THE EFFECT OF GRADUATED DRIVER LICENSING ON TEEN DRIVER CRASH INVOLVEMENT

by

Johnathon P. Ehsani

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Health Behavior and Health Education)
in The University of Michigan
2012

Doctoral Committee:

Research Professor C. Raymond Bingham, Co-Chair
Professor Marc A. Zimmerman, Co-Chair
Professor Peter X. Song
Associate Professor Cleopatra H. Caldwell
Research Professor Jean T. Shope

DEDICATION

To the safety and well-being of all young people

ACKNOWLEDGEMENTS

This dissertation research would not have been possible without the support and encouragement of many people. In particular, my parents, who gave me their blessing to pursue doctoral studies so far away from home; my wife, who has endured endless hours of speculation on how graduated driver licensing works and why; my father-in-law, who has accompanied me every step of the way; the members of my dissertation committee for joining me on this journey, and providing valuable guidance; in particular, Ray Bingham and Jean Shope who have mentored me in complementary and equally profound ways; and finally, the Center for Injury Prevention among Youth at the University of Michigan, with support from University of Michigan Transportation Research Institute, and the Office of the Vice President for Research; and the General Sir John Monash Foundation for giving me the opportunity to pursue my calling.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

GDL = Graduated Drivers Licensing

MVC = Motor Vehicle Crash

FARS = Fatality Analysis Reporting System

PDO = Property Damage Only

ABSTRACT

Purpose: The purpose of this dissertation was to answer the following questions:

1. What is the effect of each component of Graduated Driver Licensing (learner license duration, required hours of supervised driving, passenger restrictions and nighttime driving restrictions) on 16- and 17-year-old drivers' fatal crash rates?

2. What is the effect of GDL on 18-year-old drivers' crash rates, and what mechanisms might be responsible for any increase in rates?

Method: To answer question 1, states that introduced a single GDL component, independent of other components were identified. The effect of the single GDL component on 16- and 17-year-old drivers fatal crashes was estimated using single-state time series analysis, adjusting for adult crashes and gas prices.

To answer question 2, single-state time series analysis was used to estimate the effect of GDL on 16-, 17-, and 18-year-old drivers' crashes in Florida and Michigan, where GDL applies to 15- to 17-year-old drivers, and in Maryland, where GDL applies to novice drivers of all ages, adjusting for adult crashes and gas prices.

Results: A learner license period that guaranteed six-months delay in licensure to drive independently was associated with a significant decline in 16- and 17-year-old drivers' fatal crash rates. In one state, novice drivers' fatal crash rates increased 34.5% following the introduction of 30 hours of required supervised driving. A passenger restriction for the first 12 months of intermediate licensure was followed by a 46% reduction in fatal passenger crash rates that approached significance (p= .06). Nighttime driving restrictions, implemented alongside supervised driving hours, did not reduce fatal nighttime crashes. The introduction of GDL was followed by a significant increase in possible-injury/property-damage-only crashes among 18-year-old drivers in Michigan and by a significant decrease in possible-injury/property-damage-only crashes among 18-year-old drivers' rates in Maryland.

Conclusion: Some GDL components confer a safety benefit. However, the entire program is responsible for a greater reduction in crashes than the additive contribution of individual components. GDL programs applied exclusively to 16- and 17-year-old drivers may result in some teens not being licensed until age 18. Requiring all novice drivers to complete a GDL program is recommended.

CHAPTER 1

INTRODUCTION

Motor vehicle crashes (MVCs) are the leading cause of death and a leading cause of injury for teens in the United States (National Highway Traffic Safety Administration 2010). Nationally, teens are overrepresented in MVC deaths. Crash rates per mile driven for 16- to 19-year-olds are four times the rates for adult drivers (Insurance Institute for Highway Safety 2012). For every MVC death among 16- to 19-year-olds, there are an estimated 10 serious injuries requiring hospitalization and 178 minor injuries (Christoffel and Gallagher 2006). The Centers for Disease Control and Prevention has identified the prevention of teen MVCs a winnable battle, and Graduated Driver Licensing (GDL) programs have been advanced as the centerpiece of this strategy (Frieden 2011).

Graduated Driver Licensing

The original basis for proposing GDL was crash data from the early 1970s demonstrating teen divers were overrepresented in crashes in relation to their presence on the road, particularly during the hours of midnight and 6 a.m., and when peer passengers were present in the vehicle (Waller 2003). MVCs had emerged as the leading cause of fatal crashes among younger drivers two decades earlier, when deaths from infectious diseases such as tuberculosis had been effectively eliminated (Centers for Disease Control and Prevention 2009). However, it was not until the 1990s that GDL became widely adopted throughout the United States (Insurance Institute for Highway Safety 2012).

GDL is based on the premise that the mastery of driving requires time, extended practice, and a gradual progression from simple to complex driving conditions (Waller 2003). As teens gain driving experience, they *graduate* to progressively higher-risk driving conditions. The move from simple to increasingly complex conditions is mediated by teens' progression through three licensure levels.

The first level (learner license) allows teens with the least driving experience to gain practice under the supervision of a fully licensed driver (typically a parent or some other person over the age of 21 and designated by the parent). Most states require teens to hold a learner license for six months or longer. Driving during the first level of licensure occurs under supervision, meaning that learner license holders gain their initial driving experience under very safe conditions (Mayhew, Simpson et al. 2003). However, some states mandate a specific number of supervised driving hours to be completed (e.g., 30 hours) as part of the requirements of the learner license period.

The second level (intermediate license) allows teens who have gained initial experience driving with a learner license, to drive independently but with some restrictions that limit their exposure to the highest risk driving conditions (driving at night (Williams 2003) and driving with peer passengers (Chen, Baker et al. 2000)). The third level of GDL (full license) gives teens who have gained driving experience over a protracted period while fulfilling the requirements of a learner and intermediate license, permission to drive with no restrictions.

As novice drivers advance through these levels, they experience the principles of GDL in action. Each level is distinct in the requirement or restriction it demands from teen drivers. During the first level of licensure, teens are required to hold a learner license and complete a minimum number of supervised driving hours. During the second level of licensure, teens are restricted from driving with passengers, or driving at night.

Each requirement or restriction is referred to as a component of GDL. Comprehensive GDL systems include three licensing levels and three or more components (Foss 2007).

Effectiveness of Graduated Driver Licensing

Evaluations of GDL have demonstrated the effectiveness of this licensure system in reducing novice teen drivers' crash involvement. Without question, GDL has been the single most effective intervention in reducing motor vehicle-related injuries and fatalities among 16- and 17-year-olds (Insurance Institute for Highway Safety 2011). However, how GDL produces its risk-reducing effect, or more precisely, the contribution of each component of GDL (learner license duration, supervised driving hours, passenger restriction, and nighttime driving restriction) to crash reduction remains unclear (Shults, Begg et al. 2010).

Also unclear is the effect of GDL on 18-year-old drivers. Some studies indicate that GDL reduces 18-year-old drivers' crashes (Trempel 2009; McCartt, Teoh et al. 2010); while two recent studies suggest that GDL is associated with increased fatal crashes of 18-year-old drivers, such that there is no net benefit of GDL on crash fatalities for teen drivers overall (Males 2007; Masten, Foss et al. 2011). These findings raise questions about possible unintended consequences of GDL, and potentially threaten existing GDL systems that have demonstrated significant public health benefit, so a greater understanding is needed.

Establishing the effectiveness of each component of GDL on 16- and 17-year-old drivers' crashes, and the effect of GDL on 18-year-old drivers' crashes have been identified as research priorities (Hedlund, Shults et al. 2003; Shope 2007; Williams and Shults 2010). The purpose of this dissertation was to address these questions, namely to quantify the effect of each component of GDL on 16- and 17-year-old drivers' crashes, and the overall effect of GDL on 18-year-old drivers' crashes. The remainder of the introduction will review the existing literature examining these two questions.

GDL Components

Since GDL was first introduced in the United States, a sizeable body of research has consistently demonstrated its effectiveness in reducing all crash types for teen drivers (Shope and Molnar 2003; Hartling, Wiebe et al. 2004; Hedlund, Shults et al. 2006). However, this introduction will demonstrate that only a few state-level and national studies have evaluated the impact of individual components of GDL, and these are limited by weaknesses in study design as well as conceptual shortcomings. Most studies have ignored the temporal correlation among components and the resulting confounding effect of multiple GDL components implemented simultaneously. In such cases, estimates of effects associated with individual components that were implemented alongside others would be too correlated with one another to allow meaningful analysis of their separate effects. As a result, the manner in which GDL exerts its safety effects is not clearly understood. Furthermore, evaluations of GDL implementation have employed a pre-post-GDL comparison. That study design cannot distinguish changes in crashes directly attributable to GDL from differences arising from a preexisting trend, resulting in lingering questions regarding contributions to observed safety outcomes. The following sections will examine the research evidence related to each GDL component, and the effect of GDL on 18-year-old drivers, and identify the gaps in the literature that remain to be addressed.

Learner License Duration

Currently, the learner license requirements are the most widely implemented of all GDL components in the U.S., existing individually or side-by-side with other components in all fifty states and the District of Columbia. Therefore, it is surprising that the contribution of this component within a comprehensive GDL program is not well understood.

State and provincial level studies provide some evidence of the effectiveness of this component. Evaluations from Kentucky, Connecticut, and Nova Scotia have demonstrated substantial crash reductions for 16-year-old drivers when a learner license time period was mandated or an existing period was extended. In Kentucky, crash rates of 16-year-old drivers dropped by 33% when the learner license duration was extended from 30 days to six months (Agent, Steenbergen et al. 2001). This effect was primarily attributable to an 83% crash reduction among teen drivers age 16 to 16 and six months who would have been driving exclusively with a learner permit. Fatal and injury crash involvements of Connecticut 16-year-old drivers declined by 22% in the first year following the introduction of a six-month learner license period (or four months plus driver education, which was optional in that state) (Ulmer, Ferguson et al. 2001). In Nova Scotia, the crash rate for 16- and 17-year-old GDL novices, who held a learner permit for six months, was 50% lower than the pre-GDL rate when the learner license was held for only 60 days (Mayhew, Simpson et al. 2003).

National level studies examining the effect of the learner license on 16- and 17-year-old drivers' crash rates have been inconclusive. Using Fatality Analysis Reporting System (FARS) data (National Highway Traffic Safety Administration 2010), a national census of fatal crashes, two studies (Chen, Baker et al. 2006; McCartt, Teoh et al. 2010) examined the effect of a learner license period across multiple jurisdictions, and extended the duration of the evaluation period relative to the earlier state and provincial-level studies. Both studies found that learner license holding periods were not associated with reductions in 16- or 17-year-old drivers' fatal crashes. Another national study using insurance collision claims found the learner license period was associated with an increase in 16- and 17-year-old drivers' insurance collision claims (Trempel 2009).

Reasons for the differences in state and province-level studies compared to national studies are unclear. Neither group of studies controlled for pre-existing trends in crashes, meaning that changes in crash rates that were reported could have been associated with the implementation of GDL or the result of continuation of a preexisting trend. In addition, the evaluation of the learner license from Kentucky (Agent, Steenbergen et al. 2001) and all national studies excluded the year preceding the implementation of GDL and the year(s) immediately following implementation (Chen, Baker et al. 2006; Trempel 2009; McCartt, Teoh et al. 2010). Among the national studies, different durations of learner license periods are combined categories (e.g., < 3 months versus ≥ 3 months). As a result, there is a loss of information regarding the specific effect of the different learner license durations. These studies also failed to account for the confounding effect of multiple GDL components implemented simultaneously, meaning the manner in which the leaner license exerts its safety effects is not well understood.

Currently in the U.S., most states require 16- and 17-year-old teen drivers to hold a learner license for six months. However, there is no evidence to suggest that a six-month period is adequate (Foss 2007). The limitations in the study designs of previous evaluations and inconsistency of findings across state, provincial and national evaluations result in a lack of clarity, and further research is necessary to determine the effect of different learner license periods on 16- and 17-year-old drivers' subsequent crashes.

Required Supervised Driving Hours

In order to encourage driving practice within the learner license period, many states require teens to complete a minimum number of hours of supervised driving. As of March 2012, 46 states and the District of Columbia required teens to complete a specific amount of supervised driving, most commonly 50 hours (Insurance Institute for Highway

Safety 2012). However, relatively little research has been conducted on the safety effect of the required number of supervised driving hours on teen drivers' crashes, and the few studies examining the effect of supervised driving hours on 16- and 17-year-old drivers' crashes are inconclusive.

A study of Swedish teens found an average of 120 hours of supervised driving was associated with a significant reduction in crash involvement during independent licensure, compared to those who had approximately 50 hours of supervised driving practice (Gregersen, Berg et al. 2000; Gregersen, Nyberg et al. 2003; Sagberg and Gregersen 2005). In contrast, a prospective study of teen drivers in the northeastern U.S. in the first year of independent licensure found that the number of months of supervised driving was not predictive of time to first crash (McCartt, Shabanova et al. 2003). Similarly, French teens who received professional driving instruction with an extensive period of supervised driving (equivalent to approximately 3,000 miles) had the same subsequent crash likelihood as those teens who only received professional driving instruction (Page 2004).

The results of two national studies examining the effect of supervised driving hours are inconclusive. In their national study of GDL, Chen and colleagues (Chen, Baker et al. 2006) reported that 30 hours or more of supervised driving required during a learner license period lasting at least three months was associated with an 18% reduction in 16-year-old drivers' fatal crashes. However, it is unclear whether the decline in crashes was due to the supervised driving hours or the length of the learner license period. McCartt reported a small, non-significant decrease in fatal crashes following the extension of supervised driving hours by ten or twenty hours (McCartt, Teoh et al. 2010).

None of the studies were true randomized control trials, and the period of supervised driving in the European studies was considerably longer than any existing requirement in the U.S. (Simons-Morton and Ouimet 2006). National studies on the effectiveness of supervised driving have excluded several years of data prior to and after GDL implementation. Similar to studies on the learner license duration, different hours of required supervised driving practice were combined into categories (e.g., < 30 hours versus ≥ 30 hours), diluting the effect of the different hours of required practice, and leading to the possibility of grouping error, when a continuous variable is treated as categorical. Based on the existing literature, the most one can conclude is that a required number of supervised driving hours that is considerably longer than any requirement in the U.S. (at least double) may confer a safety benefit for teens. The small body of evidence examining the effect of the required number of supervised driving hours on teen drivers' crashes is inconclusive and further research is needed to quantify the effect of this component.

Passenger Restrictions

Passenger restrictions limit the transportation of passengers by teen drivers for a period of time during the intermediate license stage. These restrictions specify the number and/or age of passengers allowed in the vehicle. For example, Utah restricts passengers of any age (except family members) for the first six months of independent driving. In contrast, Rhode Island allows 16- and 17-year-olds to drive unsupervised with a single passenger below the age of 21 for the first 12 months of driving (Insurance Institute for Highway Safety 2012). Currently in the U.S., 45 states and the District of Columbia restrict the number of passengers that can be carried during at least the first months of intermediate licensure.

Numerous studies have evaluated the effect of passenger restrictions on teen drivers' crashes (Masten and Hagge 2004; Chen, Baker et al. 2006; Zwicker, Williams et al. 2006; Chaudhary, Williams et al. 2007; Fell, Todd et al. 2011; Masten, Foss et al. 2011). California was one of the first states to implement a passenger restriction, when in July 1998, teen drivers were restricted from carrying any passengers below 20 years of age for the first six months of their intermediate license (Insurance Institute for Highway Safety 2012). Evaluations of the California law indicated substantial declines in crashes resulting in a fatality or non-fatal injury where a passenger under age 20 was present in the vehicle of the teen driver (Masten and Hagge 2004; Rice, Peek-Asa et al. 2004; Cooper, Atkins et al. 2005; Zwicker, Williams et al. 2006). Beyond California, Chaudhary and colleagues reported significant declines in teen passenger crashes in Virginia and Massachusetts following the introduction of a passenger restriction in those states (Chaudhary, Williams et al. 2007).

Several national evaluations of GDL have also examined the effect of passenger restrictions on 16- and 17-year-old drivers' crashes. McCartt found that the presence of a passenger restriction component was significantly associated with a reduction in 16- and 17-year-old drivers' fatal crashes (McCartt, Teoh et al. 2010). Trempel reported that passenger restrictions allowing no or one passengers were associated with significantly fewer insurance collision claims by 16- and 17-year-old drivers (Trempel 2009), and recently, Fell reported a 9% reduction in 16- and 17-year-old drivers' fatal crashes when GDL programs included a passenger restriction (Fell, Todd et al. 2011).

The existing body of literature demonstrating the effectiveness of the passenger restriction in reducing 16- and 17-year-old drivers' crashes is compelling. However, in the majority of instances where a passenger restriction has been introduced in the U.S., it has been implemented concurrently with other restrictions. Existing state and national evaluations have rarely accounted for the confounding effect of multiple GDL components that are implemented at the same time, or were simultaneously in effect. Rather, these studies have assumed independent implementation of each component, which does not reflect the reality of how passenger restrictions were introduced.

Several authors have argued that the estimates of effects associated with individual components that were implemented alongside others would be too correlated with one another to allow meaningful analysis of their separate effects (Chen, Baker et al. 2006; Baker, Chen et al. 2007). For example, California's first passenger restriction was introduced alongside a nighttime driving restriction, and a six-month learner license period with 50 hours of required supervised driving (Insurance Institute for Highway Safety 2011). Passenger restrictions in Massachusetts and Virginia were also implemented alongside several other components. Yet, the evaluations of the restriction failed to account for temporal correlation among components.

A further limitation of the existing literature on passenger restrictions is the oversimplification of the complex provisions of the restriction. All existing national evaluations of passenger restrictions examined the number of passengers permitted in the vehicle (Trempel 2009; Fell, Todd et al. 2011; McCartt and Teoh 2011), but failed to include the age of the passengers, which has been found to be a predictor of crash risk when passengers are younger (Chen, Baker et al. 2000). Nor did the studies account for the duration the passenger restriction is in place. This oversight limits the application of the findings of these studies to one dimension of passenger restrictions, but not others. Several national studies also failed to control for pre-existing trends in teen crashes in their analysis (Trempel 2009; McCartt and Teoh 2011).

These methodological and conceptual shortcomings raise questions regarding the validity of the existing estimates of the effects of passenger restrictions. By exploiting natural experiments resulting from GDL policy implementation, instances when a passenger restriction was implemented independently of other components could be used to estimate the independent effect of this component. Using long-term, methodologically rigorous time-series analysis of individual states would control for pre-existing trends, seasonality, and time-related autocorrelation in the data, and provide a less biased assessment of the effectiveness of passenger restrictions than techniques that have been applied in the existing literature [18].

Nighttime Driving Restriction

Nighttime driving restrictions prohibit teens with an intermediate license from any unsupervised driving during certain hours, typically from late evening to early morning, when crash risk is known to be highest (Insurance Institute for Highway Safety 2011). Initial evidence of the effectiveness of nighttime driving restrictions was generated from evaluations of city or state-wide nighttime driving curfews, implemented as stand-alone policies for teen drivers (Preusser, Williams et al. 1984). A study of four states, Louisiana, Maryland, New York, and Pennsylvania, examined the effect of nighttime driving curfew laws on 16-year-old drivers' crashes. Reductions in 16-year-old drivers' crash involvements were observed in each of the four curfew states in relation to comparison states, both during the nighttime driving curfew hours, but also during other hours of the day (Preusser, Williams et al. 1984).

As states began adopting nighttime driving restrictions within comprehensive GDL systems, further evidence of the effectiveness of this restriction was established (Ulmer, Preusser et al. 2000; Foss, Feaganes et al. 2001; Shope, Molnar et al. 2001; Shope and Molnar 2004; Foss, Masten et al. 2007). Florida's nighttime driving restriction, which spans 11 p.m. to 6 a.m. for 16-year-olds and 1 a.m. to 6 a.m. for 17-year-olds, was associated with a 17% decline in the number of nighttime crash involvements of 15- to 17-year-old drivers. The reduction in crashes occurred while the proportion of teens receiving licenses increased, meaning the decline could not be attributed to reductions in licensure (Ulmer, Preusser et al. 2000). North Carolina's GDL system, which included a strong nighttime driving restriction (from 9pm to 5am), was associated with a 43% decrease in nighttime crashes, and a 20% reduction in daytime crashes of 16-year-old drivers' (Foss, Feaganes et al. 2001). Michigan's GDL law included a more relaxed nighttime driving restriction (from 12 midnight to 5 a.m.) and was associated with a 21% reduction in evening crashes (9 p.m. to 11.59 p.m.) and 53%

reduction of crashes during the restricted time (12 midnight to 5 a.m.) (Shope, Molnar et al. 2001).

National studies of GDL have also reported significant declines in 16- and 17-year-old drivers' crashes corresponding to the presence of a nighttime driving restriction. McCartt found the presence of a nighttime driving restriction was significantly associated with a reduction in 16- and 17-year-old drivers' fatal crashes (McCartt, Teoh et al. 2010). Similarly, Trempel observed that the effect of a nighttime driving restriction was associated with significantly fewer insurance collision claims by 16- and 17-year-old drivers (Trempel 2009). Karaca-Mandic found that GDL programs that included a nighttime driving restriction reduced fatal crashes by 15% (Karaca-Mandic and Ridgeway 2010). Recently, Fell reported a 10.3% decline in 16- and 17-year-old drivers' nighttime fatal crashes following the introduction of nighttime driving restrictions (Fell, Todd et al. 2011).

Collectively, these studies present a convincing body of evidence demonstrating the effectiveness of the nighttime driving restriction. However, in the majority of instances, evaluations of nighttime driving restrictions have employed a pre-post-GDL study design. As a result, the authors have not been able to distinguish a decline directly attributable to GDL from a continuation of a preexisting downward trend (Sivak and Schoettle 2010). For example, a follow-up study of the effect of Michigan's nighttime driving restriction found that changes in nighttime crash rates among 16-year-old drivers in Michigan could not be attributed to GDL, but that the downward trend in nighttime crashes began a year prior to the introduction of GDL and continued as a linear trend throughout the GDL introduction period (Elliott and Shope 2003).

Similar to passenger restrictions, in the majority of instances when nighttime driving restrictions were introduced in the United States, they were implemented along with at least one additional GDL component. State and national evaluations have rarely accounted for the confounding effect of multiple GDL components implemented simultaneously. Therefore, it is possible that existing estimates of the effect of nighttime driving restrictions may be overestimated due to issues related to study design and the misapplied assumption of independent implementation.

