteristics of inpatient hospitalization for crash victims by vehicle mode: NIS, 2001-2010

	Non-Motorcycle Motor Vehicle Inpatient Admission				Motorcycle Inpatient Admission				
	N	95% CI	%	95% CI	N	95% CI	%	95% CI	P-value
Occupant Type									
Driver/Rider	1,254,029	1,149,749 - 1,358,310	69.2	68.6 - 69.7	330,517	300,274 - 360,760	93.2	92.9 - 93.5	<0.001
Passenger	558,811	512,637 - 604,986	30.8	30.3 - 31.4	24,108	21,666 - 26,551	6.8	6.5 - 7.1	
Age									
<15	90,489	78,985 - 101,992	5.0	4.5 - 5.5	7,237	6,414 - 8,061	2.1	1.9 - 2.3	<0.001
15-20	268,603	243,443 - 293,763	14.9	14.6 - 15.1	27,390	24,340 - 30,440	7.8	7.4 - 8.1	
21-29	344,956	312,665 - 377,247	19.1	18.7 - 19.4	71,150	63,575 - 78,725	20.1	19.5 - 20.8	
30-44	391,604	356,488 - 426,719	21.7	21.3 - 22	114,141	103,424 - 124,858	32.3	31.8 - 32.8	
45-64	406,726	374,431 - 439,021	22.5	22.2 - 22.8	120,241	109,444 - 131,038	34.0	33.1 - 35	
65+	306,659	286,635 - 326,683	17.0	16.4 - 17.5	13,236	11,907 - 14,564	3.8	3.6 - 4.0	
Gender									
Male	994,049	908,710 - 1,079,388	55.1	54.8 - 55.5	307,359	279,034 - 335,685	87.4	87.1 - 87.8	<0.001
Female	809,852	746,498 - 873,205	44.9	44.6 - 45.2	44,188	39,985 - 48,390	12.6	12.3 - 12.9	
Race/Ethnicity									
White	956,173	865,392 - 1,046,954	67.9	65.7 - 70.1	223,776	201,272 - 246,281	78.9	76 - 81.5	<0.001
Black	168,802	145,305 - 192,299	12.0	10.9 - 13.2	23,567	19,608 - 27,527	8.3	7.4 - 9.4	
Hispanic	189,699	157,255 - 222,142	13.5	11.7 - 15.4	24,716	17,407 - 32,026	8.7	6.8 - 11.1	
Other	92,890	80,723 - 105,058	6.6	5.9 - 7.3	11,571	9,846 - 13,296	4.1	3.6 - 4.7	
Median Household Income for Patient's Zip Code									
1st Quartile	427,220	380,856 - 473,583	24.4	22.7 - 26.1	70,004	60,475 - 79,532	20.4	18.7 - 22.1	<0.001
2nd Quartile	456,707	417,447 - 495,967	26.1	25 - 27.1	86,922	78,252 - 95,592	25.3	24.2 - 26.4	
3rd Quartile	435,415	395,052 - 475,778	24.8	23.9 - 25.7	94,633	85,071 - 104,196	27.5	26.6 - 28.5	
4th Quartile	434,150	385,126 - 483,174	24.8	22.9 - 26.8	92,266	82,514 - 102,018	26.8	24.9 - 28.9	

Source: Healthcare Cost and Utilization Project, Nationwide Inpatient Sample (NIS).
Notes: CI: Confidence interval.

Table S6-1: Characteristics of inpatient hospitalization visits for non-motorcycle motor vehicle victims: NIS, 2001-2010

	Inpatient Admission				Length of Stay		Hospital Cost	
	N	**95% CI**	**%**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Principle Injury Diagnosis								
Crushing injury or internal injury	223,355	202,707 - 244,004	15.1	14.8 - 15.4	6.9	6.7 - 7.1	21,231	20,314 - 22,148
Fracture of lower limb	241,701	220,464 - 262,939	16.4	16 - 16.7	6.4	6.2 - 6.6	20,577	19,741 - 21,413
Fracture of neck of femur (hip)	30,412	27,664 - 33,160	2.1	2.0 - 2.1	8.3	7.9 - 8.7	25,939	24,550 - 27,327
Fracture of upper limb	119,333	109,561 - 129,104	8.1	7.9 - 8.3	4.3	4.2 - 4.5	14,393	13,826 - 14,961
Intracranial injury	322,212	287,352 - 357,073	21.8	20.9 - 22.7	6.5	6.2 - 6.9	21,050	19,940 - 22,159
Joint disorders and dislocations; trauma-related	20,236	18,527 - 21,945	1.4	1.3 - 1.4	4.1	3.8 - 4.3	13,102	12,281 - 13,923
Open woods of extremities	27,912	25,385 - 30,438	1.9	1.8 - 2.0	4.9	4.7 - 5.2	14,712	13,855 - 15,569
Open wound of head; neck; and trunk	50,256	45,437 - 55,074	3.4	3.2 - 3.6	2.4	2.3 - 2.5	8,887	8,497 - 9,277
Other fractures	319,471	292,043 - 346,899	21.6	21.2 - 22.1	5.7	5.5 - 5.8	16,314	15,676 - 16,953
Skull fractures	67,536	60,732 - 74,341	4.6	4.5 - 4.7	4.4	4.2 - 4.5	15,415	14,771 - 16,060
Spinal cord injury	28,006	24,788 - 31,225	1.9	1.8 - 2.0	13.9	13.3 - 14.5	50,701	48,444 - 52,957
Sprains and strains	27,082	24,501 - 29,663	1.8	1.7 - 2.0	2.3	2.1 - 2.4	6,241	5,953 - 6,529
Primary Payer								
Medicare	138,798	127,638 - 149,958	7.7	7.3 - 8.2	6.4	6.1 - 6.6	17,540	16,536 - 18,544
Medicaid	187,355	165,898 - 208,811	10.4	9.6 - 11.3	7.0	6.6 - 7.4	21,619	20,287 - 22,951
Private	1,061,844	965,947 - 1,157,740	59.1	57.2 - 60.9	5.4	5.2 - 5.6	16,747	16,068 - 17,426
Self-pay	246,791	219,423 - 274,159	13.7	12.7 - 14.8	4.5	4.2 - 4.7	14,417	13,605 - 15,230
No Charge	10,844	6,118 - 15,570	0.6	0.4 - 0.9	6.1	4.7 - 7.5	18,384	13,421 - 23,347
Other	151,430	131,895 - 170,964	8.4	7.6 - 9.3	5.7	5.3 - 6.0	17,932	16,994 - 18,871
Disposition of Patient								
Routine	1,310,415	1,201,851 - 1,418,980	72.4	71.6 - 73.2	3.8	3.7 - 4.0	11,633	11,109 - 12,156
Short-term hospital	51,842	47,388 - 56,295	2.9	2.7 - 3.1	6.6	6.1 - 7.1	25,836	23,839 - 27,833
Other facilities	258,834	234,821 - 282,847	14.3	13.8 - 14.9	12.7	12.3 - 13.2	37,918	36,212 - 39,625
Home health care	122,862	110,382 - 135,341	6.8	6.4 - 7.3	8.3	8 - 8.5	21,541	20,694 - 22,388
Against medical advice	18,179	16,402 - 19,956	1.0	.9 - 1.1	2.3	2.1 - 2.6	8,513	7,959 - 9,067
Died in hospital	46,274	40,573 - 51,975	2.6	2.4 - 2.7	6.2	5.9 - 6.5	35,005	33,207 - 36,803
Alive but unknown	864	488 - 1,241	0.0	0 - 0.1	7.5	6 - 8.9	36,947	28,391 - 45,503

Source: Healthcare Cost and Utilization Project, Nationwide Inpatient Sample (NIS). Notes: CI: Confidence interval.