One approach to quantifying a more precise measure of the effectiveness of nighttime driving restrictions on 16- and 17-year-old drivers' crashes is to identify instances when a nighttime driving restriction was implemented independently of other components. In such cases, inferences regarding the impact of GDL on teen crash rates would be more strongly supported than in situations where multiple GDL components were changed simultaneously.

Effect of GDL on 18-year-old drivers

With few exceptions, the staged licensing requirements of GDL apply exclusively to 15- to 17-year-old drivers (Williams and Shults 2010). In most U.S. states, individuals 18 year of age and older wishing to obtain a driver's license for the first time are required to complete a knowledge test and a driving skills test prior to receiving a regular license, effectively bypassing the learner, intermediate, and full license stages of GDL.

While a sizeable body of evidence suggests that GDL leads to significant declines in 16- and 17-year-old drivers' crashes (Foss, Feaganes et al. 2001; Shope, Molnar et al. 2001; Williams, Ferguson et al. 2005; Chen, Baker et al. 2006; Trempel 2009; McCartt, Teoh et al. 2010; Williams and Shults 2010; Masten, Foss et al. 2011), the effect of GDL on 18-year-old drivers' crashes is less clear. A study examining the effect of California's GDL on teen driver fatalities reported a 24% rise in 18-year-old drivers' fatal crashes following the introduction of GDL in July 1998 (Males 2007). A recent national study by Masten and Foss also reported a significant increase in fatal crashes of 18-year-old drivers following the introduction of GDL that was large enough that there was no net benefit from GDL on overall 16- to 19-year-old drivers' fatalities

(Masten, Foss et al. 2011). In contrast, McCartt and colleagues found that states with GDL programs that were rated by the Insurance Institute for Highway Safety as 'good' (i.e., more, stronger components) had significantly lower 18-year-old driver fatal crashes compared to states with 'fair' or 'poor' rated GDL programs (i.e., fewer, weaker components) (McCartt, Teoh et al. 2010; McCartt and Teoh 2011). Using the same taxonomy to rate GDL programs, Trempel found that 'good' GDL programs were associated with significantly fewer insurance collision claims by 18-year-old drivers (Trempel 2009).

These studies differed in the quality of methodological approaches that were employed and the data sources that were used. The studies reporting an increase in 18-year-old drivers' fatalities used time series analysis, an evaluation method that controls for pre-existing trends, seasonal variation and serial correlation between observations (McCleary and Hay 1982). Masten's national evaluation pooled individual states' time series into a single sample, making this evaluation arguably the most complete study on the effect of GDL that has been conducted to date. However, both studies utilized data from the Fatal Analysis Reporting System (FARS) and, therefore, were limited to only fatal crashes (National Highway Traffic Safety Administration 2010). Neither McCartt (McCartt, Teoh et al. 2010) nor Trempel (Trempel 2009) controlled for pre-existing trends in teen crashes in their analyses, and McCartt was limited to fatal-only crashes. Futhermore, Trempel's analysis was restricted to collision claims involving new (i.e., 0-3-year-old) motor vehicles (Trempel 2009), a sample that is known to be unrepresentative of teen drivers (Williams, Leaf et al. 2006).

Dissertation Significance

The purpose of this dissertation was twofold. The first was to quantify the effect of each component of GDL on 16- and 17-year-old drivers' crashes. The second was to quantify the overall effect of GDL on 18-year-old drivers' crashes, and shed light on the mechanisms responsible for some potential increase in crash rates in this population. By exploiting natural experiments in GDL policy implementation and using time series analysis, we estimated the effects of GDL on teen drivers' crashes with less confounding than in previous studies.

This dissertation includes five chapters in total. An introductory chapter (**Chapter 1**) and a concluding chapter (**Chapter 5**) and three research papers (**Chapters 2 – 4**). Paper 1 (**Chapter 2**) examines the effect of the learner license requirements (i.e., learner license period and supervised driving requirement) on 16- and 17-year-old drivers' fatal crash involvement. Paper 2 (**Chapter 3**) examines the effect of intermediate license restrictions (i.e., nighttime driving restriction and passenger restriction) on 16- and 17-year-old drivers' fatal crash involvement. Paper 3 (**Chapter 4**) examines the overall effect of GDL on 18-year-old drivers' injury crash rates. **Chapter 5** concludes with an integrated discussion of the research findings, including strengths and limitations of the studies, and implications for future research.

References:

Agent, K., L. Steenbergen, J. Pigman, P. Stinson Kidd, C. McCoy and S. Pollack (2001). "Impact of Partial Graduated Driver's License Program on Teen Motor Vehicle Crashes in Kentucky." Transportation Research Record: Journal of the Transportation Research Board **1779**: 54-60.

Baker, S., L. Chen and G. Li (2007). Nationwide review of graduated driver licensing. Washington, DC, AAA Foundation for Traffic Safety.

Centers for Disease Control and Prevention. (2009). "Death Rates for Selected Causes by 10-Year Age Groups, Race, and Sex: Death Registration States, 1900-32, and United States, 1933-98." National Vital Statistics System: Historical Data, 1900 - 1998 Retrieved 8th May, 2012, from http://www.cdc.gov/nchs/nvss/mortality/hist290.htm.

Chaudhary, N. K., A. F. Williams and W. Nissen (2007). Evaluation and compliance of passenger restrictions in a graduated licensing program. National Highway Traffic Safety Administration. Washington DC.

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

Chen, L. H., S. P. Baker and G. Li (2006). "Graduated driver licensing programs and fatal crashes of 16-year-old drivers: A national evaluation." Pediatrics **118**(1): 56-62.

Christoffel, T. and S. S. Gallagher (2006). Injury prevention and public health: practical knowledge, skills, and strategies Gaithersburg, MD, Aspen.

Cooper, D., F. Atkins and D. Gillen (2005). "Measuring the impact of passenger restrictions on new teenage drivers." Accident Analysis & Prevention **37**(1): 19-23.

Elliott, M. R. and J. T. Shope (2003). "Use of a Bayesian changepoint model to estimate effects of a graduated driver's licensing program." Journal of Data Science **1**: 43–63.

Fell, J. C., M. Todd and R. B. Voas (2011). "A national evaluation of the nighttime and passenger restriction components of graduated driver licensing." Journal of Safety Research **42**(4): 283-290.

Foss, R. D. (2007). "Improving graduated driver licensing systems: A conceptual approach and its implications." Journal of Safety Research **38**(2): 185-192.

Foss, R. D., J. R. Feaganes and E. A. Rodgman (2001). "Initial effects of graduated driver licensing on 16-year-old driver crashes in North Carolina." JAMA: The Journal of the American Medical Association **286**: 1588–1592.

Foss, R. D., S. V. Masten and A. H. Goodwin (2007). Long-term effects of graduated driver licensing in North Carolina. Chapel Hill, NC, University of North Carolina Highway Research Center.

Frieden, T. R. (2011). Motor Vehicle Crashes are a Winnable Battle. C. f. D. C. a. Prevention. Atlanta, Georgia, U.S. Department of Health and Human Services.

Gregersen, N. P., H. Y. Berg, I. Engstrom, S. Nolen, A. Nyberg and P. A. Rimmo (2000). "Sixteen years age limit for learner drivers in Sweden: an evaluation of safety effects." Accident Analysis & Prevention **32**(1): 25-35.

Gregersen, N. P., A. Nyberg and H. Y. Berg (2003). "Accident involvement among learner drivers - an analysis of the consequences of supervised practice." Accident Analysis & Prevention **35**(5): 725-730.

Hartling, L., N. Wiebe, K. F. Russell, J. Petruk, C. Spinola and T. P. Klassen (2004). "Graduated driver licensing for reducing motor vehicle crashes among young drivers." Cochrane Database of Systematic Reviews(2): Art. No.: CD003300.

Hedlund, J., R. A. Shults and R. Compton (2003). "What we know, what we don't know, and what we need to know about graduated driver licensing." Journal of Safety Research **34**(1): 107-115.

Hedlund, J., R. A. Shults and R. Compton (2006). "Graduated driver licensing and teenage driver research in 2006." Journal of Safety Research **37**(2): 107-121.

Insurance Institute for Highway Safety. (2011). "Fatality Facts 2009: General." Retrieved 22th July, 2011, from http://www.iihs.org/research/fatality_facts_2009/general.html.

Insurance Institute for Highway Safety. (2011). "Graduated Driver Licensing." Retrieved 26th May, 2011, from http://www.iihs.org/research/qanda/gdl.html.

Insurance Institute for Highway Safety. (2012). "Cell Phone and Texting Laws." Retrieved 16th February, 2012, from http://www.iihs.org/laws/cellphonelaws.aspx.

Insurance Institute for Highway Safety. (2012). "Fatality Facts 2009: Teenagers." Retrieved 9th March, 2012, from http://www.iihs.org/research/fatality_facts_2009/teenagers.html.

Insurance Institute for Highway Safety. (2012). "Summary table: young driver licensing systems in the U.S." Retrieved 25th March, 2012, from http://www.iihs.org/laws/GraduatedLicenseCompare.aspx.

Karaca-Mandic, P. and G. Ridgeway (2010). "Behavioral impact of graduated driver licensing on teenage driving risk and exposure." Journal of Health Economics **29**(1): 48-61.

Males, M. (2007). "California's graduated driver license law: Effect on teenage drivers' deaths through 2005." Journal of Safety Research **38**(6): 651-659.

Masten, S. V., R. D. Foss and S. W. Marshall (2011). "Graduated Driver Licensing and Fatal Crashes Involving 16- to 19-Year-Old Drivers." JAMA: The Journal of the American Medical Association **306**(10): 1098-1103.

Masten, S. V. and R. A. Hagge (2004). "Evaluation of California's graduated driver licensing program." Journal of Safety Research **35**(5): 523-535.

Mayhew, D. R., H. M. Simpson, K. Desmond and A. F. Williams (2003). "Specific and Long-Term Effects of Nova Scotia's Graduated Licensing Program." Traffic Injury Prevention **4**(2): 91-97.

McCartt, A. T., V. I. Shabanova and W. A. Leaf (2003). "Driving experience, crashes and traffic citations of teenage beginning drivers." Accident Analysis and Prevention **35**(3): 311-320.

McCartt, A. T. and E. R. Teoh (2011). "Strengthening Driver Licensing Systems for Teenaged Drivers." JAMA: The Journal of the American Medical Association **306**(10): 1142-1143.

McCartt, A. T., E. R. Teoh, M. Fields, K. A. Braitman and L. A. Hellinga (2010). "Graduated Licensing Laws and Fatal Crashes of Teenage Drivers: A National Study." Traffic Injury Prevention **11**(3): 240-248.

McCleary, R. and R. A. Hay (1982). Applied time series analysis for the social sciences Beverly Hills, CA, Sage Publications.

National Highway Traffic Safety Administration (2010). Fatality Analysis Reporting System Washington, D.C, U.S. Department of Transportation.

National Highway Traffic Safety Administration (2010). Traffic Safety Facts 2009: A compilation of motor vehicle crash data from the Fatality Analysis Reporting System and the General Estimates System. Washington, D.C, U.S. Department of Transportation.

Page, Y. (2004). "An evaluation of the effectiveness of the supervised driver-training system in France." Annual proceedings / Association for the Advancement of Automotive Medicine. Association for the Advancement of Automotive Medicine **48**: 131-145.

Preusser, D. F., A. F. Williams, P. L. Zador and R. D. Blomberg (1984). "The effect of curfew laws on motor vehicle crashes." Law and Policy **6**(1): 115–128.

Rice, T. M., C. Peek-Asa and J. F. Kraus (2004). "Effects of the California graduated driver licensing program." Journal of Safety Research **35**(4): 375-381.

Sagberg, F. and N. P. Gregersen (2005). Effects of lowering the age limit for driver training. Traffic and transport psychology: theory and application. Proceedings of the ICTTP 2004. G. Underwood. Amsterdam, Elsevier Science: 171–178.

Shope, J. T. (2007). "Graduated driver licensing: Review of evaluation results since 2002." Journal of Safety Research **38**(2): 165-175.

Shope, J. T. and L. J. Molnar (2003). "Graduated driver licensing in the United States: evaluation results from the early programs." Journal of Safety Research **34**(1): 63-69.

Shope, J. T. and L. J. Molnar (2004). "Michigan's graduated driver licensing program: Evaluation of the first four years." Journal of Safety Research **35**(3): 337-344.

Shope, J. T., L. J. Molnar, M. R. Elliott and P. F. Waller (2001). "Graduated Driver Licensing in Michigan." JAMA: The Journal of the American Medical Association **286**(13): 1593-1598.

Shults, R. A., D. J. Begg, D. R. Mayhew and H. M. Simpson. (2010). "Graduated Driver Licensing." Retrieved 25th May, 2011, from http://www.cdc.gov/MotorVehicleSafety/Teen_Drivers/GDL/GradDrvLic.html.

Simons-Morton, B. and M. C. Ouimet (2006). "Parent involvement in novice teen driving: a review of the literature." Injury Prevention **12**(suppl 1): i30-i37.

Sivak, M. and B. Schoettle (2010). "Toward Understanding the Recent Large Reductions in U.S. Road Fatalities." Traffic Injury Prevention **11**(6): 561-566.

Trempel, R. E. (2009). Graduated Driver Licensing Laws and Insurance Collision Claim Frequencies of Teenage Drivers. Arlington, VA, Highway Loss Data Institute.

Ulmer, R. G., S. A. Ferguson, A. F. Williams and D. F. Preusser (2001). "Teenage crash reduction associated with delayed licensure in Connecticut." Journal of Safety Research **32**(1): 31-41.

Ulmer, R. G., D. F. Preusser, A. F. Williams, S. A. Ferguson and C. M. Farmer (2000). "Effect of Florida's graduated licensing program on the crash rate of teenage drivers." Accident Analysis & Prevention **32**(4): 527-532.

Waller, P. F. (2003). "The genesis of GDL." Journal of Safety Research **34**(1): 17-23.

Williams, A. F. (2003). "Teenage drivers: patterns of risk." Journal of Safety Research **34**: 5–15.

Williams, A. F., S. A. Ferguson and J. K. Wells (2005). "Sixteen-Year-Old Drivers in Fatal Crashes, United States, 2003." Traffic Injury Prevention **6**(3): 202 - 206.

Williams, A. F., W. A. Leaf, B. G. Simons-Morton and J. L. Hartos (2006). "Vehicles driven by teenagers in their first year of licensure." Traffic Inj Prev **7**(1): 23-30.

Williams, A. F. and R. A. Shults (2010). "Graduated Driver Licensing Research, 2007 - Present: A Review and Commentary." Journal of Safety Research **41**(2): 77-84.

Zwicker, T. J., A. F. Williams, N. K. Chaudhary and C. M. Farmer (2006). Evaluation of California's graduated licensing system. Arlington, VA, Insurance Institute for Highway Safety.

CHAPTER 2

DOES THE LENGTH OF THE LEARNER LICENSE PERIOD OR THE HOURS OF SUPERVISED DRIVING MATTER? AN ANALYSIS OF THE EFFECT OF TWO GRADUATED DRIVER LICENSING COMPONENTS ON 16- AND 17-YEAR-OLD DRIVERS' FATAL CRASHES

INTRODUCTION

Motor vehicle crashes are the leading cause of death and a leading cause of injury for teenagers in the United States (National Highway Traffic Safety Administration 2010). Sixteen-year-old drivers in their first year of licensure have higher crash rates than of any other age group, including older teens (Insurance Institute for Highway Safety 2012). Graduated driver licensing (GDL) has been the single most effective intervention to reduce motor vehicle related injury and fatality in this population (Insurance Institute for Highway Safety 2012). GDL is based on the premise that the mastery of any complex task requires time and extended practice. All beginning drivers are inexperienced and prone to making driving errors, and therefore at a higher risk of crashing (Waller 2003). GDL shifts the focus from providing specific, detailed training to individuals directly, and exerts its influence through modifying the driving environment for novice drivers in a way that reflects the reality of learning a complex task (Foss 2007).

As a system, GDL is based on learning theory, which asserts that mastery of a skill requires extended practice, and a gradual move from simple to complex conditions (Waller 2003). An ideal GDL system includes three licensure levels (Foss and Goodwin 2003), and as novice drivers advance through these levels, they experience the principles of GDL in action. The first level (learner license) allows teens with the least driving experience to gain practice under the supervision of a fully licensed driver (typically a parent or some other person over the age of 21 and designated by the parent). The period of supervised driving has the lowest lifetime crash risk (Mayhew, Simpson et al. 2003; VicRoads 2005), meaning that learner license holders gain their initial driving experience under very safe conditions. All driving within the first level of licensure occurs under supervision, however, some states mandate a specific number of supervised driving hours to be completed (e.g., 30 hours). Most states also require a six-month learner license. A few require less, and North Carolina requires 12 months (Insurance Institute for Highway Safety 2012).

The second level (intermediate license) allows teens who have gained some initial experience driving with a learner license, to drive independently but with some restrictions that limit their exposure to the highest risk driving conditions (driving at night (Williams 2003) and driving with peer passengers (Chen, Baker et al. 2000)). The third stage of GDL gives teens who have gained driving experience over a protracted period while fulfilling the requirements of a learner and intermediate license, permission to drive with no restrictions. Increasing driving privileges by easing restrictions at each stage of licensure allows a gradual move from simple to more complex driving conditions.

There is little question that GDL reduces young drivers crashes (Insurance Institute for Highway Safety 2012), however, it is not clear how these reductions are achieved. McKnight and Peck suggest the safety effect of GDL is achieved by limiting driving to the lowest risk conditions (supervised driving) and through extending the period of practice driving (McKnight and Peck 2002). Currently, the learner license requirements are the most widely implemented of all GDL components in the U.S., existing individually or side-by-side with other components in all fifty states and the District of Columbia. Therefore, it is surprising that little is known about both the optimal number of months a learner license should be held, and the optimal number of required supervised driving hours.

Studies in Kentucky, Connecticut, and Nova Scotia indicate substantial crash reductions for 16-year-old drivers when a learner license period was mandated or an existing period was extended. In Kentucky, crash rates of 16-year-old drivers dropped by 33% when the learner license duration was extended from 30 days to six months (Agent, Steenbergen et al. 2001). This effect was primarily attributable to an 83% crash reduction among those aged 16 to 16 years and six months, who would be driving exclusively with a learner permit. Fatal and injury crash involvements of Connecticut 16-year-old drivers declined by 22% in the first year following the introduction of a six-month learner license period (or four months with driver education, which is optional in that state) (Ulmer, Ferguson et al. 2001). In Nova Scotia, the crash rate for 16- and 17-year-old GDL novices was 50% lower than the rate for pre-GDL novices when the learner license was extended from 60 days to six months (Mayhew, Simpson et al. 2003).

While these findings indicate an extension of the learner license period reduces crashes, none of these studies used licensure data, so the specific mechanism (delay in licensure or safer independent driving) by which crash reductions were achieved is unclear. Little is also known about the optimal number of months a learner license should be held for the best safety benefit. In all three states above, the learner license was extended to or mandated to be six months, however, there is no evidence to suggest whether or not a six-month period of supervised driving is adequate (Foss 2007). For example, for the states discussed above, it is unknown whether a doubling of the learner license period (to twelve months) would have resulted in the same or a larger crash reduction.

Less is known about the safety effect on teen drivers of the required number of supervised driving hours. The small body of research examining the subject is inconclusive. A study of Swedish teens found an average of 120 hours of supervised driving was associated with a significant reduction in crash involvement during independent licensure, compared to those who had approximately 50 hours of supervised driving practice (Gregersen, Berg et al. 2000; Gregersen, Nyberg et al. 2003; Sagberg and Gregersen 2005). However, teen drivers in the northeastern U.S. who completed a period of supervised driving were no different in their time-to-first-crash than those who did not have supervised driving experience (McCartt, Shabanova et al. 2003). Similarly, French teens who received professional driving instruction with an extensive period of supervised driving (equivalent to approximately 3,000 miles) had the same crash likelihood as those teens who only received professional driving instruction (Page 2004).

The Swedish study that found an average of 120 hours of supervised driving reduced teen drivers' crashes is notable because it is the only instance where the effectiveness of supervised driving hours has been reported, and the number of supervised driving hours was considerably longer than any existing requirement in the U.S., which is 60 hours (in both Kentucky and Maryland (Insurance Institute for Highway Safety 2012)). However, due to the small number of studies, it is not possible to determine whether 120 hours is the optimal number of supervised driving hours, or whether a greater number of supervised driving hours would result in the same or a larger crash reduction.

States that changed the number of months a teen holds a learner license or the required number of supervised driving hours, independent of any other GDL component, represent natural experiments where intervention effects can potentially be measured. In such cases, inferences regarding the impact of the change on teen crash rates would be more strongly supported than in situations where multiple GDL components were changed simultaneously. While it has been argued that quantifying the contribution of individual components of GDL is difficult (Foss 2007), estimating their specific contribution in such natural experiments represents an opportunity to understand the mechanisms through which GDL exerts its effect.

The purpose of this paper is to quantify the effect of two required components of the learner license on teen drivers' fatal crash rates: the length of the learner license (months) and the number of supervised driving hours. This paper begins by proposing a series of research hypotheses relating to the effect of these two components. This is followed by a description of the research methods for the study. The results of the analysis quantifying the effect of these components on 16- and 17-year-olds' fatal crash rates is then presented, followed by a discussion of the key findings.

RESEARCH HYPOTHESES

In a number of jurisdictions, sizeable reductions in novice drivers' crashes have followed the introduction of a minimum duration a learner license must be held (Agent, Steenbergen et al. 2001; Ulmer, Ferguson et al. 2001; Mayhew, Simpson et al. 2003). We hypothesize that:

1. The introduction of the learner license minimum duration as part of GDL will be followed by a reduction in 16- and 17-year-old drivers' fatal crash rates, and there will be a dose response relationship between the duration of the learner license and the reduction in fatal crash rates.

The number of required supervised driving hours that has demonstrated a reduction in novice drivers' crashes is more than double the supervised driving hours required by the states in this study sample (Gregersen, Nyberg et al. 2003). Nevertheless, we hypothesize that:

2. The introduction of a minimum number of required supervised driving hours will be followed by a decline in 16- and 17-year-old drivers' fatal crash rates, and there will be a dose response relationship between the number of supervised driving hours and the reduction in fatal crash rates.

METHODS

To test the first hypothesis, states that introduced a minimum duration of the learner license independent of other GDL components, during the period 1990 to 2009, were identified. Three states: Hawaii, South Carolina and Tennessee, mandated a learner license duration of three months, while five states: Connecticut, Kentucky, Minnesota, Virginia, and Utah, established a learner license period of six months during the time being studied. For the majority of these states, the mandatory learner license period was the first component of GDL that was implemented; however, South Carolina had existing nighttime driving restrictions when the learner license period was established (Table 2.1).