Table S6-2: Characteristics of inpatient hospitalization visits for motorcycle victims: NIS, 2001-2010

	Inpatient Admission				Length of Stay		Hospital Cost	
	N	**95% CI**	**%**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Principle Injury Diagnosis								
Crushing injury or internal injury	40,283	36,358 - 44,207	12.3	11.9 - 12.6	7.0	6.7 - 7.3	22,646	20,716 - 24,576
Fracture of lower limb	97,892	89,247 - 106,537	29.8	29.2 - 30.4	6.0	5.8 - 6.2	20,887	19,736 - 22,039
Fracture of neck of femur (hip)	6,302	5,648 - 6,956	1.9	1.8 - 2.0	7.7	7 - 8.3	27,335	24,677 - 29,994
Fracture of upper limb	44,061	40,065 - 48,057	13.4	13 - 13.8	3.8	3.7 - 4	14,344	13,584 - 15,105
Intracranial injury	55,999	48,957 - 63,041	17.1	16.3 - 17.9	8.1	7.7 - 8.5	28,875	26,709 - 31,042
Joint disorders and dislocations; trauma-related	5,118	4,587 - 5,650	1.6	1.5 - 1.7	3.8	3.5 - 4.1	12,511	11,553 - 13,470
Open woods of extremities	11,865	10,708 - 13,022	3.6	3.5 - 3.8	6.1	5.6 - 6.7	18,990	17,186 - 20,793
Open wound of head; neck; and trunk	4,706	4,144 - 5,268	1.4	1.3 - 1.6	2.9	2.6 - 3.3	10,404	9,244 - 11,563
Other fractures	44,049	39,816 - 48,283	13.4	13 - 13.9	6.2	6 - 6.5	20,319	18,989 - 21,650
Skull fractures	11,297	9,963 - 12,631	3.4	3.3 - 3.6	4.7	4.4 - 5.1	17,556	16,134 - 18,979
Spinal cord injury	4,343	3,734 - 4,952	1.3	1.2 - 1.4	16.0	14.6 - 17.4	62,804	58,433 - 67,175
Sprains and strains	2,371	2,104 - 2,638	0.7	0.7 -0 .8	2.8	2.3 - 3.3	9,870	8,666 - 11,075
Primary Payer								
Medicare	15,450	13,785 - 17,115	4.4	4.1 - 4.7	6.9	6.5 - 7.3	21,600	19,697 - 23,504
Medicaid	27,782	23,816 - 31,747	7.9	7.2 - 8.7	8.6	8.1 - 9.1	29,974	25,865 - 34,084
Private	225,480	205,189 - 245,772	63.9	62.1 - 65.7	5.9	5.7 - 6.1	20,306	19,330 - 21,282
Self-pay	53,335	47,367 - 59,303	15.1	14.2 - 16.1	5.5	5.1 - 5.8	17,709	16,577 - 18,841
No Charge	4,763	1,658 - 7,867	1.4	0.7 - 2.5	5.2	4.5 - 5.8	23,812	16,184 - 31,440
Other	26,025	22,271 - 29,779	7.4	6.6 - 8.3	6.2	5.9 - 6.5	21,631	20,309 - 22,952
Disposition of Patient								
Routine	256,475	233,342 - 279,608	72.4	71.4 - 73.5	4.3	4.1 - 4.4	13,979	12,977 - 14,981
Short-term hospital	11,645	10,134 - 13,156	3.3	2.9 - 3.7	6.9	6.1 - 7.7	30,551	28,159 - 32,944
Other facilities	43,787	38,431 - 49,142	12.4	11.7 - 13.1	15.5	14.8 - 16.1	53,077	49,831 - 56,324
Home health care	30,395	26,949 - 33,841	8.6	8.0 - 9.2	9.0	8.7 - 9.4	25,173	24,020 - 26,327
Against medical advice	2,930	2,507 - 3,354	0.8	0.7 - 0.9	3.6	3 - 4.1	12,624	10,982 - 14,266
Died in hospital	8,645	7,429 - 9,862	2.4	2.3 - 2.6	4.6	4.2 - 5	35,347	32,825 - 37,869
Alive but unknown	212	76.4 - 348	0.1	0 - 0.1	8.8	5.2 - 12.4	40,433	242,17 - 56,650

Source: Healthcare Cost and Utilization Project, Nationwide Inpatient Sample (NIS).
Notes: CI: Confidence interval.