To test the second hypothesis, states that introduced a required number of supervised driving hours independent of other GDL components, during the period 1990 to 2009, were identified (Table 2.2). Six states: Arizona, Kentucky, Maine, Minnesota, New Hampshire, and Rhode Island, introduced a law independently of any other GDL components that required novice drivers to complete a specified number of supervised driving hours, ranging from 20 to 60. In Arizona and Maine, this law was the first GDL component to be implemented, while in Kentucky, Minnesota, New Hampshire and Rhode Island, the supervised driving hour requirement added to an existing GDL system.

Inclusion Criteria

States were excluded from the sample if they introduced multiple GDL components simultaneously with the component of interest, or had a learner license age below 15. Because at least two years of data post-implementation were required to estimate the effect of a component, states introducing GDL components after December 2007 were also excluded from the sample.

Data and Measures

Monthly counts of fatal crashes involving at least one teen driver (aged 16 or 17 years) in cars, trucks/pickups, vans/minivans, and sport utility vehicles were obtained for the contiguous period 1990 to 2009 from the Fatality Analysis Reporting System (FARS) for the states being analyzed (National Highway Traffic Safety Administration 2010). FARS is a yearly census of fatal traffic crashes within the 50 States, the District of Columbia, and Puerto Rico. Every vehicle crash on a public roadway that results in at least one fatality is recorded in the FARS database with information retrieved from police accident reports (Guarino and Champaneri 2010). Fatalities are included in FARS if the victim dies within 30 days of being injured in a crash on a U.S. public road involving a vehicle with an engine (National Highway Traffic Safety Administration 2010). Ideally, data from all injury crashes (not just fatal crashes) occurring in each candidate state would also be included; however, only a limited number of states make their injury crash data available to researchers (National Highway Traffic Safety Administration 2011), so such an approach could not be taken for this study.

Ideally, fatal crash rates would be based on the number of licensed teen drivers, however, licensure data reported by the Federal Highway Administration underreport the actual number of licensed teens, and licensure data are difficult to obtain from individual states (Insurance Institute for Highway Safety 2006). Miles driven by each teen would also be ideal, but are also unavailable and are difficult to measure. Therefore, crash rates were based on the number of teens in the overall population. Annual population estimates by state and age were obtained from the U.S. Census Bureau (Bureau of the Census. U.S. Department of Commerce 1999; Bureau of the Census. U.S. Department of Commerce 2010). Monthly values were interpolated using cubic spline curves; which are the smoothest curve that exactly fits a set of data points (Bartels, Beatty et al. 1998). Age-group-specific monthly fatal crash involvement rates of 16- and 17-year-old drivers per 100,000 population were calculated using monthly fatal crash counts and monthly population estimates. Data for drivers younger than 16 years were excluded because only a few states allow unsupervised driving by 15-year-olds (Insurance Institute for Highway Safety 2012), resulting in data that were too sparse to permit meaningful analysis (National Highway Traffic Safety Administration 2010).

Covariates

Comparison population

The monthly fatal crash rate for drivers age 25 to 54 was used as a covariate representing crashes for the typical adult driving population. Applying the identical method used to estimate 16- and 17-year-old fatal crash rates, age-group-specific monthly fatal crash rates of 25- to 54-year-old drivers per 100,000 population were calculated using monthly fatal crash counts and monthly population estimates. The purpose of the comparison population is to adjust for variability in the teen driver crash rates due to extraneous factors affecting drivers of all ages and to test the effect of GDL against a comparison population of persons unaffected by GDL. Although time series analyses control for pre-existing secular trends in crash rates, the inclusion of the crash rates of another age group as a historical covariate to control for unmeasured factors that affect all drivers enhances the validity of the findings.

Gas prices

An inverse relationship between gas prices and fatal crashes has been identified for drivers of all ages (Sivak and Schoettle 2010); however, research suggests teen driving behavior may be more sensitive to higher gas prices, relative to older drivers (Morrisey and Grabowski 2010). Monthly national average gas prices, obtained from the U.S. Energy Information Administration (U.S. Energy Information Administration 2011), were used as a covariate in the analyses to adjust for their effect on the amount of driving exposure and resulting crash risk level.

GDL laws

For each state, indicator variables were included for GDL components that were introduced before or after the learner license requirements being studied.

Analytical Method

To estimate the effects of each GDL component, monthly fatal crash rates per 100,000 population of 16- and 17-year-olds were analyzed using Auto-Regressive Integrated Moving Average (ARIMA) interrupted time series analysis (McCleary and Hay 1982) for each state that independently introduced or changed the GDL component of interest. Interrupted time-series analyses compare observations before and after some identifiable event, with the goal of evaluating the impact of the intervention. The transfer function relates an intervention to its effect on fatality rates. In this analysis, the transfer function has two parameters. The first parameter, ω, is the magnitude of the asymptotic change (rise or fall) in level after the intervention. The second parameter, δ, reflects the onset of the change. If the null hypothesis that ω is 0 is retained, there is no impact of the intervention. If ω is significant, the size of the change is ω (as a percentage) (Tabachnick and Fidell 2007). For these analyses, δ was fixed at 0, meaning the anticipated change in fatal crash rates would be abrupt and lasting, referred to as a sudden impact permanent change model.

Analytical strategy

For each state, the models were estimated using the natural logarithm of the monthly fatal crash rate per 100,000 population. Using the natural logarithm, the coefficient representing the intervention effects (ω) is directly interpretable (using the formula $100 \times [e^{\omega} - 1]$) as the percentage change in the post-intervention series relative to the pre-intervention series (McDowall, McCleary et al. 1980). Results presented are based on the models using the natural logarithm of fatal crash rates as the primary outcome variable.

The analyses were conducted in three stages. First, a linear regression model was estimated for the teen driver crash rates and the covariates: adult crash rates, gas prices, and GDL laws. Second, the model for each state was statistically adjusted for trends and seasonal variation. Autoregressive and moving average orders were identified using auto-correlation and partial-auto-correlation functions of the series residuals. Finally, the original regression model was re-estimated with the inclusion of the autoregressive or moving average orders identified in the second stage. Outliers were also detected and controlled for in the final model. Analyses were conducted using the SCA Time Series and Forecasting System, a specialized time-series analysis software package (Scientific Computing Associates 2011).

RESULTS

The annual fatal crash rates across five year intervals for states that implemented GDL learner license requirements (duration of the learner license or number of supervised driving hours) independent of other GDL components during the period 1990 to 2009 are presented in Table 2.3. Teen drivers' fatal crash rates were generally higher than adult drivers' fatal crash rates for most years, with the exception of Rhode Island. There was considerable variation among states' teen and adult fatal crash rates, with teen crash rates generally highest in Kentucky and South Carolina, and lowest in Hawaii and Rhode Island. Adult drivers' crash rates were highest in South Carolina and lowest in Connecticut.

Teen drivers' crash rates were typically highest in 1990, and usually twice the magnitude of the adult crash rate within the same state. Both teen and adult crash rates declined over the study period, although the decline was more pronounced among teens, such that by 2009, teen crash rates were lower or comparable to adult crash rates in most states in the study sample.

Learner License Period

The results of the analysis of the effect of the learner license duration partially confirm the first hypothesis. Under certain conditions, a six-month learner license period was followed by a reduction in teen drivers' fatal crash rates. Specifically, there was a significant reduction in fatal teen crash rates following the introduction of a six-month learner license in Virginia, Minnesota and Connecticut (Table 2.4). There were no significant changes in the fatal crash rates of 16- and 17-year-old drivers following the introduction of a learner license for the remainder of the states in the sample. Adult fatal crashes accounted for some of the variability in teen fatal crashes for each state in the sample, with the exception of Hawaii and Connecticut.

In Virginia, the introduction of the six-month learner license in July 1998 was associated with a modest, but statistically significant decline in teen drivers' fatal crash rates (-5.5%). In Minnesota, the introduction of a six-month learner license in February 1997 was followed by a significant decline in teen drivers' fatal crashes (-18.9%). In Connecticut, the introduction of the six-month learner license in January 1997 was followed by a significant decline in 16- and 17-year-old drivers' fatal crash rates (-16.6%).

Supervised Driving Hours

Based on the statistical model's findings, the second hypothesis is rejected - the introduction of required hours of supervised driving was not followed by a significant reduction of teen drivers' fatal crashes in any state included in the sample (Table 2.5). In Minnesota, the introduction of 30 hours of required supervised driving practice corresponded with a significant 34.5% increase in 16- and 17-year-old drivers' fatal crash rates (34.5%). The implementation of a required number of supervised driving hours was not associated with teen drivers' crashes in Arizona, Kentucky, Maine, New

Hampshire or Rhode Island. Adult fatal crashes predicted some of the variability in teens' fatal crashes in each state except New Hampshire.

DISCUSSION

In three states: Connecticut, Minnesota, and Virginia, the implementation of a six-month learner license was associated with a significant decline in 16- to 17-year-old drivers' fatal crashes. Learner license periods less than six months were not associated with a reduction in crashes. Required supervised driving hours did not result in a decline in teen drivers' fatal crash rates in any state. In Minnesota, the introduction of 30 hours of required supervised driving was followed by an increase in teen drivers' fatal crash rates.

While the decline in crashes for Connecticut, Minnesota, and Virginia was smaller than previously reported effects of a specific learner license period (Agent, Steenbergen et al. 2001; Ulmer, Ferguson et al. 2001; Mayhew, Simpson et al. 2003), determining why a decline occurred in these states and not others, requires an examination of the role of licensing age on learner license duration. Each one of these states introduced a six-month learner license, however, due to variations in the minimum licensing age in each state, the actual duration of teens' learner license periods is likely different.

Williams outlines three distinct scenarios related to introducing a required learner license period (Williams 2007). In those states that require the same minimum age (e.g., 16 years) for both the learner license and the intermediate license, adding a learner license holding period guarantees license delay. In states that have a younger learner license age (e.g., 15 years 6 months) with the difference between the learner license minimum age and the intermediate license minimum age (e.g., 16 years) being the same as the required holding period (6 months), a delay in licensure may occur. Finally, states that have a younger learner license age (e.g., 15 years) with the difference between the learner license age and the initial license age (e.g., 16 years) significantly greater than the holding period (e.g., 3 months), a delay in licensure is unlikely to result just from an extension of the holding period for a learner license.

Using these criteria, the introduction of a learner license guaranteed license delay by six months in two study states (Virginia and Connecticut) and by three months in Hawaii and South Carolina. In Kentucky, a delay in licensure may occur because the difference between the learner license minimum age (16 years) and the intermediate license minimum age (16 years 6 months) was the same as the required holding period (6 months). In the remaining three states (Minnesota, Tennessee, and Utah), the learner license period was unlikely to cause a delay in licensure because the difference between the learner's minimum age and the initial license minimum age was greater than the duration of the required holding period.

The extended learner license has been hypothesized to be a primary mechanism through which GDL reduced teen drivers' crash rates (Williams 2007). Therefore, it would be expected that in those states where a learner license holding period guarantees license delay a reduction in crash rates would be more likely than in those states that did not guarantee delay. If we assume that a dose response relationship exists between the delay in licensure caused by the learner license and fatal crash rates, then Virginia and Connecticut were most likely to experience a decline, followed by Hawaii and South Carolina.

The results of this study provide evidence supporting the assumption of a dose response and Williams' scenarios. The significant decline in crashes in Virginia and Connecticut suggests that a learner license period that guarantees a six-month delay in licensure saves teen drivers' lives. The absence of a decline in Hawaii and South Carolina suggests that the delay in licensure should exceed three months in order to result in a significant decline in fatal crashes. The decline in crashes in Minnesota, where a delay in licensing was least likely, suggests that license delay may not be the only mechanism through which the learner license exerts safety effects.

It was hypothesized that the implementation of a required number of supervised driving hours would be associated with a decline in teen drivers' fatal crashes. The increase in teen drivers' fatal crash rates in Minnesota was unexpected and should be interpreted with caution. Given that an increase in teen drivers' fatal crashes following the introduction of required supervised driving hours was not observed in any other state in the sample, this result may be due to state level differences in compliance and enforcement, or the unique sequence and combination of laws that was implemented in Minnesota. The increase in crashes may also be the result of an increase in the number of learner licenses issued, as teens may have rushed to begin driving before this GDL component came into effect, a phenomenon that has been observed in other states (Masten and Hagge 2004). However, licensure data for Minnesota teens was not available to confirm this hypothesis. A recent study testing the effect of the supervised driving hour requirement in Minnesota using all injury crashes (not just fatal crashes) found no association between the law and crash rates (The University of North Carolina Highway Safety Research Center In Press).

This study adds to the literature by finding that a learner license period that guarantees a six-month delay in licensure is associated with a significant decline in teen drivers' fatal crash rates. Although the primary objective of the learner license is to allow for an extended period of practice driving under safe conditions, the findings of this study suggest the decline in crashes associated with the learner license are primarily due to delayed licensing. A learner license period that guarantees license delay by 6 months is likely result in a decline in teen crashes in those states where the learner license periods do not currently guarantee a delay. However, this study could not establish whether a doubling of the learner license period (to twelve months) would result in the same or a larger crash reduction. Nor could we establish an association between the number of required supervised driving hours and fatal crashes.

These findings were based on fatal crashes involving drivers. Fatal crashes represent a small and atypical subset of all crashes, where the etiology of fatal crashes differs from that of less serious crashes (Lam 2003). Significant changes in fatal crash rates were observed in large states, suggesting the absence of an effect in smaller states was due to insufficient power. Four states in the sample have relatively small populations (Hawaii, Maine, New Hampshire and Rhode Island) and fatal crashes are rare events, increasing the probability of a floor effect, (where crash rates cannot take on a value lower than zero). However, estimating the models for these states using quarterly data, which reduced the number of time points but potentially increased variation in the series, did not alter the results that were based on monthly data.

An alternative explanation is that in the majority of cases, the implementation of a single GDL component did not result in a significant reduction in fatal crashes. Research by Chen and Baker suggests that teen drivers' fatal crashes decline significantly when three or more GDL components are in effect (Chen, Baker et al. 2006). Similarly, Morrisey and colleagues found that states with GDL legislation that was rated by the Insurance Institute for Highway Safety as 'good' (i.e., more, stronger components) had significantly lower teen driver fatal crashes compared to states with 'fair' or 'poor' rated GDL (i.e., fewer, weaker components) (Morrisey, Grabowski et al. 2006; McCartt and Teoh 2011). Given that eight of the thirteen states in this study implemented required driving hours or a learner license period as the first element of GDL, independently of other components, it seems plausible that the introduction of these laws was not enough to be associated with a reduction in teen drivers' fatal crashes.

Future research examining the effect of GDL learner license requirements (duration of the learner license period or number of supervised driving hours) on teen drivers should extend the analysis to include all crash types: property-damage-only crashes, injury crashes, as well as fatal crashes. While it may be the case that an extension of the learner license holding period has the same effect on non-fatal and fatal crashes, this approach has not been tested empirically. The same is true for requiring a minimum number of supervised driving hours. Currently, only a limited number of states make non-fatal injury crash data available to researchers (National Highway Traffic Safety Administration 2011), yet the largest proportion of teen drivers' crashes is non-fatal. These data would allow an examination of the effects of GDL on crash types different severity.

Table 2.1: States that introduced a learner license period independent of other GDL components

State	Previously existing GDL components (effective date)	New addition to GDL (effective date)
Virginia	None	6 month learner license (7/96)
Tennessee	None	3 month learner license (1/96)
Minnesota	None	6 month learner license (2/97)
South Carolina	6pm – 6am driving nighttime restriction (since 1976) 15 day practice permit (since 1995)	3 month learner license (7/98)
Kentucky	None	6 month learner license (10/96)
Connecticut	None	6 month learner license (1/97)
Utah	40 hours supervised driving (07/04) 30 hours supervised driving (07/03) No passengers for first 6 months (07/01) 12am – 6am driving restriction (07/99) 30 hours supervised driving (07/99)	6 month learner license (08/06)
Hawaii	None	3 month learner license (7/97)

Table 2.2: States that introduced a required number of supervised driving hours independent of other GDL components

State	Previously existing GDL components (effective date)	New addition to GDL (effective date)
Arizona	None	25 hours supervised driving (1/00)
Minnesota	6 month learner license (2/97)	40 hours supervised driving (1/99)
Kentucky	6 month learner license (10/96)	60 hours supervised driving (10/06)
Maine	None	35 hours supervised driving (1/98)
New Hampshire	3 month learner license (1/98) 1am – 5am driving restriction (1/98)	20 hours supervised driving (9/99)
Rhode Island	6 month learner license (1/99) 1am – 5am nighttime driving restriction (1/99)	50 hours supervised driving (7/03)

Table 2.3. Annual fatal crash rates* for states that changed learner license requirements across five-year intervals, 1990-2009.

	1990		1994		1999		2004		2009	
States implementing Learner License Holding Period	Teen^	Adult^^	Teen	Adult	Teen	Adult	Teen	Adult	Teen	Adult
Virginia	3.00	1.27	2.93	1.44	2.29	1.25	2.36	1.36	1.01	1.05
Tennessee	3.40	1.90	5.57	2.65	5.20	2.67	3.51	2.59	1.96	1.91
Minnesota	2.99	.98	2.43	1.54	2.71	1.48	2.58	1.28	1.08	.87
South Carolina	4.16	2.29	3.35	2.60	4.57	3.05	2.84	3.02	2.66	2.44
Kentucky	4.20	1.68	3.53	2.31	4.58	2.36	3.69	2.92	2.61	2.27
Connecticut	2.71	1.07	2.00	1.13	1.44	1.02	1.73	1.01	.49	.90
Utah	1.84	1.10	3.94	1.83	3.47	1.83	2.12	1.54	.98	1.10
Hawaii	1.77	1.15	1.10	1.18	1.29	1.07	2.29	1.59	.51	.95
States implementing Required Supervised Driving Hours	Teen	Adult	Teen	Adult	Teen	Adult	Teen	Adult	Teen	Adult
Arizona	2.11	1.60	3.49	2.49	3.64	2.33	3.10	2.14	.70	1.29
Minnesota	2.99	.98	2.43	1.54	2.71	1.48	2.58	1.28	1.08	.87
Kentucky	4.20	1.68	3.53	2.31	4.58	2.36	3.69	2.92	2.61	2.27
Maine	2.52	1.32	2.87	1.60	3.61	1.55	3.56	1.56	.93	1.65
New Hampshire	2.47	1.21	1.39	1.02	2.40	1.35	4.23	1.52	1.54	.94
Rhode Island	1.79	1.46	.69	1.29	.62	1.81	2.04	1.65	.28	1.69

***** Age-group-specific annual fatal crash involvement rates of drivers per 100,000 population, were estimated by averaging the monthly fatal crash rate, calculated using monthly fatal crash counts and monthly population estimates for each age group.

^ 16- and 17-year-olds
^^ 25- to 54-year-olds

Table 2.4. Parameters of best-fitting sudden permanent change ARIMA models estimating the effect of learner license duration on 16- and 17- year olds' fatal crash rates per capita, 1990 – 2009

State	Model Component	Parameter (Lag)	Estimate	p
Virginia	**6 month learner license Effective July 1996**	**ω**	**-.0562**	**.04**
	Three passengers younger than 16 Effective July 1998	ω	.0390	.15
	12 a.m. – 4 a.m. driving restriction 9 month learner license 40 hours supervised driving One passenger younger than 18 until age 17 Three passengers younger than 18 thereafter Effective July 2001	ω	-.0044	.86
	One passenger younger than 18 for first 12 months Three passengers younger than 18 thereafter Effective July 2003	ω	-.0154	.62
	45 hours supervised driving Effective July 2008	ω	-.0257	.43
	Control series (25-54 yr-olds)	β	.5128	<.01
	Gas price	β	-.0002	.25
	Noise (AR or MA component)	MA (1)	.7223	<.01
	Noise (AR or MA component)	MA (6)	.2422	<.01
	Noise (AR or MA component)	AR (1)	.6592	<.01
	Constant	None		
Tennessee	**3 month learner license Effective January 1996**	**ω**	**.0083**	**.90**
	6 month learner license 50 hours supervised driving 11 p.m. – 6 a.m. driving restriction Single passenger restriction Effective July 2001	ω	-.2063	.01
	Control series (25-54 yr-olds)	β	.8871	<.01
	Gas price	β	-.0010	.06
	Noise (AR or MA component)	None		
	Constant		.6486	.01
Minnesota	**6 month learner license Effective February 1997**	**ω**	**-.2092**	**.03**
	30 hours supervised driving Effective January 1999	ω	.2931	<.01
	12 a.m. – 5 a.m. driving restriction One passenger younger than 20 for first 6 months Three passengers younger than 20 for second 6 months Effective August 2008	ω	-.2698	.02
	Control series (25-54 yr-olds)	β	.5796	<.01
	Gas price	β	-.0014	<.01
	Noise (AR or MA component)	None		
	Constant		.8546	<.01

Component of interest highlighted in bold

Table 2.4 continued

State	Model Component	Parameter (Lag)	Estimate	p
South Carolina	**3 month learner license Effective July 1998**	**ω**	**-.0283**	**.75**
	6 month learner license 40 hours supervised driving 6 p.m. – 6 a.m. EST driving restriction 8 p.m. – 6 a.m. EDT driving restriction Two passengers younger than 21 Effective September 2003	ω	-.0512	.63
	Control series (25-54 yr-olds)	β	.4586	.01
	Gas price	β	-.0016	.01
	Noise (AR or MA component)	MA (12)	-.1293	.05
	Constant		1.0368	<.01
Kentucky	**No passengers for first 6 months Effective October 1996**	**ω**	**-.0942**	**.15**
	60 hours supervised driving Effective October 2006	ω	-.0433	.81
	12 a.m. – 6 a.m. driving restriction One passenger younger than 20 Effective April 2007	ω	-.0166	.93
	Control series (25-54 yr-olds)	β	.4850	.01
	Gas price	β	-.0014	.02
	Noise (AR or MA component)	None		
	Constant		1.2077	<.01
Connecticut	**6 month learner license Effective January 1997**	**ω**	**-.1820**	**.04**
	No passengers for first three months (with exceptions) Effective October 2003	ω	-.0067	.97
	20 hours supervised driving 12 a.m. – 5 a.m. driving restriction No passengers for first six months (with exceptions) Effective October 2005	ω	-.1128	.56
	40 hours supervised driving No passengers for first 12 months (with exceptions) Effective August 2008	ω	-.3240	.05
	Control series (25-54 yr-olds)	β	.3730	.09
	Gas price	β	-.0004	.97
	Noise (AR or MA component)	None		
	Constant		.7112	<.01