Table S6-3: Gasoline tax rates: by states, 2001 - 2010

State	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Alabama	18	18	18	18	18	18	18	18	18	18
Alaska	8	8	8	8	8	8	8	8	8	8
Arizona	18	18	18	18	18	18	18	18	18	18
Arkansas	19.5	21.7	21.7	21.7	21.7	21.5	21.5	21.5	21.5	21.5
California	18	18	18	18	18	18	18	18	18	18
Colorado	22	22	22	22	22	22	22	22	22	22
Connecticut	32	25	25	25	25	25	25	25	25	25
Delaware	23	23	23	23	23	23	23	23	23	23
Dist. of Col.	20	20	20	20	20	20	20	20	23.5	23.5
Florida	13.6	13.9	14.1	14.3	14.5	14.9	15.3	15.6	16.1	16
Georgia	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Hawaii	16	16	16	16	16	16	17	17	17	17
Idaho	25	25	25	25	25	25	25	25	25	25
Illinois	19	19	19	19	19	19	19	19	19	19
Indiana	15	15	18	18	18	18	18	18	18	18
Iowa	20	20.1	20.1	20.3	20.7	20.7	21	21	21	21
Kansas	20	21	23	24	24	24	24	24	24	24
Kentucky	16.4	16.4	16.4	16.4	18.5	19.7	21	22.5	24.1	25.6
Louisiana	20	20	20	20	20	20	20	20	20	20
Maine	19	22	22	25.2	25.9	26.8	27.6	28.4	29.5	29.5
Maryland	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5
Massachusetts	21	21	21	21	21	21	21	21	21	21
Michigan	19	19	19	19	19	19	19	19	19	19
Minnesota	20	20	20	20	20	20	20	22.5	27.1	27.5
Mississippi	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
Missouri	17	17	17	17	17	17	17	17	17	17
Montana	27.75	27.75	27.75	27.75	27.75	27.75	27.75	27.75	27.75	27.75
Nebraska	24.5	24.5	24.6	24.8	25.3	27.1	27	26	26.4	27.1
Nevada	24	24	24	24	24	24	24	24	24	24
New Hampshire	19.5	19.5	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.6
New Jersey	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
New Mexico	18.875	18.875	18.875	18.875	18.875	18.875	18.875	18.875	18.875	18.875
New York	22.05	22.65	22.05	22.65	23.25	23.95	24.65	24.45	25.15	24.35
North Carolina	24.3	24.2	23.4	24.3	26.6	29.9	29.95	30.15	30.15	32.15
North Dakota	21	21	21	21	23	23	23	23	23	23
Ohio	22	22	24	26	28	28	28	28	28	28
Oklahoma	17	17	17	17	17	17	17	17	17	17
Oregon	24	24	24	24	24	24	24	24	24	24
Pennsylvania	26	26.6	25.9	26.2	30	31.2	31.2	30	30	31.2
Rhode Island	29	29	29	30	30	30	30	30	30	32
South Carolina	16	16	16	16	16	16	16	16	16	16
South Dakota	22	22	22	22	22	22	22	22	22	22
Tennessee	20	20	20	20	20	20	20	20	20	20
Texas	20	20	20	20	20	20	20	20	20	20
Utah	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5
Vermont	19	19	19	19	19	19	20	21	20	20
Virginia	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Washington	23	23	28	28	31	34	36	37.5	37.5	37.5
West Virginia	25.35	25.65	25.35	25.35	27	27	31.5	32.2	32.2	32.2
Wisconsin	26.4	27.3	28.1	28.5	29.1	29.9	30.9	30.9	30.9	30.9
Wyoming	14	14	14	14	14	14	14	14	14	14
State Average [a]	19.29	20.17	19.07	19.13	19.25	20.3	19.25	20.48	20.78	21.82

Source: Federal Highway Administration.

Notes: a. Weighted average based on gross gallons taxed.