Component of interest highlighted in bold

Table 2.4 continued

State	Model Component	Parameter (Lag)	Estimate	p
Utah	12am – 6am driving restriction 30 hours supervised driving Effective July 1999	ω	.0295	.83
	No passengers for first 6 months Effective July 2001	ω	-.0881	.60
	30 hours supervised driving Effective July 2003	ω	.1449	.49
	40 hours supervised driving Effective July 2004	ω	.0890	.70
	6 month learner license Effective August 2006	**ω**	**.0967**	**.58**
	Control series (25-54 yr-olds)	β	.6120	<.01
	Gas price	β	-.0030	.03
	Noise (AR or MA component)	None		
	Constant		.8262	<.01
Hawaii	**3 month learner license Effective July 1997**	**ω**	**-.1122**	**.35**
	6 month learner license 11 p.m. – 5 a.m. driving restriction One passenger younger than 18 Effective September 2003	ω	-.0310	.90
	Control series (25-54 yr-olds)	β	.1957	.33
	Gas price	β	-.0012	.39
	Noise (AR or MA component)	None		
	Constant		.6307	.01

Component of interest highlighted in bold

Table 2.5. Parameters of best-fitting sudden permanent change ARIMA models estimating the effect of supervised driving hours on 16- and 17- year-olds' fatal crash rates per capita, 1990 – 2009

State	Model Component	Parameter (Lag)	Estimate	p
Arizona	**25 hours supervised driving Effective January 2000**	**ω**	**-.1955**	**.27**
	5 month learner license Effective July 2000	ω	.0597	.74
	6 month learner license 30 hours supervised driving 12 a.m. – 5 a.m. driving restriction One passenger younger than 18 for first 6 months Effective July 2008	ω	-.2520	.05
	Control series (25-54 yr-olds)	β	.6422	<.01
	Gas price	β	-.0006	.29
	Noise (AR or MA component)	None		
	Constant		.6250	.01
Minnesota	6 month learner license Effective February 1997	ω	-.2092	.03
	30 hours supervised driving Effective January 1999	**ω**	**.2931**	**<.01**
	12 a.m. – 5 a.m. driving restriction One passenger younger than 20 for first 6 months Three passengers younger than 20 for second 6 months Effective August 2008	ω	-.2698	.02
	Control series (25-54 yr-olds)	β	.5796	<.01
	Gas price	β	-.0014	<.01
	Noise (AR or MA component)	None		
	Constant		.8546	<.01
Kentucky	No passengers for first 6 months Effective October 1996	ω	-.0942	.15
	60 hours supervised driving Effective October 2006	**ω**	**-.0433**	**.81**
	12 a.m. – 6 a.m. driving restriction One passenger younger than 20 Effective April 2007	ω	-.0166	.93
	Control series (25-54 yr-olds)	β	.4850	.01
	Gas price	β	-.0014	.02
	Noise (AR or MA component)	None		
	Constant		1.2077	<.01

Component of interest highlighted in bold

Table 2.5 continued

State	Model Component	Parameter (Lag)	Estimate	p
Maine	**35 hours supervised driving Effective January 1998**	**ω**	**-.1492**	**.43**
	No passengers for first 3 months Effective August 2000	ω	.0173	.94
	6 month learner license 12 a.m. – 5 a.m. driving restriction No passengers for first 6 months Effective September 2003	ω	.2022	.39
	Control series (25-54 yr-olds)	β	.4254	.04
	Gas price	β	-.0026	.07
	Noise (AR or MA component)	None		
	Constant		.9811	<.01
New Hampshire	3 month learner license 1am – 5am driving restriction Effective January 1998	ω	-.0820	.70
	20 hour supervised driving Effective September 1999	**ω**	**.0542**	**.82**
	One passenger for first 6 months Effective January 2003	ω	-.0268	.90
	40 hour supervised driving Effective June 2009	ω	.0052	.99
	Control series (25-54 yr-olds)	β	.2238	.26
	Gas price	β	-.0011	.39
	Noise (AR or MA component)	None		
	Constant		.8102	<.01
Rhode Island	6 month learner license 1am – 5am driving restriction Effective January 1999	ω	-.0639	.64
	50 hours supervised driving Effective July 2003	**ω**	**.1006**	**.63**
	One passenger younger than 21 for the first 12 months Effective July 2005	ω	-.0956	.73
	Control series (25-54 yr-olds)	β	.3132	.02
	Gas price	β	-.0009	.95
	Noise (AR or MA component)	None		
	Constant		.3022	.17

Component of interest highlighted in bold

REFERENCES

Agent, K., L. Steenbergen, J. Pigman, P. Stinson Kidd, C. McCoy and S. Pollack (2001). "Impact of Partial Graduated Driver's License Program on Teen Motor Vehicle Crashes in Kentucky." Transportation Research Record: Journal of the Transportation Research Board **1779**: 54-60.

Bartels, R. H., J. C. Beatty and B. A. Barsky (1998). An Introduction to Splines for Use in Computer Graphics and Geometric Modelling. San Francisco, CA, Morgan Kaufmann.

Bureau of the Census. U.S. Department of Commerce (1999). 1990 to 1999 annual time series of state population estimates by age and sex: 1990 to 1999.

Bureau of the Census. U.S. Department of Commerce (2010). State single year of age and sex population estimates: 2000 to 2009.

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

Chen, L. H., S. P. Baker and G. Li (2006). "Graduated driver licensing programs and fatal crashes of 16-year-old drivers: A national evaluation." Pediatrics **118**(1): 56-62.

Foss, R. and A. Goodwin (2003). "Enhancing the effectiveness of graduated driver licensing legislation." Journal of Safety Research **34**(1): 79-84.

Foss, R. D. (2007). "Improving graduated driver licensing systems: A conceptual approach and its implications." Journal of Safety Research **38**(2): 185-192.

Gregersen, N. P., H. Y. Berg, I. Engstrom, S. Nolen, A. Nyberg and P. A. Rimmo (2000). "Sixteen years age limit for learner drivers in Sweden: an evaluation of safety effects." Accident Analysis & Prevention **32**(1): 25-35.

Gregersen, N. P., A. Nyberg and H. Y. Berg (2003). "Accident involvement among learner drivers - an analysis of the consequences of supervised practice." Accident Analysis & Prevention **35**(5): 725-730.

Guarino, J. and A. Champaneri (2010). Factors Involved in Fatal Vehicle Crashes. Washington D.C. , Research and Innovative Technology Adminstration. Bureau of Transportation Statistics.

Insurance Institute for Highway Safety. (2006). "Motor Vehicle Registration and Licensed Driver Information." Retrieved 13th September, 2011, from www.iihs.org/laws/comments/pdf/fhwa_ds_atm_030906.pdf.

Insurance Institute for Highway Safety. (2012). "Cell Phone and Texting Laws." Retrieved 16th February, 2012, from http://www.iihs.org/laws/cellphonelaws.aspx.

Lam, L. T. (2003). "Factors associated with young drivers car crash injury: comparisons among learner, provisional, and full licensees." Accident Analysis & Prevention **35**(6): 913-920.

Masten, S. V. and R. A. Hagge (2004). "Evaluation of California's graduated driver licensing program." Journal of Safety Research **35**(5): 523-535.

Mayhew, D. R., H. M. Simpson, K. Desmond and A. F. Williams (2003). "Specific and Long-Term Effects of Nova Scotia's Graduated Licensing Program." Traffic Injury Prevention **4**(2): 91-97.

McCartt, A. T., V. I. Shabanova and W. A. Leaf (2003). "Driving experience, crashes and traffic citations of teenage beginning drivers." Accident Analysis and Prevention **35**(3): 311-320.

McCartt, A. T. and E. R. Teoh (2011). "Strengthening Driver Licensing Systems for Teenaged Drivers." JAMA: The Journal of the American Medical Association **306**(10): 1142-1143.

McCleary, R. and R. A. Hay (1982). Applied time series analysis for the social sciences Beverly Hills, CA, Sage Publications.

McDowall, D., R. McCleary, E. E. Meiringer and A. H. Hay (1980). Interrupted time series analysis. Thousand Oaks, California, Sage Publications.

McKnight, A. J. and R. C. Peck (2002). "Graduated driver licensing: what works?" Injury Prevention **8**(suppl 2): ii32-ii38.

Morrisey, M. A. and D. C. Grabowski (2010). "Gas prices, beer taxes and GDL programmes: effects on auto fatalities among young adults in the US." Applied Economics **43**(25): 3645-3654.

Morrisey, M. A., D. C. Grabowski, T. S. Dee and C. Campbell (2006). "The strength of graduated drivers license programs and fatalities among teen drivers and passengers." Accident Analysis and Prevention **38**(1): 135-141.

National Highway Traffic Safety Administration (2010). Fatality Analysis Reporting System Washington, D.C, U.S. Department of Transportation.

National Highway Traffic Safety Administration (2010). Traffic Safety Facts 2009: A compilation of motor vehicle crash data from the Fatality Analysis Reporting System and the General Estimates System. Washington, D.C, U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2011). "SDS Overview." Retrieved 12th September, 2011.

Page, Y. (2004). "An evaluation of the effectiveness of the supervised driver-training system in France." Annual proceedings / Association for the Advancement of Automotive Medicine. Association for the Advancement of Automotive Medicine **48**: 131-145.

Sagberg, F. and N. P. Gregersen (2005). Effects of lowering the age limit for driver training. Traffic and transport psychology: theory and application. Proceedings of the ICTTP 2004. G. Underwood. Amsterdam, Elsevier Science: 171–178.

Scientific Computing Associates (2011). Time-series analysis and forecasting software. WorkBench Version 6.2.0.

Sivak, M. and B. Schoettle (2010). "Toward Understanding the Recent Large Reductions in U.S. Road Fatalities." Traffic Injury Prevention **11**(6): 561-566.

Tabachnick, B. G. and L. S. Fidell (2007). Using Multivariate Statistics. Boston, Allyn and Bacon.

The University of North Carolina Highway Safety Research Center (In Press). The Role of Supervised Driving Requirements in a Graduated Driver Licensing Program.

U.S. Energy Information Administration. (2011). "Energy Prices." Total Energy Retrieved 9th September, 2011, from http://205.254.135.24/totalenergy/data/monthly/index.cfm#prices.

Ulmer, R. G., S. A. Ferguson, A. F. Williams and D. F. Preusser (2001). "Teenage crash reduction associated with delayed licensure in Connecticut." Journal of Safety Research **32**(1): 31-41.

VicRoads (2005). Young Driver Safety and Graduated Licensing Discussion Paper.

Waller, P. F. (2003). "The genesis of GDL." Journal of Safety Research **34**(1): 17-23.

Williams, A. F. (2003). "Teenage drivers: patterns of risk." Journal of Safety Research **34**: 5–15.

Williams, A. F. (2007). "Contribution of the components of graduated licensing to crash reductions." Journal of Safety Research **38**(2): 177-184.

CHAPTER 3

DO PASSENGER AND NIGHTTIME GDL RESTRICTIONS WORK? AN ANALYSIS OF THEIR INDEPENDENT EFFECTS ON 16- AND 17-YEAR-OLD DRIVERS' FATAL CRASHES

INTRODUCTION

Motor vehicle crashes are the leading cause of death and a leading cause of injury for teenagers in the United States (National Highway Traffic Safety Administration 2010). Sixteen-year-old drivers in their first year of licensure have higher crash rates than any other age group, including older teens (Insurance Institute for Highway Safety 2012). Teen drivers' fatal crash risk is particularly high while driving with peer passengers and/or at night (Williams, Preusser et al. 1995; Chen, Baker et al. 2000). Teen drivers' fatal crash risk increases with each additional peer passenger in the vehicle. The relative risk of death among 16- to 17-year-olds who have one peer passenger in the vehicle is significantly greater than when driving alone. Carrying at least three peer passengers results in a threefold increase in the likelihood of a fatal crash (Chen, Baker et al. 2000). Driving between the hours of 9 p.m. and 5 a.m. accounts for approximately 15% of 16- to 17-year-olds' total miles driven, however, 40% of teen drivers' fatal crashes occur between these hours (Williams and Pruesser 1997).

Graduated driver licensing (GDL) eases young drivers onto roadways by limiting their exposure to progressively higher risk driving experiences (National Highway Traffic Safety Administration. U.S. Department of Transportation 1996). The move from simple to increasingly complex driving conditions is mediated by teens' progression through three licensure levels (Foss and Goodwin 2003). The first level (learner license) allows teens to gain driving practice and experience under the supervision of a fully licensed driver (typically a parent or other person over age 21 who is designated by the parent). The second level (intermediate license) allows teens to drive independently but with restrictions that limit their exposure to the highest risk driving conditions (i.e., driving with passengers and driving at night). Passenger restrictions limit the number and/or age of passengers a teen driver can carry during the first months of independent driving (typically for the first 6 months of intermediate licensure). Nighttime driving restrictions prohibit teens with intermediate licenses from any driving between certain hours, typically late night to early morning, when crash risk is known to be highest (Insurance Institute for Highway Safety 2011). The final stage of GDL gives teens, who have gained driving experience while fulfilling the requirements of learner and intermediate licenses, permission to drive with no restrictions.

Both passenger and nighttime driving restrictions are widely adopted components of states' graduated licensing programs (Williams 2007). California was one of the first states to implement a passenger restriction as part of a comprehensive GDL program, when in July 1998, teen drivers were restricted from carrying any passengers below 20 years of age for the first six months of their intermediate license (Insurance Institute for Highway Safety 2012). Evaluations of the California law indicated substantial declines in fatal and non-fatal injury teen passenger crashes, which are defined as crashes resulting in a fatality or non-fatal injury where a passenger under age 20 was present in the vehicle of the teen driver (Masten and Hagge 2004; Rice, Peek-Asa et al. 2004; Cooper, Atkins et al. 2005; Zwicker, Williams et al. 2006). Beyond California, Chaudhary and colleagues reported significant declines in fatal/non-fatal injury teen passenger crashes in Massachusetts and Virginia following the introduction of passenger restrictions in January 1998 and July 2001, respectively (Chaudhary, Williams et al. 2007). National studies of GDL have also reported significant declines in passenger crashes subsequent to the introduction of passenger restrictions (Chen, Baker et al. 2006; Fell, Todd et al. 2011; Masten, Foss et al. 2011).

Nighttime restrictions were first implemented as city- or state-wide nighttime driving curfews in the late 1970s and early 1980s as stand alone policies for teen drivers (Preusser, Williams et al. 1984). In a study of four states' nighttime driving curfew laws (Louisiana, Maryland, New York, and Pennsylvania), significant reductions in 16-year-old drivers' nighttime crash involvements were observed in all four states (Preusser, Williams et al. 1984). Nighttime driving restrictions were later implemented as part of comprehensive GDL systems, and have demonstrated efficacy within this context in both state level and national evaluations (Ulmer, Preusser et al. 2000; Foss, Feaganes et al. 2001; Shope, Molnar et al. 2001; Shope and Molnar 2004; Chen, Baker et al. 2006; Foss, Masten et al. 2007; McCartt, Teoh et al. 2010; Fell, Todd et al. 2011).

In the majority of instances when a passenger or nighttime driving GDL restriction has been introduced in the United States, it has been implemented along with at least one additional GDL component. However, state and national evaluations have rarely accounted for the confounding effect of multiple GDL components implemented simultaneously. Rather, these studies have assumed independent implementation of each component, which does not reflect the reality of how these laws were introduced. Most evaluations of passenger and nighttime restrictions also used a pre- and post-GDL study design that is unable to distinguish if a decline in crashes was directly attributable to GDL, or the result of a preexisting downward trend (Elliott and Shope 2003; Sivak and Schoettle 2010). The purpose of this paper was to quantify the effects of passenger and nighttime driving restrictions using a sample of states that introduced them independently of any other GDL component, employing an analytical approach that accounts for long-term trends (Masten and Hagge 2004).

RESEARCH HYPOTHESES

This study will test two hypotheses:

1. The introduction of a GDL restriction on driving with passengers will be followed by a reduction in teen drivers' fatal passenger and overall fatal crash rates, reflecting a dose-response relationship between duration of the passenger restriction or number of passengers allowed and a reduction in fatal passenger and overall fatal crash rates.
2. The introduction of a GDL nighttime driving restriction will be followed by a reduction in teen drivers' fatal nighttime and overall fatal crash rates, reflecting a dose-response relationship between the length of the nighttime restriction and a reduction in fatal nighttime and overall fatal crash rates.

METHODS

To test the first hypothesis, states that introduced a passenger restriction independently of other GDL components, during the period 1990 to 2009, were identified (Table 3.1). In these states, inferences regarding the effect of the restriction would be less confounded and more definitive than in situations where multiple GDL components were changed simultaneously. Eight states implemented passenger restrictions independently of other GDL components. Each state had existing GDL components in place when the intermediate license passenger restriction was introduced. States were excluded from the sample if they introduced multiple GDL components simultaneously with the component of interest, or had an intermediate license age below 16 years. Because at least two years of data post-implementation were required to estimate a component's effect, states introducing a passenger or nighttime driving restriction after December 2007 were excluded from the sample.

There was considerable variation among states in the three possible provisions of passenger restrictions (duration, number of passengers, and age of passengers). Regarding the duration, Connecticut and Maine fixed the duration of the passenger restriction to the first three months of intermediate licensure, while Utah and New Hampshire fixed the duration of the passenger restriction to the first six months of intermediate licensure. Colorado, Missouri and Rhode Island each stipulated different passenger limits for the first 12 months, while North Carolina introduced a passenger restriction that lasted the duration of the intermediate license. Regarding the number of passengers, three states, Connecticut, Maine and Utah, allowed no passengers with the exception of parents or family members, when teen drivers are under the passenger restriction. New Hampshire, North Carolina and Rhode Island, permitted a single passenger. In Colorado and Missouri, the number of passengers allowed changed after the first six months of independent driving, from none to one passenger in Colorado, and from one to three passengers in Missouri. Regarding passenger age, two states, North Carolina and Rhode Island, specified the age of the passengers (limits applied to passengers under age 21), while the remainder did not.

To test the second hypothesis, states that introduced a nighttime driving restriction independently of other GDL components during the period 1990 to 2009, were sought. No states fulfilled that inclusion criterion, therefore, the criterion was modified to include those states where the nighttime restriction was introduced as the first intermediate license restriction of a GDL system, simultaneously with other components (e.g., minimum holding period) (Table 3.2). Nebraska and Utah introduced nighttime driving restrictions from 12 midnight to 6 a.m. as their first intermediate GDL components, along with supervised driving requirements for their learner phases.

Measures

The primary measure of the effectiveness of an intermediate license restriction is the outcome that is specific to the restriction itself. In the case of the passenger restriction, the specific outcome is fatal passenger crashes, while for the nighttime driving restriction it is fatal nighttime crashes. Total fatal crashes will be used as a secondary outcome measure for both restrictions.

Monthly counts of fatal crashes, fatal passenger crashes, and fatal nighttime crashes involving at least one teen driver (aged 16 or 17 years) in cars, trucks/pickups, vans/minivans, and sports utility vehicles were obtained for the contiguous period 1990 to 2009 from the Fatality Analysis Reporting System (FARS) for the states being analyzed (National Highway Traffic Safety Administration 2010). FARS is a yearly census of fatal traffic crashes within the 50 states, the District of Columbia, and Puerto Rico. Every vehicle crash on a public roadway that results in at least one fatality is recorded in the FARS database with information retrieved from police crash reports (Guarino and Champaneri 2010). In FARS, a fatality is defined as a death occurring within 30 days of being injured in a crash on a public road involving at least one vehicle with an engine (National Highway Traffic Safety Administration 2010). A fatal passenger crash was defined as a crash involving at least one teen driver, where a passenger was present in the vehicle driven by a teen driving. A fatal nighttime crash was defined as a crash involving at least one teen driver during the nighttime driving restriction (12 midnight to 6 a.m.).

Ideally, the sample would include data from all injury crashes (not just fatal crashes) occurring in each candidate state; however, only a limited number of states make their injury crash data available to researchers (National Highway Traffic Safety Administration 2011), so that approach could not be taken for this study. Likewise, crash rates based on the number of licensed teen drivers would be the most precise estimate of the effect of the GDL restrictions on crashes. However, licensure data reported by the Federal Highway Administration underreport the actual number of licensed teens, and like crash data, licensure data are difficult to obtain from individual states (Insurance Institute for Highway Safety 2006). Miles driven by each teen would also be an ideal measure of exposure, but are difficult to measure and generally unavailable. Therefore, crash rates were based on the number of teens in the overall population of each state. Annual population estimates by state and age were obtained from the United States Census Bureau (Bureau of the Census. U.S. Department of Commerce 1999; Bureau of the Census. U.S. Department of Commerce 2010). Monthly values were interpolated using cubic spline curves, which are the smoothest curves that exactly fit a set of data points (Bartels, Beatty et al. 1998). Age-group-specific monthly fatal crash involvement rates of 16- and 17-year-old drivers per 100,000 population were calculated using monthly fatal crash counts and monthly population estimates. Data for drivers younger than 16 years were excluded because only a few states allow unsupervised driving by 15-year-olds (Insurance Institute for Highway Safety 2012), making it difficult to compare findings among states.

Several states in the sample had relatively small populations, increasing the probability of a floor effect, where crash rates cannot take on a value lower than zero. To compensate for this effect, states with a 16- to 17-year-old population below 85,000 (Maine, Nebraska, New Hampshire, Rhode Island, and Utah) were modeled using quarterly data. Quarterly fatal crash involvement rates were calculated using the monthly crash counts and population estimates.

Covariates

Comparison population

In each study state, monthly fatal crash rates, fatal passenger crash rates and fatal nighttime crash rates for drivers age 25 to 54 were used as covariates representing crashes for the typical adult driving population. Applying the identical method used to estimate 16- to 17-year-old fatal crash rates, age-group-specific fatal crash rates of 25- to 54-year-old drivers per 100,000 population were calculated using overall, nighttime, and passenger monthly fatal crash counts and monthly population estimates. The purpose of the comparison population was to adjust for variability in the teen driver crash rates due to extraneous factors affecting drivers of all ages, and to test the effect of the GDL restrictions against a comparison population of persons unaffected by GDL. Although time series analyses control for pre-existing secular trends in crash rates, the inclusion of the crash rates of another age group as a historical covariate to control for unmeasured factors that affect all drivers enhances the validity of the findings.

Gas prices

An inverse relationship between gas prices and fatal crashes has been identified for drivers of all ages (Sivak and Schoettle 2010); however, research suggests that teen driving behavior may be more sensitive to higher gas prices relative to older drivers (Morrisey and Grabowski 2010). Monthly national average gas prices, obtained from the United States Energy Information Administration (U.S. Energy Information Administration 2011), were used as covariates in the analyses to adjust for their effects on the amount of driving exposure, and resulting crash risk level.

GDL laws

For each state, indicator variables were included for GDL components that were introduced before or after the intermediate driving restrictions being studied.

Analytical Method

To estimate the effects of each GDL component, monthly (and quarterly where needed) fatal crash rates per 100,000 population of 16- and 17-year-old drivers were analyzed using Auto-Regressive Integrated Moving Average (ARIMA) interrupted time series analysis (McCleary and Hay 1982) for each state. Interrupted time-series analyses compares observations before and after some identifiable event, with the goal of evaluating the impact of the intervention. The transfer function relates an intervention to its effect on fatality rates. In this analysis, the transfer function has two parameters. The first parameter, ω, is the magnitude of the asymptotic change (rise or fall) in level after the intervention. The second parameter, δ, reflects the onset of the change. If the null hypothesis that ω is 0 is supported, there is no impact of the intervention. If ω is significant, the size of the change is ω (as a percentage) (Tabachnick and Fidell 2007). For these analyses, δ was fixed at 0, meaning the anticipated change in fatal crash rates would be abrupt and lasting, referred to as a sudden impact permanent change model.

Analytical strategy

For each state, the models were estimated using the natural logarithm of the monthly (or quarterly) fatal crash rate per 100,000 population. Using the natural logarithm, the coefficient representing the intervention effects (ω) is directly interpretable (using the formula $100 \times [e^{\omega} - 1]$) as the percentage change in the post-intervention series relative to the pre-intervention series (McDowall, McCleary et al. 1980). Results presented are based on the models using the natural logarithm of fatal crash rates as the primary outcome variable.

The analyses were conducted in three stages. First, a linear regression model was estimated for the teen driver crash rates and the covariates: adult crash rates, gas prices, and GDL laws. Second, the model for each state was statistically adjusted for trends and seasonal variation. Autoregressive and moving average orders were identified using auto-correlation and partial-auto-correlation functions of the series residuals. Finally, the original regression model was re-estimated with the inclusion of the autoregressive or moving average orders identified in the second stage. Outliers were also detected and controlled for in the final model. Analyses were conducted using the SCA Time Series and Forecasting System, a specialized time-series analysis software package (Scientific Computing Associates 2011).

RESULTS

The fatal crash rates across five year intervals for states that implemented GDL intermediate license requirements (passenger restriction or nighttime driving restriction) independently of other GDL components during the period 1990 to 2009 are presented in Table 3.3. Teen drivers' fatal crash rates were generally higher than adult drivers' fatal crash rates for all states for most years, with the exception of Rhode Island. There was considerable variation among states' teen and adult fatal crash rates, with teen crash rates highest in Nebraska, and lowest in Rhode Island. Adult drivers' fatal crash rates were highest in North Carolina and lowest in New Hampshire.

Teen drivers' crash rates were typically highest in 1990, and usually twice as high as adult crash rates in the same state. Both teen and adult crash rates declined over the study period, although the decline was more pronounced among teens, such that by 2009, teen crash rates were lower or comparable to adult crash rates for most states in the study sample.

Passenger Restriction

The results of the analysis of the effect of the passenger restriction provided little support for the first hypothesis (Table 3.4). In Rhode Island, the introduction of a law that restricted driving to a single passenger below the age of 21 for the first 12 months of intermediate licensure was followed by a 46% reduction [100 x ($e^{-.6175}$ – 1) = - 46%] in teen driver passenger fatal crash rates that approached significance ($p = .06$). This effect was observable when using quarterly, not monthly, fatal crash rates.

There were no significant changes in the overall or passenger fatal crash rates of 16- and 17-year-old drivers corresponding to the introduction of a passenger restriction for the remainder of the states in the sample. Dose-response relationships between the duration of the passenger restriction or the number of passengers allowed and a reduction in teen drivers' fatal crash rates were not observed. Adult crashes explained some of the variability in teens' fatal crash rates in Colorado, Missouri, North Carolina and Utah.

Nighttime Driving Restriction

Based on the results of the statistical model used for this study, the second hypothesis was rejected. The introduction of nighttime driving restrictions did not result in a reduction of teen drivers' overall fatal crashes or fatal nighttime crashes in Utah or Nebraska (Table 3.5). Adult crashes explained some of the variability in teens' fatal crash rates in Utah.

Additional findings

In Connecticut, the introduction of the six-month learner license in January 1997 was followed by a significant decline in both the overall teen driver fatal crash rate and the passenger fatal crash rate, declining by 16.6% and 20.4% respectively. In North Carolina, the introduction of a 12 month learner permit and extended nighttime driving restriction in December 1997 was followed by a 15.6% decline in the overall teen driver fatal crash rate, and a 15.5% reduction in the teen driver passenger crash rate, both statistically significant.

DISCUSSION

The purpose of this study was to examine the independent effects of GDL intermediate restrictions, namely passenger and night restrictions, on teen drivers' fatal crashes. This purpose was challenging to accomplish for several reasons. Drawing from a potential study population of fifty states, we identified eight instances where a passenger restriction was implemented independently of any other GDL component, creating a natural experiment where intervention effects could potentially be measured. Each state had existing GDL components in place, however, when the passenger restriction was introduced, meaning we could not estimate the independent effect of that restriction, but instead, only the additive effect of the passenger restriction. We identified no cases where a nighttime driving restriction was introduced as a standalone restriction. By loosening the inclusion criteria for the evaluation of nighttime driving restrictions, we identified two instances where the restriction was implemented as the first intermediate restriction in a GDL system, although simultaneously with a required number of supervised driving hours in the learner phase. Using this carefully selected sample, we tested the effect of each restriction using an analytical approach that accounts for long terms trends, a technique that has been recommended but infrequently applied in GDL evaluation research (Hartling, Wiebe et al. 2004).

The observed decline in passenger fatal crashes in Rhode Island is notable for being larger than the previously reported effects in other studies (Masten and Hagge 2004; Zwicker, Williams et al. 2006; Chaudhary, Williams et al. 2007). Rhode Island's passenger restriction was among the most stringent in the study sample in terms of its duration (12 months), and allowance of only a single passenger. Colorado's passenger restriction was also for 12 months, but allowed no passengers for the first six months and a single passenger for the second six months. Based on epidemiological evidence suggesting that crash risk increases with each additional passenger in the vehicle (Chen, Baker et al. 2000), the crash risk for Rhode Island teen drivers in the first six months of independent licensure should be partially elevated, relative to teen drivers in Colorado. The fact that a significant decline in fatal passenger crashes was not observed in Colorado means we could not identify an association between the number of passengers allowed in a teen driver's vehicle and a decline in crashes.

With the exception of Rhode Island, these analyses did not demonstrate a decline in teen drivers' fatal crashes following implementation of a passenger restriction. This finding contrasts with existing research that has generally reported significant declines in injury and fatal crashes following the introduction of a passenger driving restriction (Masten and Hagge 2004; Rice, Peek-Asa et al. 2004; Cooper, Atkins et al. 2005; Chen, Baker et al. 2006; Zwicker, Williams et al. 2006; Chaudhary, Williams et al. 2007; McCartt, Teoh et al. 2010; Fell, Todd et al. 2011). One explanation may be the presence of additional GDL components that were unaccounted for in previous evaluations. For example, California's passenger restriction was introduced simultaneously with a 12 midnight to 5 a.m. driving restriction, and a six month learner license period with 50 hours of required supervised driving (Insurance Institute for Highway Safety 2011), making the exact contribution of the passenger restriction difficult to quantify. Another explanation could be suboptimal compliance with or enforcement of a passenger restriction. In Colorado and Utah, the passenger restriction was limited to secondary enforcement, which means that officers could not stop teens for driving with passengers, and could only issue a citation for a passenger restriction violation if a teen driver was stopped for another reason (National Highway Traffic Safety Administration 2006). In four states (Connecticut, Maine, North Carolina and Utah), passenger restrictions do not apply to siblings, which could further complicate enforcement efforts. Survey research suggests that both novice teen drivers and their parents are less supportive of passenger restrictions than nighttime restrictions (Ferguson and Williams 1996), and this attitude may translate into lower compliance with passenger restrictions (Williams, Leaf et al. 2006).

The importance of identifying and implementing effective policies that reduce passenger fatal crashes cannot be underestimated. Despite the presence of passenger restrictions in 44 states and the District of Columbia, passenger crashes and teens driving with passengers remain a significant problem, according to FARS data. Recent estimates suggest that over 40% of 16- to 17-year-old drivers in fatal crashes were transporting teens with no adult occupant in the vehicle (Williams, Ferguson et al. 2005), and 60% percent of teenage passenger deaths in 2009 occurred in vehicles driven by another teenager (Insurance Institute for Highway Safety 2012). These data suggest that compliance with, and enforcement of, existing passenger restrictions may be inadequate. Approaches to enhancing compliance with passenger restrictions need to balance the epidemiological evidence that every additional peer passenger increases crash risk, with the reality that a complete passenger ban is likely to be violated. Given that one passenger is associated with a modestly higher crash risk (Chen, Baker et al. 2000), one could question whether lower compliance with a complete passenger ban could be offset by higher compliance with a limit of one passenger.

Our hypothesis that the introduction of a nighttime driving restriction would be followed by a decline in teen drivers' nighttime and overall fatal crashes was not supported. The hours of the nighttime driving restriction in the study sample could provide an explanation for this finding. While the hours between 12 midnight and 6 a.m. have a highly elevated crash risk, the total number of fatal crashes occurring during that time is small, and may be insufficient to yield either statistically or practically significant changes (McKnight and Peck 2002). The bulk of the nighttime crash problem among novice teen drivers is skewed toward the hours between 9 p.m. and 12 a.m. and not those after midnight (Foss and Goodwin 2003; Insurance Institute for Highway Safety 2012). Currently, in the majority of jurisdictions where a nighttime restriction is in place in the United States, it begins at midnight or later. Several states also allow exemptions for non-recreational driving (work or school-related), and ten states have only secondary enforcement of the nighttime driving restriction (National Highway Traffic Safety Administration 2006). This suggests that reductions in teen drivers' nighttime crashes in the United States may be possible if existing nighttime driving restrictions began earlier, and the nighttime driving restriction was subject to primary enforcement.

This study identified significant declines in teen drivers' overall and passenger fatal crash rates in North Carolina following the implementation of a 12-month learner permit and 9 p.m. to 5 a.m. nighttime driving restriction in December 1997. In Connecticut, the introduction of a six-month learner license holding period in January 1997 was followed by a sizeable significant decline in overall and passenger fatal crash rates. While these findings do not address the primary research hypotheses of this study, they suggest that declines in passenger crashes cannot be attributed to passenger restrictions alone, if other GDL components are already in place. In reality, the significant declines in passenger crashes as a result of passenger restrictions reported in previous evaluations were likely the result of synergistic or combined effects from several simultaneously implemented GDL components rather than the effect of passenger restrictions alone.

With the exceptions of studies from North Carolina (Foss 2009) and Utah (Hyde, Cook et al. 2005), this research represents the first state-level evaluations of GDL to be conducted for the states in this study sample. In addition, this study adds to the literature by finding that with exception of a single state, individually implemented passenger and nighttime driving restrictions did not result in reductions in teen drivers' fatal crashes in the states studied, a finding that contrasts with existing research on the effect of passenger and nighttime driving restrictions (Lin and Fearn 2003; Cooper, Atkins et al. 2005; Chaudhary, Williams et al. 2007; Fell, Todd et al. 2011). It is possible that the declines observed in previous studies are due to the synergy resulting from the combination of multiple GDL components, rather than the passenger or nighttime restriction itself.

The sample for this study was limited to the instances where states introduced an intermediate license driving restriction independently of other GDL components. In every instance that a passenger restriction was implemented in this sample, however, it was introduced within an existing GDL system of varying strength. Consequently, the additive effect of multiple co-existing GDL components could not be disentangled. Further, the findings of this study are based only on fatal crashes involving teen drivers. Fatal crashes represent a small and atypical subset of all crashes, and the etiology of fatal crashes may differ from that of less serious crashes (Lam 2003).

Future research examining the effect of intermediate license restrictions on teen drivers' should extend the analysis to include injury and property damage only (PDO) as well as fatal crashes. Currently, this data is available in state's crash records, which include all crashes occurring on public roadways involving a fatality, disabling injury, non-disabling injury, possible injury or property damage valued at $1000 or more. However, only a limited number of states make injury crash data available to researchers (National Highway Traffic Safety Administration 2011). The increased sample size that would be gained by using comprehensive state crash data would reduce limited power as an impediment to testing critical hypotheses, and provide a more stable estimate of the independent effects of passenger and nighttime driving restrictions on serious teen driver crashes.

This study's purpose was to examine the independent effects of GDL passenger and nighttime driving restrictions on teen drivers' fatal crashes. With the exception of Rhode Island, these analyses did not identify a decline in teen drivers' fatal crashes attributable solely to the implementation of passenger and nighttime driving restrictions, a finding that contrasts with existing reports on the effect of passenger and nighttime driving restrictions on teen drivers' fatal crashes. We attribute the previously reported declines to the synergy resulting from the combination of multiple GDL components, rather than the passenger or nighttime restrictions alone. This interpretation suggests that passenger and nighttime driving restrictions are most effective when they are implemented as part of comprehensive, multi-component graduated driver licensing systems, rather than as isolated restrictions.

Table 3.1: States that added an intermediate license passenger restriction independently of other GDL components between 1990 and 2009.

State	Previously existing GDL (effective date)	New addition to GDL (effective date)
Connecticut	6 month learner permit (1/97)	No passengers for first 3 months (parent/guardian excepted) (10/03)
Colorado	6 month learner permit 50 hour supervised driving requirement 12am – 5am nighttime driving restriction (7/99) 12 month learner permit (7/04)	No passenger for first 6 months. One passenger for second 6 months (7/05)
Maine	35 hour supervised driving requirement (8/98)	No passengers for first 3 months (immediate family members excepted) (8/00)
Missouri	6 month learner permit 20 hour supervised driving requirement (1/01) 40 hour supervised driving requirement (1/07)	One passenger for first 6 months. Three passengers for second 6 months (9/06)
New Hampshire	3 month learner permit 1am – 5am nighttime driving restriction (1/98) 20 hour supervised driving requirement (9/99)	One passenger for first 6 months (1/03)
North Carolina	12 month learner permit 9pm – 5am nighttime driving restriction (12/97)	One passenger younger than 21 (12/02)
Rhode Island	6 month learner permit 1am – 5am nighttime driving restriction (1/99) 50 hour supervised driving requirement (7/03)	One passenger younger than 21 for first 12 months (7/05)
Utah	30 hour supervised driving requirement 12am – 5am nighttime driving restriction (7/99)	No passengers for first 6 months (immediate family members excepted) (7/01)

Table 3.2: States that added an intermediate license nighttime driving restriction independently of other GDL components between 1990 and 2009.

State	Previously existing GDL (effective date)	New addition to GDL (effective date)
Nebraska	50 hour supervised driving requirement (1/99)	12am – 6am nighttime driving restriction (1/99)
Utah	30 hour supervised driving requirement (1/99)	12am – 6am nighttime driving restriction (7/99)

Table 3.3. Total annual fatal crash rates for states adding intermediate license requirements at five-year intervals, 1990-2009.

	1990		1994		1999		2004		2009	
States introducing Passenger Restrictions	Teen*	Adult#	Teen	Adult	Teen	Adult	Teen	Adult	Teen	Adult
Connecticut	2.71	1.07	2.00	1.13	1.44	1.02	1.73	1.01	.49	.90
Colorado	3.09	1.21	3.78	1.77	3.75	1.66	3.20	1.61	1.30	1.19
Maine	2.52	1.32	2.87	1.60	3.61	1.55	3.56	1.56	.93	1.65
Missouri	3.58	1.61	5.39	2.15	5.03	2.15	3.95	2.18	2.05	1.68
New Hampshire	2.47	1.21	1.39	1.02	2.40	1.35	4.23	1.52	1.54	.94
North Carolina	3.38	1.74	4.10	2.12	3.76	2.33	3.35	2.09	1.56	1.71
Rhode Island	1.79	1.46	.69	1.29	.62	1.81	2.04	1.65	.28	1.69
Utah	1.84	1.10	3.94	1.83	3.47	1.83	2.12	1.54	.98	1.10
States introducing Nighttime Driving Restrictions	Teen	Adult	Teen	Adult	Teen	Adult	Teen	Adult	Teen	Adult
Nebraska	5.09	.78	5.37	1.60	4.01	1.95	2.85	1.63	3.65	1.57
Utah	1.84	1.10	3.94	1.83	3.47	1.83	2.12	1.54	.98	1.10

* 16-17-years
# 25-54-years

Table 3.4. Parameters of best-fitting sudden permanent change ARIMA models estimating the effect of passenger restrictions on 16- and 17- year olds' all fatal and fatal passenger crash rates per capita, 1990 – 2009.

State	Model Component	Parameter (Lag)	All Crashes Estimate	p	Parameter (Lag)	Passenger Crashes Estimate	p
Connecticut	6 month learner permit Effective January 1997	ω	-.1820	.04	ω	-.2286	.01
	No passengers for first 3 months (with exceptions) Effective October 2003	**ω**	**-.0067**	**.97**	**ω**	**-.0712**	**.62**
	20 hours supervised driving 12 a.m. – 5 a.m. driving restriction No passengers for first six months (with exceptions) Effective October 2005	ω	-.1128	.56	ω	-.3384	.07
	40 hours supervised driving No passengers for first 12 months (with exceptions) Effective August 2008	ω	-.3240	.05	ω	-.2435	.13
	Control series (25-54 yr-olds)	β	.3730	.09	β	-.1550	.54
	Gas price	β	-.0004	.97	β	.0016	.16
	Noise (AR or MA component)	None			None		
	Constant		.7112	<.01		.6438	<.01
Colorado	6 month learner permit 50 hour supervised driving 12am – 5am driving restriction Effective July 1999	ω	-.0638	.33	ω	-.0782	.35
	12 month learner permit Effective July 2004	ω	.1617	.21	ω	.1071	.52
	No passengers for first 6 months 1 passenger for second 6 months Effective July 2005	**ω**	**-.2562**	**.08**	**ω**	**-.1930**	**.29**
	Control series (25-54 yr-olds)	β	.5876	<.01	β	.6552	<.01
	Gas price	β	-.0020	.03	β	-.0015	.18
	Noise (AR or MA component)	MA (1)	.1676	.23	AR (2)	-.1349	.03
		AR (4)	-.2159	.84			
	Constant		1.2658	.42		.9999	<.01

Component of interest highlighted in bold
 # Based on quarterly crash data

Table 3.4 continued

State	Model Component	Parameter (Lag)	All Crashes Estimate	p	Parameter (Lag)	Passenger Crashes Estimate	p
Maine#	35 hour supervised driving Effective August 1998	ω	-.0103	.96	ω	.0159	.94
	No passengers for first 3 months (with exceptions) Effective August 2000	**ω**	**-.1130**	**.65**	**ω**	**.0441**	**.87**
	6 month learner permit 12 a.m. – 5 a.m. driving restriction No passengers for first 6 months Effective September 2003	ω	.2671	.30	ω	.2621	.49
	Control series (25-54 yr-olds)	β	.6670	.10	β	.7437	.15
	Gas price	β	-.0028	.08	β	-.0028	.08
	Noise (AR or MA component)	None			None		
	Constant		1.3062	.12		1.0846	.20
Missouri	20 hours supervised driving 6 month learner permit Effective August 1998	ω	-.1026	.12	ω	-.0856	.23
	1 passenger for first 6 months 3 passengers for second 6 months Effective September 2006	**ω**	**-.0754**	**.69**	**ω**	**-.0095**	**.96**
	40 hours supervised driving Effective January 2007	ω	-.1747	.35	ω	-.1017	.62
	Control series (25-54 yr-olds)	β	.7582	<.01	β	.6934	<.01
	Gas price	β	-.0005	.44	β	-.0011	.11
	Noise (AR or MA component)	None			None		
	Constant		.8493	<.01		.9779	<.01

Component of interest highlighted in bold
 # Based on quarterly crash data

Table 3.4 continued

State	Model Component	Parameter (Lag)	All Crashes Estimate	p	Parameter (Lag)	Passenger Crashes Estimate	p
New Hampshire[#]	3 month learner permit 1am – 5am driving restriction Effective January 1998	ω	-.1402	.54	ω	.0185	.93
	20 hour supervised driving Effective September 1999	ω	.0171	.95	ω	-.1824	.45
	1 passenger for first 6 months Effective January 2003	**ω**	**-.0454**	**.85**	**ω**	**-.1756**	**.43**
	40 hour supervised driving Effective June 2009	ω	.0125	.98	ω	-.3054	.41
	Control series (25-54 yr-olds)	β	.2600	.46	β	-.1878	.65
	Gas price	β	-.0010	.47	β	.0005	.73
	Noise (AR or MA component)	None			None		
North Carolina	12 month learner permit 9pm – 5am driving restriction Effective December 1997	ω	-.1700	<.01	ω	-.1682	<.01
	1 passenger younger than 21 Effective December 2002	**ω**	**.01101**	**.89**	**ω**	**-.0299**	**.73**
	Control series (25-54 yr-olds)	β	.8109	<.01	β	.6671	<.01
	Gas price	β	-.0016	<.01	β	-.0009	.08
	Noise (AR or MA component)	None			AR (5)	.1329	.03
	Constant		.8162	<.01		.7390	<.01

Component of interest highlighted in bold
[#] Based on quarterly crash data

Table 3.4 continued

State	Model Component	Parameter (Lag)	All Crashes Estimate	p	Parameter (Lag)	Passenger Crashes Estimate	p
Rhode Island#	6 month learner permit 1am – 5am driving restriction Effective January 1999	ω	-.0874	.62	ω	-.0589	.71
	50 hour supervised driving Effective July 2003	ω	.2426	.39	ω	-.0281	.90
	1 passenger younger than 21 for the first 12 months Effective July 2005	**ω**	**-.2708**	**.45**	**ω**	**-.6175**	**.06**
	Control series (25-54 yr-olds)	β	.3027	.32	β	-.1097	.63
	Gas price	β	-.0001	.97	β	.0029	.16
	Noise (AR or MA component)	None			None		
	Constant		1.2416	.07		1.3922	<.01
Utah#	12am – 6am driving restriction 30 hours supervised driving Effective July 1999	ω	.0032	.98	ω	-.2239	.11
	No passengers for first 6 months (with exceptions) Effective July 2001	**ω**	**-.0645**	**.59**	**ω**	**.1035**	**.54**
	30 hours supervised driving Effective July 2003	ω	.1074	.49	ω	-.0218	.92
	40 hours supervised driving Effective July 2004	ω	.1270	.47	ω	-.0205	.93
	6 month learner permit Effective August 2006	ω	-.0940	.46	ω	-.2137	.22
	Control series (25-54 yr-olds)	β	1.1911	<.01	β	1.1947	<.01
	Gas price	β	-.0016	.12	β	.0004	.77
	Noise (AR or MA component)	MA (1)	.3253	<.01	None		

Component of interest highlighted in bold
 # Based on quarterly crash data

Table 3.5. Parameters of best-fitting sudden permanent change ARIMA models estimating the effect of nighttime driving restrictions on 16- and 17- year olds' all fatal and fatal nighttime crash rates per capita, 1990 – 2009.