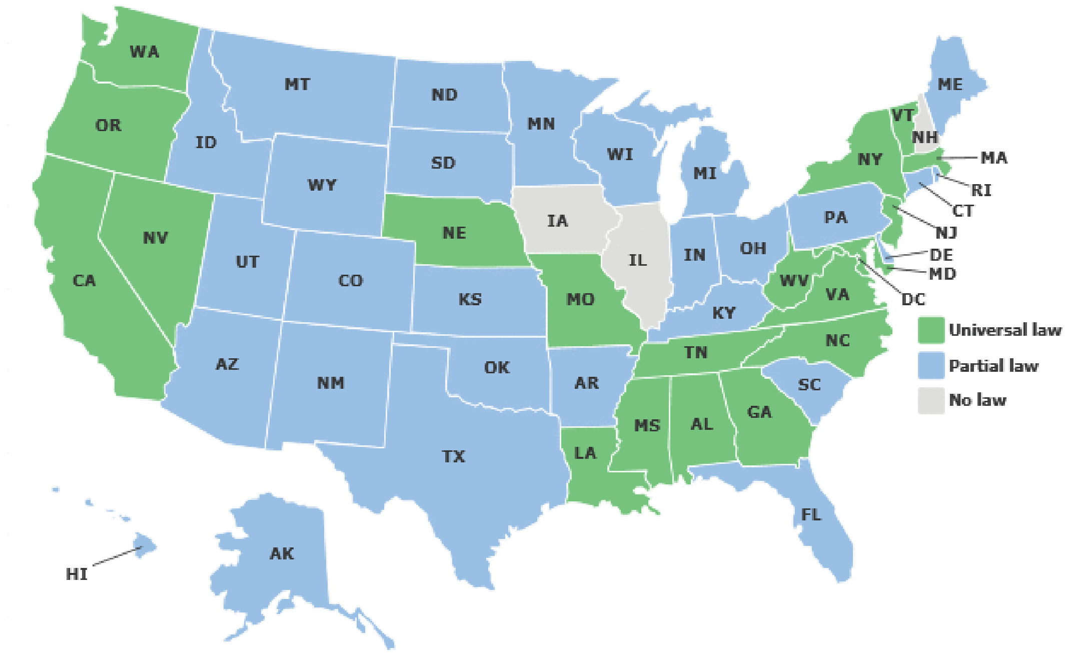

Figure S6-1: Map of motorcycle helmet laws

Source: Insurance Institute for Highway Safety

Table S7.1 Parameter functions

Parameters	Definitions	Unit
Annual injury #	MC injury # + Veh injury #	Person
Congestion (Traffic volume to road capacity)	Veh VMT/ Highway capacity (Lane-miles)	No Unit
Effect of congestion on PMT	0.3432+ Congestion (Traffic volume to road capacity) *(-0.0649)	No Unit
Effect of injury response	"Tolerable injury Inc #"*(Time-2000)/"Motor vehicle (MV) injury #"	No Unit
Lane-mile Inc	Highway capacity (Lane-miles) * Lane-mile Inc rate	Mile
MC Dec	MC injury # *MC quite rate	Vehicle
MC Inc	Pop Inc*Initial MC per capita+Motorcycle*Gas price Inc or Tax Inc*MC gas elasticity	Vehicle
MC injury #	MC VMT*Normal MC injury incidence rate	Person
MC VMT	INTEG (MC VMT Inc-MC VMT Dec, 9639)	Million miles
MC VMT Dec	MC Dec*Initial VMT per MC	Million miles
MC VMT Inc	MC Inc*Initial VMT per MC+MC VMT*MC VMT gas elasticity* Gasoline price Inc/Tax Inc	Million miles
Motorcycle (MC) #	INTEG (MC Inc-MC Dec, 4,903,056)	Vehicle
Non-motorcycle motor vehicle (Veh) #	INTEG (Veh Inc-Veh Dec, 229,678,778)	Vehicle
Passenger-miles traveled (PMT)	INTEG (PMT Inc, 46508)	Million miles
PMT Inc	Passenger miles traveled*Gas price Inc or Tax Inc*PMT gas elasticity+PMT Inc per capita*"Population (Pop)")+Passenger miles traveled*Effect of congestion on PMT*(1+Effect of injury response)	Million miles
Pop Inc	Pop Inc rate* Population (Pop)	Person
Population (Pop)	INTEG (Pop Inc, 248,968,955)	Person
Veh Dec	Non-motorcycle motor vehicle (Veh) # * Gasoline price Inc/Tax Inc *Veh gas elasticity	Vehicle
Veh Inc	Pop Inc*Initital Veh per capita	Vehicle
Veh injury #	Veh VMT*Normal Veh injury incidence rate	Person
Veh VMT	INTEG (V-VMT Inc - V-VMT Dec , 2,778,908)	Million miles
V-VMT Dec	Veh VMT* Gasoline price Inc/Tax Inc *Veh VMT gas elasticity+PMT Inc	Million miles
V-VMT Inc	Initial VMT per Veh*Veh Inc	Million miles