State	Model Component	Parameter (Lag)	All Crashes Estimate	p	Parameter (Lag)	Nighttime Crashes Estimate	p
Nebraska[#]	**12am – 6am driving restriction 50 hours supervised driving Effective January 1999**	**ω**	**-.0599**	**.65**	**ω**	**-.1761**	**.08**
	6 month learner permit One passenger younger than 19 for the first 6 months Effective January 2008	ω	-.0615	.79		-.1602	.36
	Control series (25-54 yr-olds)	β	.5722	.05	β	.5275	.23
	Gas price	β	-.0004	.97	β	-.0004	.96
	Noise (AR or MA component)	None			None		
	Constant		1.3967	.03		.8967	.13
Utah[#]	**12am – 6am driving restriction 30 hours supervised driving Effective July 1999**	**ω**	**.0032**	**.98**	**ω**	**.0335**	**.70**
	No passengers for first 6 months Effective July 2001	ω	-.0645	**.59**	ω	-.0120	.91
	30 hours supervised driving Effective July 2003	ω	.1074	.49	ω	.0188	.88
	40 hours supervised driving Effective July 2004	ω	.1270	.47	ω	.0061	.97
	6 month learner permit Effective August 2006	ω	-.0940	.46	ω	.1493	.17
	Control series (25-54 yr-olds)	β	1.1911	<.01	β	.0203	.94
	Gas price	β	-.0016	.12	β	-.0013	.14
	Noise (AR or MA component)	MA (1)	.3253	<.01	None		
	Constant	None				1.3731	<.01

Component of interest highlighted in bold
[#] Based on quarterly crash data

REFERENCES

Bartels, R. H., J. C. Beatty and B. A. Barsky (1998). An Introduction to Splines for Use in Computer Graphics and Geometric Modelling. San Francisco, CA, Morgan Kaufmann.

Bureau of the Census. U.S. Department of Commerce (1999). 1990 to 1999 annual time series of state population estimates by age and sex: 1990 to 1999.

Bureau of the Census. U.S. Department of Commerce (2010). State single year of age and sex population estimates: 2000 to 2009.

Chaudhary, N. K., A. F. Williams and W. Nissen (2007). Evaluation and compliance of passenger restrictions in a graduated licensing program. National Highway Traffic Safety Administration. Washington DC.

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

Chen, L. H., S. P. Baker and G. Li (2006). "Graduated driver licensing programs and fatal crashes of 16-year-old drivers: A national evaluation." Pediatrics **118**(1): 56-62.

Cooper, D., F. Atkins and D. Gillen (2005). "Measuring the impact of passenger restrictions on new teenage drivers." Accident Analysis & Prevention **37**(1): 19-23.

Elliott, M. R. and J. T. Shope (2003). "Use of a Bayesian changepoint model to estimate effects of a graduated driver's licensing program." Journal of Data Science **1**: 43–63.

Fell, J. C., M. Todd and R. B. Voas (2011). "A national evaluation of the nighttime and passenger restriction components of graduated driver licensing." Journal of Safety Research **42**(4): 283-290.

Ferguson, S. A. and A. F. Williams (1996). "Parents' views of driver licensing practices in the United States." Journal of Safety Research **27**(2): 73-81.

Foss, R. and A. Goodwin (2003). "Enhancing the effectiveness of graduated driver licensing legislation." Journal of Safety Research **34**(1): 79-84.

Foss, R. D. (2009). Effect of Adding a Passenger Restriction to an Existing GDL System. Transportation Research Board Young Driver Subcommittee Mid-year Meeting. Washington DC.

Foss, R. D., J. R. Feaganes and E. A. Rodgman (2001). "Initial effects of graduated driver licensing on 16-year-old driver crashes in North Carolina." JAMA: The Journal of the American Medical Association **286**: 1588–1592.

Foss, R. D., S. V. Masten and A. H. Goodwin (2007). Long-term effects of graduated driver licensing in North Carolina. Chapel Hill, NC, University of North Carolina Highway Research Center.

Guarino, J. and A. Champaneri (2010). Factors Involved in Fatal Vehicle Crashes. Washington D.C. , Research and Innovative Technology Adminstration. Bureau of Transportation Statistics.

Hartling, L., N. Wiebe, K. F. Russell, J. Petruk, C. Spinola and T. P. Klassen (2004). "Graduated driver licensing for reducing motor vehicle crashes among young drivers." Cochrane Database of Systematic Reviews(2): Art. No.: CD003300.

Hyde, L. K., L. J. Cook, S. Knight and L. M. Olson (2005). "Graduated driver licensing in Utah: Is it effective?" Annals of Emergency Medicine **45**(2): 147-154.

Insurance Institute for Highway Safety. (2006). "Motor Vehicle Registration and Licensed Driver Information." Retrieved 13th September, 2011, from www.iihs.org/laws/comments/pdf/fhwa_ds_atm_030906.pdf.

Insurance Institute for Highway Safety. (2011). "Fatality Facts 2009: General." Retrieved 22th July, 2011, from http://www.iihs.org/research/fatality_facts_2009/general.html.

Insurance Institute for Highway Safety. (2011). "Graduated Driver Licensing." Retrieved 26th May, 2011, from http://www.iihs.org/research/qanda/gdl.html.

Insurance Institute for Highway Safety. (2012). "Cell Phone and Texting Laws." Retrieved 16th February, 2012, from http://www.iihs.org/laws/cellphonelaws.aspx.

Insurance Institute for Highway Safety. (2012). "Fatality Facts 2009: Teenagers." Retrieved 9th March, 2012, from http://www.iihs.org/research/fatality_facts_2009/teenagers.html.

Lam, L. T. (2003). "Factors associated with young drivers car crash injury: comparisons among learner, provisional, and full licensees." Accident Analysis & Prevention **35**(6): 913-920.

Lin, M.-L. and K. T. Fearn (2003). "The provisional license: nighttime and passenger restrictions - a literature review." Journal of Safety Research **34**(1): 51-61.

Masten, S. V., R. D. Foss and S. W. Marshall (2011). "Graduated Driver Licensing and Fatal Crashes Involving 16- to 19-Year-Old Drivers." JAMA: The Journal of the American Medical Association **306**(10): 1098-1103.

Masten, S. V. and R. A. Hagge (2004). "Evaluation of California's graduated driver licensing program." Journal of Safety Research **35**(5): 523-535.

McCartt, A. T., E. R. Teoh, M. Fields, K. A. Braitman and L. A. Hellinga (2010). "Graduated Licensing Laws and Fatal Crashes of Teenage Drivers: A National Study." Traffic Injury Prevention **11**(3): 240-248.

McCleary, R. and R. A. Hay (1982). Applied time series analysis for the social sciences Beverly Hills, CA, Sage Publications.

McDowall, D., R. McCleary, E. E. Meiringer and A. H. Hay (1980). Interrupted time series analysis. Thousand Oaks, California, Sage Publications.

McKnight, A. J. and R. C. Peck (2002). "Graduated driver licensing: what works?" Injury Prevention **8**(suppl 2): ii32-ii38.

Morrisey, M. A. and D. C. Grabowski (2010). "Gas prices, beer taxes and GDL programmes: effects on auto fatalities among young adults in the US." Applied Economics **43**(25): 3645-3654.

National Highway Traffic Safety Administration (2006). Traffic Safety Facts Research Note: States with Primary Enforcement Laws Have Lower Fatality Rates. Washington, D.C, U.S. Department of Transportation.

National Highway Traffic Safety Administration (2010). Fatality Analysis Reporting System Washington, D.C, U.S. Department of Transportation.

National Highway Traffic Safety Administration (2010). Traffic Safety Facts 2009: A compilation of motor vehicle crash data from the Fatality Analysis Reporting System and the General Estimates System. Washington, D.C, U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2011). "SDS Overview." Retrieved 12th September, 2011.

National Highway Traffic Safety Administration. U.S. Department of Transportation (1996). Graduated driver licensing system for novice drivers. Washington, DC

Preusser, D. F., A. F. Williams, P. L. Zador and R. D. Blomberg (1984). "The effect of curfew laws on motor vehicle crashes." Law and Policy **6**(1): 115–128.

Rice, T. M., C. Peek-Asa and J. F. Kraus (2004). "Effects of the California graduated driver licensing program." Journal of Safety Research **35**(4): 375-381.

Scientific Computing Associates (2011). Time-series analysis and forecasting software. WorkBench Version 6.2.0.

Shope, J. T. and L. J. Molnar (2004). "Michigan's graduated driver licensing program: Evaluation of the first four years." Journal of Safety Research **35**(3): 337-344.

Shope, J. T., L. J. Molnar, M. R. Elliott and P. F. Waller (2001). "Graduated Driver Licensing in Michigan." JAMA: The Journal of the American Medical Association **286**(13): 1593-1598.

Sivak, M. and B. Schoettle (2010). "Toward Understanding the Recent Large Reductions in U.S. Road Fatalities." Traffic Injury Prevention **11**(6): 561-566.

Tabachnick, B. G. and L. S. Fidell (2007). Using Multivariate Statistics. Boston, Allyn and Bacon.

U.S. Energy Information Administration. (2011). "Energy Prices." Total Energy Retrieved 9th September, 2011, from http://205.254.135.24/totalenergy/data/monthly/index.cfm#prices.

Ulmer, R. G., D. F. Preusser, A. F. Williams, S. A. Ferguson and C. M. Farmer (2000). "Effect of Florida's graduated licensing program on the crash rate of teenage drivers." Accident Analysis & Prevention **32**(4): 527-532.

Williams, A. F. (2007). "Contribution of the components of graduated licensing to crash reductions." Journal of Safety Research **38**(2): 177-184.

Williams, A. F., S. A. Ferguson and J. K. Wells (2005). "Sixteen-Year-Old Drivers in Fatal Crashes, United States, 2003." Traffic Injury Prevention **6**(3): 202 - 206.

Williams, A. F., W. A. Leaf, B. G. Simons-Morton and J. L. Hartos (2006). "Parents' views of teen driving risks, the role of parents, and how they plan to manage the risks." Journal of Safety Research **37**(3): 221-226.

Williams, A. F., D. F. Preusser, R. G. Ulmer and H. B. Weinstein (1995). "Characteristics of Fatal Crashes of 16-Year-Old Drivers: Implications for Licensure Policies." Journal of Public Health Policy **16**(3): 347-360.

Williams, A. F. and D. F. Pruesser (1997). "Night driving restrictions for youthful drivers: a literature review and commentary." Journal of Public Health Policy **18**(3): 334–345.

Zwicker, T. J., A. F. Williams, N. K. Chaudhary and C. M. Farmer (2006). Evaluation of California's graduated licensing system. Arlington, VA, Insurance Institute for Highway Safety.

CHAPTER 4

DELAYING THE INEVITABLE? THE EFFECT OF GDL ON 18-YEAR-OLD DRIVERS' CRASHES IN FLORIDA, MICHIGAN AND MARYLAND

INTRODUCTION

Motor vehicle crashes are the leading cause of death and a leading cause of injury for teens in the United States (National Highway Traffic Safety Administration 2010). Graduated driver licensing (GDL) has been the single most effective intervention to reduce motor-vehicle-related injury and fatalities among 16- and 17-year-olds (Insurance Institute for Highway Safety 2011). GDL eases young drivers onto roadways by limiting their exposure to progressively higher risk driving conditions (National Highway Traffic Safety Administration. U.S. Department of Transportation 1996). The move from simple to increasingly complex driving conditions is mediated by teens' progression through three licensure levels (Foss and Goodwin 2003). The first level (learner license) allows teens to gain driving practice and experience under the supervision of a fully licensed driver (typically a parent or other person over age 21 who is designated by the parent). The second level (intermediate license) allows teens to drive independently but with restrictions that limit their exposure to the highest risk driving conditions (i.e., driving with passengers (Chen, Baker et al. 2000) and driving at night (Williams 2003)). The final stage of GDL gives teens who have gained driving experience while fulfilling the requirements of learner and intermediate licenses, permission to drive with no restrictions. With few exceptions, the staged licensing requirements of GDL apply exclusively to 15- to 17-year-old drivers (Williams and Shults

2010). In most U.S. states, an 18-year-old wishing to obtain a driver license for the first time is not required to follow GDL requirements, but typically only needs to complete a knowledge test and a driving skills test prior to receiving a regular license.

While a sizeable body of evidence suggests that GDL leads to significant declines in 16- and 17-year-old drivers' crashes (Foss, Feaganes et al. 2001; Shope, Molnar et al. 2001; Williams, Ferguson et al. 2005; Chen, Baker et al. 2006; Trempel 2009; McCartt, Teoh et al. 2010; Williams and Shults 2010; Masten, Foss et al. 2011), the effect of GDL on 18-year-old drivers' crashes is less clear. A study examining the effect of California's GDL on teen driver fatalities reported a 24% rise in 18-year-old fatal crashes following the introduction of GDL in July 1998 (Males 2007). A recent national study by Masten and colleagues also reported a significant post-GDL increase in fatal crashes of 18-year-old drivers large enough that no net benefit from GDL on overall 16- to 19-year-old drivers' fatalities remained (Masten, Foss et al. 2011). In contrast, McCartt and colleagues found that states with GDL legislation rated by the Insurance Institute for Highway Safety as 'good' (i.e., more, stronger components) had significantly lower 18-year-old driver fatal crashes than states with 'fair' or 'poor' GDL (i.e., fewer, weaker components) (McCartt, Teoh et al. 2010; McCartt and Teoh 2011). Using the same taxonomy to rate GDL legislation, Trempel found that 'good' GDL programs were associated with significantly fewer insurance collision claims by 18-year-old drivers (Trempel 2009).

Both studies that reported an increase in 18-year-old drivers' fatalities employed time series analysis, an evaluation method that controls for pre-existing trends, seasonal variation and serial correlation between observations (McCleary and Hay 1982). Masten's national evaluation pooled individual states' time series into a single sample, making this evaluation arguably the most complete study on the effect of GDL that has been conducted to date. However, both studies utilized data from the Fatal Analysis

Reporting System (FARS) and, therefore, were limited to only fatal crashes (National Highway Traffic Safety Administration 2010). Neither McCartt (McCartt, Teoh et al. 2010) nor Trempel (Trempel 2009) controlled for pre-existing trends in teen crashes in their analysis, and McCartt was limited to fatal-only crashes. Trempel's analysis was restricted to collision claims involving new (i.e., 0-3-year-old) motor vehicles (Trempel 2009), a sample that is known to be unrepresentative of teen drivers (Williams, Leaf et al. 2006).

While few studies have examined the effect of GDL on 18-year-old drivers' crashes and their results are mixed, the studies that reported increased fatal crash rates among 18-year-old drivers raise serious questions about potential unintended consequences of GDL. Two mechanisms have been proposed to explain the observed increase in 18-year-old drivers' crash rates. The first is an 'offset effect', where a proportion of teen drivers, either wishing to avoid the requirements of GDL or for other reasons, do not get licensed to drive until age 18 (Masten and Hagge 2004). As a result, the increased crash risk associated with inexperience for these new drivers is shifted from 16 to 18 years of age. The second mechanism results from a proportion of teens not advancing well through GDL prior to their turning 18 and getting a regular license. These drivers may still lack independent driving experience when they receive their regular driver license at age 18 (Dee, Grabowski et al. 2005). The result from either mechanism could be an increase in 18-year-old driver crash rates.

To conclusively determine the mechanism responsible for an increase in 18-year-old drivers' crashes, one would track thousands of young drivers' using longitudinal state crash and licensure records, linking individual's crashes with their age at licensure. However, licensure data reported by the Federal Highway Administration underreport the actual number of licensed teens, and these data are difficult to obtain from individual states (Insurance Institute for Highway Safety 2006). In their absence, we can exploit natural experiments resulting from GDL policy implementation to shed some light on the issue. By comparing teen drivers' crash rates in states where GDL applies exclusively to 15- to 17-year-olds with rates in states where GDL extends to all novice drivers regardless of age, inferences could be made about the underlying mechanism responsible for an increase in 18-year-old drivers' crashes.

If an increase in 18-year-old drivers' crash rates was observed in states where GDL applies to 15- to 17-year-old drivers only, one could infer that the responsible mechanism might be the offset effect. The assumption would be that in these states a sizeable proportion of teens are delaying licensing until age 18, at which point they begin driving without the benefit of experiencing GDL. Meanwhile, in states where GDL applies to novice drivers of all ages, and every new driver experiences GDL, there would not be an increase in crashes at age 18. Alternatively, if an increase in 18-year-old drivers' crash rates was observed in states where GDL applies only to 15- to 17-year-old drivers and also in states where GDL applies to all novice drivers one could infer that the primary mechanism responsible for the increase in 18-year-old drivers' crashes is that teens licensed under GDL lack unrestricted driving experience when they get a regular license, and therefore are more likely to crash.

The purpose of this paper is to determine the effect of GDL on 18-year-old drivers' crash rates, and to shed light on a possible mechanism responsible for some potential increase in crash rates by comparing two states where GDL provisions apply exclusively to 15- to 17-year-old drivers (Florida, Michigan), to a state where GDL applies to novice drivers of all ages (Maryland). The effects of GDL on 16- and 17-year-old drivers will also be examined, to extend the evaluation period relative to previous studies and confirm positive outcomes in this population.

RESEARCH HYPOTHESES

The implementation of a GDL program would result in (1) a significant decline in the crash rates of 16-year-old drivers, and (2) a significant decline in the crash rates of 17-year-old drivers. With regard to an effect of GDL on crashes of 18-year-old-drivers, two hypotheses will be tested: (3) there will be an increase in 18-year-old drivers' crash rates in states where GDL applies exclusively to 15- to 17-year-old drivers, and no change or a decrease in 18-year-old drivers' crash rates in states where GDL applies to all novice drivers; and (4) there will be an increase in 18-year-old drivers' crash rates in states where GDL applies exclusively to 15- to 17-year-old drivers, and an increase in 18-year-old drivers' crash rates in states where GDL applies to all novice drivers.

METHODS

To test these hypotheses, state crash record data, which include all reported crashes occurring on public roadways, were obtained for Florida, Michigan and Maryland. These states represent three distinct approaches to the implementation of GDL policy (Table 4.1). Florida is credited with having implemented the first GDL program in the United States in July 1996, when the state required a six-month learner permit period for teen drivers aged 16- or 17-years-old and restricted driving of 16-year-olds between the hours of 11 p.m. and 6 a.m. and of 17-year-olds between the hours of 1 a.m. and 5 a.m. In October 2000, Florida augmented its GDL program by extending the learner permit period to 12 months and requiring 50 hours of supervised practice driving. Complete crash record data for Florida were obtained for the contiguous period 1990 to 2009.

Michigan introduced a three-phase GDL program in April 1997 that included a learner license period lasting a minimum of 6 months and the completion of 50 hours of supervised driving. Teens driving with an intermediate license were restricted from driving between the hours of 12 midnight to 5 a.m. Complete crash record data for Michigan were obtained for the contiguous period 1992 to 2009.

Maryland's GDL program is unique in the United States, in that it requires novice drivers of all ages to complete the same learner permit phase, but imposes restrictions on passenger and nighttime driving only to novice drivers under 18-years-of-age. Since 1979, Maryland has had a nighttime driving restriction for drivers under 18 years of age, prohibiting their driving between the hours of 1 a.m. and 6 a.m.(Preusser, Ferguson et al. 1998). The hours of the nighttime driving restriction were revised in 1985 to begin at 12 midnight and continue until 5 a.m. From July 1999, novice drivers of all ages in Maryland were required to hold a learner permit for four months and to complete 40 hours of supervised driving. In October 2005, the learner permit period was extended from four to six months, and the required number of supervised driving hours was increased from 40 to 60 hours for novice drivers of all ages. In addition, a passenger driving restriction was added, banning drivers under age 18 from carrying passengers younger than age 18 for the first five months of intermediate licensure. In October 2009, the learner permit period was extended to nine months. Complete crash record data for Maryland were obtained for the contiguous period 1998 to 2009. All state crash record data used in this study were provided by the Center for Management of Information for Safe and Sustainable Transportation of the University of Michigan Transportation Research Institute (University of Michigan Transportation Research Institute 2012).

Measures

Novice Driver Crash Rates: Monthly counts of all reported crashes occurring on public roadways (fatal/disabling injury, non-disabling injury, and possible-injury/property-damage-only (PDO)) involving at least one teen driver (16-, 17- or 18-year-old) in cars, trucks/pickups, and sport utility vehicles were obtained for Florida, Michigan and Maryland. Crashes that involve any injury (fatal or non-fatal) are required to be reported.

However the states differ slightly in their criteria for crashes where only property damage occurs. Florida requires property damage crashes valued at $500 or more to be reported to the police, while in Michigan the property damage should be $1,000 or more. In Maryland, a crash is reported if it involves immobilizing property damage or if an individual involved in the crash requests a report.

The number of licensed teen drivers would provide the most precise estimate of the effect of the GDL programs on crash rates, if it were available. However, licensure data reported by the Federal Highway Administration underreport the actual number of licensed teens, and these data are difficult to obtain from individual states (Insurance Institute for Highway Safety 2006). Miles driven by each teen would also be an ideal indicator of exposure, but are difficult to measure and generally unavailable. Therefore, crash rates were based on the number of 16-, 17-, and 18-year old teens in the overall population of each state. Annual population estimates by state and age were obtained from the United States Census Bureau (Bureau of the Census. U.S. Department of Commerce 1999; Bureau of the Census. U.S. Department of Commerce 2010). Monthly values were interpolated using cubic spline curves, which are the smoothest curves that best fit a set of data points (Bartels, Beatty et al. 1998). Age-group-specific monthly crash involvement rates of 16-, 17-, and 18-year-old drivers per 100,000 population were calculated using monthly crash counts and population estimates. Fifteen-year-old drivers were excluded from the study because driving in this age group typically occurs under supervision, which has the lowest lifetime crash risk (Mayhew, Simpson et al. 2003; VicRoads 2005).

Covariates

<u>Adult driver crash rates:</u> Monthly crash rates for drivers age 35 to 54 were estimated using the identical method used to estimate teen driver crash rates. The purpose of the comparison population was to adjust for variability in the teen driver crash

rates due to extraneous factors affecting drivers of all ages, and to test the effect of GDL against a comparison population of persons unaffected by the program. Although time series analyses control for pre-existing secular trends in crash rates, the inclusion of the crash rates of another age group as a historical covariate to control for unmeasured factors that affect all drivers enhances the validity of the findings.

Gas prices: An inverse relationship between gas prices and crashes has been identified for drivers of all ages (Sivak and Schoettle 2010); however, research suggests that teen driving behavior may be more sensitive to higher gas prices, relative to older drivers (Morrisey and Grabowski 2010). Monthly national gas prices were obtained from the U.S. Energy Information Administration and included as a covariate (U.S. Energy Information Administration 2011).

GDL effective date: The precise points at which GDL programs were expected to affect crash rates were determined by inspection of the details of each state's GDL system. This information was obtained from the Insurance Institute for Highway Safety GDL effective date database (Insurance Institute for Highway Safety 2012) and each state's Department of Motor Vehicles website (Florida Department of Highway Safety and Motor Vehicles 2009; Maryland Motor Vehicle Administration 2012; Michigan Secretary of State 2012). The date at which GDL would apply to each age group in the study sample was calculated by identifying the first month that GDL would impact the age group. For example, Florida's first GDL program was implemented in July 1996. From this date onward, GDL applied to all new teen drivers in the state, but existing teen drivers were exempt from the program. Therefore, the point at which 17-year-old drivers were directly affected by Florida's GDL was July 1997, as the initial cohort of teens affected by GDL advanced through the system. Similarly, the point at which 18-year-old drivers were directly affected by GDL was July 1998. This approach to identifying the date at which GDL affected each year-of-age in the study population was applied to each state in the sample. Because at least two years of post-implementation data points were required to estimate effects, GDL laws introduced after January 2008 were not included in the analyses.

Analytical Method

Monthly crash rates per 100,000 population of 16-, 17-, and 18-year-old drivers were analyzed using Auto-Regressive Integrated Moving Average (ARIMA) interrupted time series analysis (McCleary and Hay 1982) for each state. Interrupted time-series analyses compare observations before and after some identifiable event, with the goal of evaluating the impact of the intervention. The transfer function relates an intervention to its effect on crash rates. In this analysis, the transfer function has two parameters. The first parameter, ω, is the magnitude of the asymptotic change (rise or fall) in level after the intervention. The second parameter, δ, reflects the onset of the change. If the null hypothesis that ω is 0 is supported, there is no impact of the intervention. If ω is significant, the size of the change is ω as a percentage (Tabachnick and Fidell 2007). For these analyses, δ was fixed at 0, meaning the anticipated change in crash rates would be abrupt and lasting, referred to as a sudden-impact permanent-change model.

Analytical strategy

For Michigan and Maryland, analyses were conducted using fatal/disabling injury, non-disabling injury, and possible-injury/PDO crash rates as three separate outcome measures. Florida crash data showed evidence of underreporting that varied across time for 'possible-injury/PDO' crashes. Therefore, this crash severity category was excluded from the Florida analyses.

For each state, the models were estimated using the natural logarithm of the monthly crash rates per 100,000 population. Using the natural logarithm, the coefficient representing the intervention effect (ω) is directly interpretable (using the formula 100 x $[e^{\omega} - 1]$) as the percentage change in the post-intervention series relative to the pre-intervention series (McDowall, McCleary et al. 1980). Results reported are based on the models using the natural logarithm of crash rates as the outcome variable.

The analyses were conducted in three stages. First, a linear regression model was estimated for the teen driver crash rates and the covariates: adult crash rates, gas prices, and GDL laws. Second, the model for each state was statistically adjusted for trends and seasonal variation. Autoregressive and moving average orders were identified using auto-correlation and partial-auto-correlation functions of the series residuals. Finally, the original regression model was re-estimated with the inclusion of the autoregressive or moving average orders identified in the second stage. Outliers were also detected and controlled for in the final model. Analyses were conducted using the SCA Time Series and Forecasting System, a specialized time-series analysis software package (Scientific Computing Associates 2011).

RESULTS

For each state, crash rates increased with age, across each level of crash severity (Table 4.2). Crash rates were higher prior to the introduction of GDL, than after GDL. This observation held for each state, year-of-age, and crash severity level, with a single exception. In Florida, 18-year-old drivers' non-disabling injury crashes increased following the second revision of Florida's GDL program. Fatal/disabling, and non-disabling crash rates were highest among Florida teens relative to teens in Michigan and Maryland. Possible-injury/PDO crash rates were higher for all three age groups of teen drivers in Michigan, compared to Maryland.

16-year-old drivers' crash rates

The results of the analysis partially confirm the first hypothesis: 16-year-old drivers' crash rates significantly declined in each state following the introduction of GDL or revision of existing GDL programs. However, the decrease was not uniform and varied across each level of crash severity (Table 4.3). The introduction of GDL in Florida in July 1996 was not followed by a significant decline in 16-year-old drivers' crash rates (Tables 4.3 and 4.4). However, Florida's second GDL program, effective in October 2000, resulted in significant declines in fatal/disabling injury (-5.4%) and non-disabling injury crash rates (-6.8%). Following the introduction of GDL in Michigan in April 1997, 16-year-old drivers' crash rates significantly declined in each level of crash severity. Fatal/disabling injury crashes declined by over one fifth (-21.6%), non-disabling injury crashes were 6.7% lower, and possible-injury/PDO crashes fell 23.1% (Tables 4.3 and 4.5). In Maryland, 16-year-old drivers' non-disabling injury crash rates were significantly lower (-12.1%) following the introduction of GDL in July 1999. Maryland's revision of GDL in October 2005 was followed by significant declines in 16-year-old drivers' non-disabling injury and possible-injury/PDO crash rates, which were 26.4% and 11.2% lower respectively (Tables 4.3 and 4.6).

17-year-old drivers' crash rates

The pattern of results was similar, although weaker, for 17-year-old drivers' crash rates (Table 4.3). Seventeen-year-old drivers' crash rates significantly declined in each state following the introduction of GDL or a revision of existing GDL programs, although this decline varied across levels of crash severity. Florida's first GDL program was not associated with any changes in 17-year-old drivers' crashes. However, similar to the pattern observed among 16-year-old drivers, Florida's revised GDL program was followed by significant declines in fatal/disabling and non-disabling injury crashes, falling 9.3% and 7.9% respectively (Tables 4.3 and 4.4). In Michigan, 17-year-old drivers' fatal/disabling injury crash rates were 10.9% lower following the introduction of GDL, while possible-injury/PDO crashes declined by 2.9% (Tables 4.3 and 4.5). In Maryland, 17-year-old fatal/disabling injury crashes decreased by 14.3% following the introduction of GDL, and were further reduced 25.4% following revision of the program. While there was no effect on non-disabling injury crash rates, Maryland's revised GDL program resulted in an 8.7% decline in possible-injury/PDO crash rates (Tables 4.3 and 4.6).

18-year-old drivers' crash rates

In Florida, the introduction and revision of GDL was not associated with any significant changes in 18-year-old drivers' crash rates (Tables 4.3 and 4.4). In Michigan, the introduction of GDL was followed by a statistically significant 3.6% increase in possible-injury/PDO crashes among 18-year-old drivers, but no change in fatal/disabling or non-disabling injury crashes (Tables 4.3 and 4.5). In Maryland, where GDL applied to novice drivers of all ages, the introduction of GDL was not associated with an increase in 18-year-old drivers' crash rates at any level of crash severity. On the contrary, 18-year-old drivers' possible-injury/PDO crash rates significantly declined (-6.9%) following the first revision of Maryland's GDL program (Tables 4.3 and 4.6). These results provide modest support for the third hypothesis of this study, that there will be an increase in 18-year-old drivers' crash rates in states where GDL applies only to 15- to 17-year-old drivers, and that in states where GDL applies to novice drivers of all ages, 18-year-old drivers' crash rates will remain unchanged or decrease.

DISCUSSION

This study's purpose was twofold. The first was to examine the effects of GDL on 18-year-old drivers' crash rates (while confirming positive outcomes among 16- and 17-year-old drivers). The second was to shed light on a potential mechanism responsible for any increase in 18-year-old drivers' crash rates by comparing states where GDL provisions apply exclusively to 15- to 17-year-old drivers (Florida and Michigan) with a state where the GDL learner permit requirement applies to novice drivers of all ages (Maryland). In the absence of licensing data, it was not possible to determine conclusively whether the observed changes in 18-year-old drivers' crashes were entirely due to a proportion of teens being licensed for the first time at age 18, or because teens licensed under GDL lack sufficient independent driving experience. However, using this carefully selected sample of states, we tested our hypotheses on three levels of crash severity, employing an analytical approach that accounted for long term trends. After adjusting for confounding factors, we found that 18-year-old drivers' possible-injury/PDO crash rates increased in Michigan and declined in Maryland, providing some support for the 'offset effect,' whereby 18-year-old novice drivers' crashes may increase following implementation of GDL.

The 3.6% increase in 18-year-old drivers' possible-injury/PDO crash rates in Michigan supports our hypothesis that 18-year-olds' crashes increase in states where GDL applies exclusively to 15- to 17-year-old drivers. The absence of a change in crashes of greater injury severity raises issues regarding the differential effects of GDL on crash types, and the extent of GDL's effect on 18-year-old drivers. Reductions in possible-injury/PDO crashes are consistent with GDL's objective to protect novice drivers from the consequences of their inexperience as they learn to drive independently. GDL is not a program to control risk-taking behaviors such as speeding and alcohol-impaired driving, which are often involved in the differing etiology of fatal and disabling injury crashes (Lam 2003). Consequently, GDL should influence crashes attributable to lack of experience more than those crashes attributable to deliberate risk-taking or neglectful driving behavior (McKnight and McKnight 2003). The absence of a change in 18-year-old drivers' crashes in Florida has been observed in previous evaluations of Florida's GDL program (Ulmer, Preusser et al. 2000), and may be due to the unfortunate exclusion in these analyses of possible-injury/PDO crashes, or other state-specific factors.

One such state-specific factor, for example, is that unlike Michigan, Florida's GDL was incrementally implemented in two stages. States where GDL components have been gradually introduced and the concept of graduated licensing has become an accepted norm, such as Florida, may be less likely to experience an increase in a proportion of teens delaying licensing until age 18 in response to a change in the law. In states that had placed few restrictions on teen driving previously, and subsequently introduced a comprehensive GDL law at a single time point, such as Michigan, GDL may represent a profound shift in the culture of driving for teens, resulting in a greater number of teens delaying licensing until age 18 in order to avoid the provisions of the law. Other factors may be at play, such as required driver education or the cost of driver education.

The 6.9% reduction in 18-year-old drivers' possible-injury/PDO crash rates in Maryland also provides support for the offset hypothesis that 18-year-old drivers' crashes decrease in states where GDL applies to novice drivers of all ages. Unlike the declines in 16- and 17-year-old drivers' fatal/disabling and non-disabling injury crashes following the introduction of GDL in Maryland, possible-injury/PDO crashes were the only crash type that declined for 18-year-old drivers. This finding may be due to the unique provision of Maryland's GDL that requires all novice drivers, regardless of age, to complete a learner permit phase, although restrictions on passenger and nighttime driving applies only to novice drivers below age 18. The absence of a decline in the most severe crash types may be the consequence of drivers age 18 being unprotected from the high-risk conditions of driving with peer passengers (Chen, Baker et al. 2000) and driving at night (Williams 2003).

Given that a long-term safety benefit of advancing through GDL has been previously reported (Masten and Foss 2010), it is plausible that reductions in 18-year-old drivers' crashes resulting from safer driving by teens who have completed GDL are being masked by increased crash rates of newly licensed 18-year-old drivers. The increase in 18-year-old drivers' fatal crashes in California reported by Males (Males 2007) may suggest a greater proportion of teens becoming licensed at age 18 in California, relative to Michigan or Florida. Similarly, Masten's national findings (Masten, Foss et al. 2011) may have been skewed by the proportion of teens licensed at age in the two largest states, California and Texas, that constitute over 20% of the fatal crashes in the United States.

Our findings build on previous research that examined GDL effects in the states used in this study. Ulmer and colleagues concluded that the introduction of Florida's first GDL program in July 1996, reduced fatal and injury crash rates among 15- to 17-year-old drivers by 9%, but not 18-year-old drivers' crash rates (Ulmer, Preusser et al. 2000). By extending the post-GDL evaluation period in Florida and adjusting crash rates for long term trends, we observed significant reductions in 16- and 17-year-old drivers' fatal/disabling and non-disabling injury crash rates following the enhancement of the existing GDL program in October 2001, and also found 18-year-old drivers' crash rates remained unchanged for the duration of the study period. Shope and associates concluded that Michigan's GDL reduced the overall crash rate for 16-year-old drivers by 25% (Shope, Molnar et al. 2001), with a similar reduction reported in a four-year follow up study (Shope and Molnar 2004). By including older teen drivers in this study, we demonstrated that the protective effects of Michigan's GDL extended to significant declines in 17-year-old drivers' fatal/disabling injury crashes and possible-injury/PDO crashes. Using three levels of crash severity, we exposed the differential effects of Michigan's GDL on crash outcomes, suggesting that the largest decreases in crashes were concentrated among the most and the least severe crash types. For Maryland, Kirley reported an 18% decline in the overall crash rate, and a 37% decline in the non-fatal crash rate for 16-year-old drivers in Maryland following the introduction of GDL in July 1999 (Kirley, Feller et al. 2008). Using a longer follow-up period, we were able to detect significant declines in 16-, 17- and 18-year-old drivers' crash rates following the changes in Maryland's GDL in October 2005, and observed that those reductions were not uniformly distributed by crash severity.

This study was based on crash rates calculated using the number of teens in the overall population. With this approach we were able to determine that the public health impact of GDL on 18-year-old drivers was limited to modest increases in possible-injuries/POD crashes in Michigan and modest reductions in possible-injuries/PDO crashes in Maryland. A more precise evaluation of the effect of GDL would require the age of licensure (and GDL stage) associated with each individual driver's crash record. With this more detailed information, time-to-event analysis could be used to compare first-time crash incidence of teens licensed under GDL to those licensed at age 18. This study examined the effects of GDL on 18-year-old drivers' crash rates by comparing states where GDL provisions applied exclusively to 15- to 17-year-old drivers (Florida and Michigan) to a state where GDL applied to novice drivers of all ages (Maryland). The absence of individual licensure data did not allow us to determine whether changes in 18-year-old drivers' crashes were due to some teens not becoming licensed until age 18. However, we found that 18-year-old drivers possible-injury/PDO crash rates increased in Michigan and declined in Maryland, which is consistent with the presence of an 'offset effect' that reflects the crashes of novice 18-year-old drivers.

Table 4.1. GDL components and effective dates in Florida, Michigan and Maryland.

State	GDL Components (effective date)
Florida	6 month minimum holding period and nighttime driving restriction (7/96) 12 month minimum hold period and 50 hr supervised driving requirement (10/00)
Michigan	6 month minimum holding period, 50 hr supervised driving requirement and 12 midnight – 5 a.m. nighttime driving restriction (4/97)
Maryland	4 month minimum holding period and 40 hr supervised driving requirement (7/99) 6 month minimum holding period and 60 hr supervised driving requirement (10/05) No passengers younger than 18 for first five months (10/05)

Table 4.2. Crash rate by state, year-of-age, and crash type.

State	Age in Years	GDL effective date(s)	Crash rate per 100,000 population		
			Pre-GDL	Post-first GDL effective date^	Post-second GDL effective date
Florida	16	Fatal and Disabling Injury	77.7	56.3	38.1
		Non-disabling Injury	181.7	124.3	86.7
	17	Fatal and Disabling Injury	89.0	63.9	57.5
		Non-disabling Injury	200.6	137.0	127.5
	18	Fatal and Disabling Injury	97.8	73.9	75.0
		Non-disabling Injury	208.0	157.2	165.2
Michigan	16	Fatal and Disabling Injury	43.1	18.9	-
		Non-disabling Injury	92.9	50.6	-
		Possible Injury and PDO#	995.4	688.7	-
	17	Fatal and Disabling Injury	43.3	22.1	-
		Non-disabling Injury	88.9	58.5	-
		Possible Injury and PDO#	1019.0	866.3	-
	18	Fatal and Disabling Injury	45.3	24.4	-
		Non-disabling Injury	89.8	62.2	-
		Possible Injury and PDO#	1060.1	939.8	-
Maryland	16	Fatal and Disabling Injury	38.1	21.6	7.5
		Non-disabling Injury	66.1	51.2	22.8
		Possible Injury and PDO#	264.7	228.1	121.9
	17	Fatal and Disabling Injury	47.6	32.6	15.0
		Non-disabling Injury	92.6	81.8	52.6
		Possible Injury and PDO#	374.6	355.5	265.9
	18	Fatal and Disabling Injury	48.9	30.2	15.4
		Non-disabling Injury	97.6	79.8	55.7
		Possible Injury and PDO#	393.4	376.0	276.8

^ Rates for Florida and Maryland are based on the crashes after the introduction of the first program, and before the introduction of the second program

Property Damage Only

* p < .05

Table 4.3. Percentage change in crash rate by state, year-of-age and crash type.

State	Age in Years	GDL effective date(s)	Percentage Change^ in Fatal and Disabling Injury Crashes	Percentage Change^ in Non-disabling Injury Crashes	Percentage Change^ in Possible Injury and PDO# Crashes
Florida	**16**	July 1996	- 2.8	-2.4	-
		October 2000	**-5.4**	**-6.8**	-
	17	July 1997	3.2	0.8	-
		October 2001	**-9.3**	**-7.9**	-
	18	July 1998	3.0	0.7	-
		October 2002	-5.7	-4.1	-
Michigan	**16**	April 1997	**-21.6**	**-6.7**	**-23.1**
	17	April 1998	**-10.9**	-4.1	**-2.9**
	18	April 1999	-0.2	0.1	**3.6**
Maryland	**16**	July 1999	-10.3	**-12.1**	5.8
	16	October 2005	-10.9	**-26.4**	**-11.2**
	17	July 2000	**-14.3**	-0.3	-1.4
	17	October 2006	**-25.4**	-9.3	**-8.7**
	18	July 2001	-9.0	-1.3	0.4
	18	October 2007	-4.5	-4.0	**-6.9**

^ Values based on ARIMA model
# Property Damage Only
· Statistically significant percentages highlighted in bold

Table 4.4. Parameters of best-fitting sudden permanent change ARIMA models estimating the effect of Florida's GDL system on 16-, 17-, and 18-year olds' crash rates per capita, 1990 – 2009

Age (years)	Model Component	Fatal and Disabling Injury			Non-disabling Injury		
		Parameter (Lag)	**Crash Estimate**	**p**	**Parameter (Lag)**	**Crash Estimate**	**p**
16	6 month learner permit 11pm - 6am driving restriction (age 16) 1am - 5am driving restriction (age 17) Effective July 1996	ω	-.0292	.07	ω	-.0238	.12
	12 month learner permit 50 hour supervised driving Effective October 2000	ω	**-.0555**	**<.01**	ω	**-.0701**	**<.01**
	Control series (25-54 yr-olds)	β	.1123	<.01	β	.1845	<.01
	Gas price	β	-.0006	<.01	β	-.0008	<.01
	Noise (AR or MA component)	MA (1)	.7058	<.01	MA (1)	.6627	<.01
		AR (1)	.7636	<.01	AR (1)	.6893	<.01
		Constant	.6907	<.01	Constant	.9033	<.01
17	6 month learner permit 11pm - 6am driving restriction (age 16) 1am - 5am driving restriction (age 17) Effective July 1997	ω	.0312	.45	ω	.0082	.60
	12 month learner permit 50 hour supervised driving Effective October 2001	ω	**-.0973**	**.03**	ω	**-.0824**	**<.01**
	Control series (25-54 yr-olds)	β	.6027	<.01	β	.3271	<.01
	Gas price	β	-.0012	<.01	β	-.0006	<.01
	Noise (AR or MA component)	AR (12)	.2466	<.01	MA (1)	.4782	<.01
					AR (1)	.5797	<.01
		Constant	1.3922	<.01	Constant	.9066	<.01
18	6 month learner permit 11pm - 6am driving restriction (age 16) 1am - 5am driving restriction (age 17) Effective July 1998	ω	.0298	.39	ω	.0079	.73
	12 month learner permit 50 hour supervised driving Effective October 2002	ω	-.0591	.19	ω	-.0412	.14
	Control series (25-54 yr-olds)	β	.6740	<.01	β	.6134	<.01
	Gas price	β	-.0006	.04	β	-.0005	<.01
	Noise (AR or MA component)	AR (12)	.2287	.01	AR (1)	.1268	.02
					AR (12)	.1035	.02
		Constant	1.2814	<.01	Constant	1.6644	<.01

Statistically significant law is highlighted in bold

Table 4.5. Parameters of best-fitting sudden permanent change ARIMA models estimating the effect of Michigan's GDL system on 16-, 17-, and 18-year olds' crash rates per capita, 1992 – 2009

Age (yrs)	Model Component	Fatal and Disabling Injury			Non-disabling Injury			Possible Injury/ Property Damage Only		
		Parameter (Lag)	Crash Estimate	p	Parameter (Lag)	Crash Estimate	p	Parameter (Lag)	Crash Estimate	p
16	6 month learner permit 20 hour supervised driving 12am - 5am driving restriction Effective April 1997	ω	**-.2429**	**<.01**	ω	**-.0696**	**.01**	ω	**-.2632**	**<.01**
	Control series (25-54 yr-olds)	β	.4804	<.01	β	.4355	<.01	β	.5045	<.01
	Gas price	β	-.0024	<.01	β	-.0004	.01	β	-.0014	<.01
	Noise (AR or MA component)	MA (1)	-.2737	<.01	AR (1)	.3779	<.01	MA (1)	-.5072	<.01
		MA (6)	.2047	.01	AR (12)	.5056	<.01	AR (1)	-.2532	<.01
		AR (12)	.2498	<.01				AR (12)	.4152	<.01
		Constant	1.7077	<.01	Constant	None		Constant	2.1823	<.01
17	6 month learner permit 20 hour supervised driving 12am - 5am driving restriction Effective April 1998	ω	**-.1154**	**.01**	ω	-.0420	.10	ω	**-.0297**	**.01**
	Control series (25-54 yr-olds)	β	.5253	<.01	β	.6705	<.01	β	.7382	<.01
	Gas price	β	-.0009	<.01	β	-.0010	<.01	β	-.0010	<.01
	Noise (AR or MA component)	MA (6)	.2638	<.01	MA (6)	.1620	.02	MA (1)	-.4159	<.01
		AR (12)	.3804	<.01	AR (12)	.3008	<.01	MA (6)	.2316	<.01
								AR (12)	.1666	<.01
		Constant	.9772	<.01	Constant	1.0370	<.01	Constant	1.4053	<.01
18	6 month learner permit 20 hour supervised driving 12am - 5am driving restriction Effective April 1999	ω	-.0022	.94	ω	.0007	.98	ω	**.0356**	**.02**
	Control series (25-54 yr-olds)	β	.4930	<.01	β	.7493	<.01	β	.8062	<.01
	Gas price	β	.0001	.48	β	-.0008	<.01	β	-.0012	<.01
	Noise (AR or MA component)	MA (12)	.4674	<.01	AR (6)	-.1591	<.01	MA (1)	-.3927	<.01
		AR (12)	.6425	<.01	AR (12)	.2565	<.01	MA (6)	.1518	<.05
								MA (12)	-.3866	<.01
								AR (12)	.0749	<.05
		Constant	None		Constant	1.5031	<.01	Constant	1.6785	<.01

Statistically significant law is highlighted in bold

Table 4.6. Parameters of best-fitting sudden permanent change ARIMA models estimating the effect of Maryland's GDL system on 16-, 17-, and 18-year olds' crash rates per capita, 1998 – 2009

Age (yrs)	Model Component	Fatal and Disabling Injury			Non- Disabling Injury			Possible Injury/ Property Damage Only		
		Parameter (Lag)	**Crash Estimate**	**p**	**Parameter (Lag)**	**Crash Estimate**	**p**	**Parameter (Lag)**	**Crash Estimate**	**p**
16	4 month learner permit 40 hour supervised driving Effective July 1999	ω	-.1091	.22	ω	**-.1290**	**.03**	ω	-.0598	.13
	6 month learner permit 60 hour supervised driving No passengers younger than 18 years Effective October 2005	ω	-.1156	.23	ω	**-.3062**	**<.01**	ω	**-.1188**	**<.01**
	Control series (25-54 yr-olds)	β	1.0734	<.01	β	1.2056	<.01	β	.8184	<.01
	Gas price	β	-.0024	<.01	β	-.0015	<.01	β	-.0013	<.01
	Noise (AR or MA component)	AR (1)	.1768	.01				AR (1)	.2847	<.01
		Constant	None		Constant	None		Constant	None	
17	4 month learner permit 40 hour supervised driving Effective July 2000	ω	**-.1551**	**<.01**	ω	-.0030	.94	ω	-.0136	.60
	6 month learner permit 60 hour supervised driving No passengers younger than 18 years Effective October 2006	ω	**-.2935**	**<.01**	ω	-.0979	.06	ω	**-.0910**	**<.01**
	Control series (25-54 yr-olds)	β	.6991	<.01	β	.8207	<.01	β	.8463	<.01
	Gas price	β	-.0011	.01	β	-.0007	.04	β	-.0003	<.01
	Noise (AR or MA component)							MA (1)	-.3223	<.01
								AR (12)	.2884	<.01
		Constant	1.9275	<.01	Constant	1.6375	<.01	Constant	None	
18	4 month learner permit 40 hour supervised driving Effective July 2001	ω	-.0948	.09	ω	-.0127	.63	ω	.0040	.80
	6 month learner permit 60 hour supervised driving No passengers younger than 18 years Effective October 2007	ω	-.0459	.52	ω	-.0404	.27	ω	**-.0720**	**<.01**
	Control series (25-54 yr-olds)	β	.9246	<.01	β	.7409	<.01	β	.6711	<.01
	Gas price	β	.0003	.49	β	-.0001	.55	β	-.0002	.04
	Noise (AR or MA component)	AR (12)	.2956	<.01	MA (1)	.2652	<.01	MA (6)	.3584	<.01
					AR (1)	.4229	<.01	AR (1)	.1691	.01
								AR (12)	.3267	<.01
		Constant	None		Constant	None		Constant	None	

Statistically significant law is highlighted in bold

REFERENCES

Bartels, R. H., J. C. Beatty and B. A. Barsky (1998). An Introduction to Splines for Use in Computer Graphics and Geometric Modelling. San Francisco, CA, Morgan Kaufmann.

Bureau of the Census. U.S. Department of Commerce (1999). 1990 to 1999 annual time series of state population estimates by age and sex: 1990 to 1999.

Bureau of the Census. U.S. Department of Commerce (2010). State single year of age and sex population estimates: 2000 to 2009.

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

Chen, L. H., S. P. Baker and G. Li (2006). "Graduated driver licensing programs and fatal crashes of 16-year-old drivers: A national evaluation." Pediatrics **118**(1): 56-62.

Dee, T. S., D. C. Grabowski and M. A. Morrisey (2005). "Graduated driver licensing and teen traffic fatalities." Journal of Health Economics **24**(3): 571-589.

Florida Department of Highway Safety and Motor Vehicles. (2009). "License Requirements for Teens - Graduated Driver Licensing." Retrieved 3rd March, 2012, from http://www.flhsmv.gov/ddl/teendriv.html.

Foss, R. and A. Goodwin (2003). "Enhancing the effectiveness of graduated driver licensing legislation." Journal of Safety Research **34**(1): 79-84.

Foss, R. D., J. R. Feaganes and E. A. Rodgman (2001). "Initial effects of graduated driver licensing on 16-year-old driver crashes in North Carolina." JAMA: The Journal of the American Medical Association **286**: 1588–1592.

Insurance Institute for Highway Safety. (2006). "Motor Vehicle Registration and Licensed Driver Information." Retrieved 13th September, 2011, from www.iihs.org/laws/comments/pdf/fhwa_ds_atm_030906.pdf.

Insurance Institute for Highway Safety. (2011). "Graduated Driver Licensing." Retrieved 26th May, 2011, from http://www.iihs.org/research/qanda/gdl.html.

Insurance Institute for Highway Safety. (2012). "Effective dates of Graduated Driver Licensing Components." Retrieved 29th February, 2012, from www.iihs.org/laws/pdf/gdl_effective_dates.pdf.

Kirley, B. B., A. Feller, E. Braver and P. Langenberg (2008). "Does the Maryland graduated driver licensing law affect both 16-year-old drivers and those who share the road with them?" Journal of Safety Research **39**(3): 295-301.

Lam, L. T. (2003). "Factors associated with young drivers car crash injury: comparisons among learner, provisional, and full licensees." Accident Analysis & Prevention **35**(6): 913-920.

Males, M. (2007). "California's graduated driver license law: Effect on teenage drivers' deaths through 2005." Journal of Safety Research **38**(6): 651-659.

Maryland Motor Vehicle Administration. (2012). "Rookie Driver Program." Retrieved 3rd March, 2012, from http://www.mva.maryland.gov/Driver-Services/RookieDriver/default.htm.

Masten, S. V. and R. D. Foss (2010). "Long-term effect of the North Carolina graduated driver licensing system on licensed driver crash incidence: A 5-year survival analysis." Accident Analysis & Prevention **42**(6): 1647-1652.

Masten, S. V., R. D. Foss and S. W. Marshall (2011). "Graduated Driver Licensing and Fatal Crashes Involving 16- to 19-Year-Old Drivers." JAMA: The Journal of the American Medical Association **306**(10): 1098-1103.

Masten, S. V. and R. A. Hagge (2004). "Evaluation of California's graduated driver licensing program." Journal of Safety Research **35**(5): 523-535.

Mayhew, D. R., H. M. Simpson, K. Desmond and A. F. Williams (2003). "Specific and Long-Term Effects of Nova Scotia's Graduated Licensing Program." Traffic Injury Prevention **4**(2): 91-97.

McCartt, A. T. and E. R. Teoh (2011). "Strengthening Driver Licensing Systems for Teenaged Drivers." JAMA: The Journal of the American Medical Association **306**(10): 1142-1143.

McCartt, A. T., E. R. Teoh, M. Fields, K. A. Braitman and L. A. Hellinga (2010). "Graduated Licensing Laws and Fatal Crashes of Teenage Drivers: A National Study." Traffic Injury Prevention **11**(3): 240-248.

McCleary, R. and R. A. Hay (1982). Applied time series analysis for the social sciences Beverly Hills, CA, Sage Publications.

McDowall, D., R. McCleary, E. E. Meiringer and A. H. Hay (1980). Interrupted time series analysis. Thousand Oaks, California, Sage Publications.

McKnight, A. J. and A. S. McKnight (2003). "Young novice drivers: careless or clueless?" Accident Analysis & Prevention **35**(6): 921-925.

Michigan Secretary of State. (2012). "Graduated Driver Licensing."   Retrieved 3rd March, 2012, from http://www.michigan.gov/sos/0,4670,7-127-1627_60169_60175---,00.html.

Morrisey, M. A. and D. C. Grabowski (2010). "Gas prices, beer taxes and GDL programmes: effects on auto fatalities among young adults in the US." Applied Economics **43**(25): 3645-3654.

National Highway Traffic Safety Administration (2010). Fatality Analysis Reporting System Washington, D.C, U.S. Department of Transportation.

National Highway Traffic Safety Administration (2010). Traffic Safety Facts 2009: A compilation of motor vehicle crash data from the Fatality Analysis Reporting System and the General Estimates System. Washington, D.C, U.S. Department of Transportation.

National Highway Traffic Safety Administration. U.S. Department of Transportation (1996). Graduated driver licensing system for novice drivers. Washington, DC

Preusser, D. F., S. A. Ferguson and A. F. Williams (1998). "The effect of teenage passengers on the fatal crash risk of teenage drivers." Accident Analysis and Prevention **30**(2): 217-222.

Scientific Computing Associates (2011). Time-series analysis and forecasting software. WorkBench Version 6.2.0.

Shope, J. T. and L. J. Molnar (2004). "Michigan's graduated driver licensing program: Evaluation of the first four years." Journal of Safety Research **35**(3): 337-344.

Shope, J. T., L. J. Molnar, M. R. Elliott and P. F. Waller (2001). "Graduated Driver Licensing in Michigan." JAMA: The Journal of the American Medical Association **286**(13): 1593-1598.

Sivak, M. and B. Schoettle (2010). "Toward Understanding the Recent Large Reductions in U.S. Road Fatalities." Traffic Injury Prevention **11**(6): 561-566.

Tabachnick, B. G. and L. S. Fidell (2007). Using Multivariate Statistics. Boston, Allyn and Bacon.

Trempel, R. E. (2009). Graduated Driver Licensing Laws and Insurance Collision Claim Frequencies of Teenage Drivers. Arlington, VA, Highway Loss Data Institute.

U.S. Energy Information Administration. (2011). "Energy Prices." Total Energy Retrieved 9th September, 2011, from http://205.254.135.24/totalenergy/data/monthly/index.cfm#prices.

Ulmer, R. G., D. F. Preusser, A. F. Williams, S. A. Ferguson and C. M. Farmer (2000). "Effect of Florida's graduated licensing program on the crash rate of teenage drivers." Accident Analysis & Prevention **32**(4): 527-532.

University of Michigan Transportation Research Institute. (2012). "Center for the Management of Information for Safe and Sustainable Transportation." Retrieved 24th March, 2012, from http://www.michigantrafficcrashfacts.org/cmisst/.

VicRoads (2005). Young Driver Safety and Graduated Licensing Discussion Paper.

Williams, A. F. (2003). "Teenage drivers: patterns of risk." Journal of Safety Research **34**: 5–15.

Williams, A. F., S. A. Ferguson and J. K. Wells (2005). "Sixteen-Year-Old Drivers in Fatal Crashes, United States, 2003." Traffic Injury Prevention **6**(3): 202 - 206.

Williams, A. F., W. A. Leaf, B. G. Simons-Morton and J. L. Hartos (2006). "Vehicles driven by teenagers in their first year of licensure." Traffic Inj Prev **7**(1): 23-30.

Williams, A. F. and R. A. Shults (2010). "Graduated Driver Licensing Research, 2007 - Present: A Review and Commentary." Journal of Safety Research **41**(2): 77-84.

CHAPTER 5

CONCLUSION

The aims of this dissertation were to determine the effect of: 1) several components of GDL on 16- and 17-year-old drivers' fatal crashes; and 2) GDL on 18-year-old drivers' injury crash rates and shed light on a possible mechanism responsible for any increase. Chapters 2 and 3 addressed the first aim, and Chapter 4 examined the second aim.

To address the first aim, we used natural experiments in GDL policy implementation, where a single GDL component was independently implemented during the period 1990 through 2009. Using this sample, we estimated the effect of individual GDL components. Previous research examining the effects of individual GDL requirements and restrictions had rarely been designed to account for the confounding effect of simultaneously implemented GDL components; nevertheless, analysis designs assumed independent implementation of each component. To address this lapse, in chapters 2 and 3, interrupted time series analysis was used to examine the effect of each GDL component individually. Interrupted time series analysis is also ideal for examining changes related to isolated events while accounting for long-term trends in teen drivers' crashes. This is another way in which these analyses extended previous studies examining the effect of GDL that had used pre- and post-GDL evaluation designs that were unable to distinguish changes in crashes directly attributable to GDL from differences arising from a preexisting trend.

We observed two GDL components that were independently associated with a decline in 16- and 17-year-old drivers' fatal crash rates: a learner license period that guaranteed a six-month licensing delay and a strong passenger restriction. Supervised driving hours and nighttime driving restrictions associated with a reduction in 16- and 17-year-old drivers' fatal crashes. These findings raise a number of questions regarding how and why certain GDL components appear to affect driving behavior, while others seem not to. There is little question that GDL systems reduce young drivers' crashes, and the deaths and injuries that result (Foss 2002). However, the relative contribution of each components and how they produce a reduction in crashes and fatalities has remained elusive.

Advances in understanding the development of expertise and mastery can be used to shed light on the findings from Chapters 2 and 3. Research suggests that the acquisition of expertise with a complex task, such as driving, is multidimensional (Rikers and Paas 2005). Expertise requires extended time to develop, and demands deliberate practice (Keating and Halpern-Felsher 2008) that is most effective when it is coordinated and focused on sequentially improving one capability at a time (Ericsson 2005). Expertise is best acquired when there is a gradual progression from simple to complex conditions (Gagne and Paradise 1961). A final component of expertise is automaticity. A skill becomes automatic when its related competency has become incorporated into a routine (Keating and Halpern-Felsher 2008).

The architecture of GDL is structured to accommodate the development of expertise. Conceptually, the extended learner license is intended to allow teens to gain practice under very safe conditions over a protracted period of time (Mayhew, Simpson et al. 2003), with the objective of developing basic driving skills. Our finding that the introduction of a six-month learner licensure period that guaranteed licensing delay was followed by a significant reduction in fatal crash rates among 16- and 17-year-old drivers suggests that an extended time period for practice driving may be one of the mechanisms responsible for the effectiveness of GDL.

The supervised driving requirement mandates novice teen drivers to practice during the learner license period. Effortful, deliberate, and guided practice is an important component of expertise acquisition (Ericsson 2006; Keating and Halpern-Felsher 2008). This places the onus on the supervisor to structure driving practice in a productively. In its current form the supervised driving requirement of GDL does not require those who are supervising novice drives to structure the practice in a particular way, nor does it provide any guidelines for driving supervisors, and may explain why we found no significant reduction in fatal crashes following the introduction of supervised driving requirements. Further research is necessary to understand how teens learn to drive and how safe driving can be most effectively taught (Keating and Halpern-Felsher 2008).

As novice drivers progress through each stage of GDL, they experience increasing complexity in the driving environment. Beginning with an extended period of supervised driving, followed by independent driving with restrictions limiting their exposure to the highest risk driving conditions (driving at night or driving with passengers), and finally to driving independently with no restrictions, this progression is consistent with research that suggests expertise is best acquired when there is a gradual progression from simple to complex conditions (Gagne and Paradise 1961). Within this context, specific driving skills are embedded into routines, and become increasingly automatic as teens gain practice. Conceptually, passenger and nighttime driving restrictions should be effective in reducing fatal crash rates among 16- and 17-year-old drivers. The absence of significant reductions in 16- and 17-year-old drivers' fatal crash rates following the introduction of nighttime driving restrictions merits further investigation. As discussed in Chapter 3, the sample used for the evaluation of the nighttime driving restriction was limited to two small states where driving was restricted between the hours of 12 midnight and 6 a.m. The total number of fatal crashes occurring during that time was small, and may have been insufficient to yield statistically significant changes.

Learning to drive safely not only requires the acquisition of specific knowledge and skills needed for driving, but also mature functioning of a broader set of self-regulatory capacities that promote reliable self-control over behavior (Dahl 2008). Emerging evidence indicates that changes in the prefrontal cortex (PFC) of the brain, correspond to changes in decision making, and self-regulatory capacities during adolescence (Keating 2004). Research suggests that on average, adolescents are not cognitively mature enough to fully execute safe driving skills, with particular risks arising from regulatory challenges that occur in complex and distracting contexts (Keating and Halpern-Felsher 2008). Limiting the number of passengers in the vehicle, which represent a source of potential distraction and social influence, the passenger restriction eliminates an element of driving complexity that teen drivers may be ill equipped to handle. This is reflected in our finding that the introduction of a strict passenger restriction was followed by a reduction in 16- and 17-year-old drivers' fatal passenger crashes.

The results of Chapters 2 and 3 indicate that when individual GDL components were examined independently, reductions in 16- and 17-year-old drivers' fatal crashes were modest and in most instances not significant. This is in stark contrast with overall evaluations of GDL that have shown significant reductions in teen drivers' fatal crashes of 20 percent or more (Shope and Molnar 2003; Shope 2007). These findings suggest there may be a non-linear relationship between the number of components in a GDL policy and the degree of reduction in 16- and 17-year-old drivers' fatal crashes, and that GDL exerts its effect operating as a single system rather than as an aggregation of individually effective components. Previous evaluations had assumed the total effect of a GDL program was the cumulative or additive contribution of its individual components

(Chen, Baker et al. 2006; Morrisey, Grabowski et al. 2006; Trempel 2009; Karaca-Mandic and Ridgeway 2010; McCartt and Teoh 2011). In contrast, our findings suggest that while some components show a safety effect when examined in isolation these effects to not sum to equal the overall observed effect of GDL. This supports the conclusion that GDL operates most effectively as a single integrated system.

One mechanism that might explain the differences in crash reductions of comprehensive GDL systems relative to single components is the role of parental involvement in monitoring and enforcing GDL. While differences in the risk perceptions among parents or individual preferences towards components may limit the effectiveness of any single components, a comprehensive GDL program provides parents with more tools at their disposal for teen driver monitoring and management (Simons-Morton and Ouimet 2006).

An alternative explanation for the modest impact of individual GDL components relative to a comprehensive GDL system is the role and influence of driving norms and culture. Risk management literature suggests that the modifications to structures and policies are powerful instruments for cultural and behavioral change (Reason 1998). Through modifying the driving environment and regulating when, and with whom newly-licensed teens drive, GDL may be effectively changing the driving culture among teens (Moeckli and Lee 2007). Any shift in newly-licensed teens' driving culture is likely to be more pronounced following the introduction of a comprehensive GDL system relative to when one of two GDL components are in effect. Further research is necessary to understand the impact of driving culture as a potential mechanism for explaining the non-linear relationship between the number of components in a GDL policy and the degree of reduction in 16- and 17-year-old drivers' fatal crashes.

It should be noted that the study sample for Chapters 2 and 3 was limited to fatal crashes. Some have argued that fatal crashes represent a small subset of all crashes, and the etiology of fatal crashes differs from that of less serious crashes, where high-risk behaviors are more common among drivers involved in fatal crashes (Lam 2003). Future research examining the effect GDL components on teen drivers' crash rates should be extended to include all crash types. While only a limited number of states make crash data available to researchers (National Highway Traffic Safety Administration 2011), these data would allow an examination of the differential effects of GDL on crash severity.

Furthermore, the study sample was constrained to those instances where a single GDL component implemented independently was identified during the period 1990 to 2009. In several instances, the component of interest was the first element of a GDL system to be implemented, allowing us to quantify an independent effect. However, several states had existing GDL components in place when the new component was implemented, introducing the possibility of order effects. For example, in every instance where a passenger restriction was introduced, it was nested within an established GDL system. Similarly, we identified no cases where a nighttime driving restriction was introduced as a standalone restriction. We did not control for order effects, and this may be a potential source of bias in our findings.

Chapter 4 addressed the second aim of the dissertation: to determine the effect of GDL on 18-year-old drivers' crash rates and shed light on a possible mechanism responsible for any increase in crash rates. Using three levels of crash severity as outcomes, we exploited a natural experiment resulting from GDL policy implementation to compare the states where GDL provisions apply exclusively to 15- to 17-year-old drivers (Florida, Michigan) to a state where GDL applies to novice drivers of all ages (Maryland). Prior to this research, evidence of the effect of GDL on 18-year-old drivers' crashes was mixed, and little was understood about the mechanisms responsible for a change in crash rates in this population (Males 2007; Trempel 2009; McCartt, Teoh et al. 2010; Masten, Foss et al. 2011).

We found that the introduction of GDL was followed by a significant increase in possible-injury/property-damage-only crashes among 18-year-old drivers in Michigan (where GDL applies to 16- and 17-year-old drivers) and by a significant decrease in possible-injury/property-damage-only crashes among 18-year-old drivers' rates in Maryland (where GDL applies to novice drivers of all ages). This result established support for the presence of an offset effect, where a proportion of teens are not licensed until age 18, and for these individuals the risk associated with inexperience is delayed and manifests as elevated possible-injury/property-damage-only crashes among 18-year-old drivers.

Beginning drivers of any age go through a learning process in which more errors are made in the early stages than later. In their current form, most GDL systems in the U.S. do not apply beyond the age of 17. Therefore, novice drivers aged 18 years and above are not afforded an opportunity to develop expertise in the safer driving conditions that GDL systems create, and are effectively unprotected from their own inexperience. More research is required to understand the characteristics of teens who choose to be licensed at age 18. Currently, very little is known about the differential effects of GDL by racial or socio-economic group, but some evidence exists that GDL exerts a greater safety effect on certain populations, relative to others. A recent study reported reductions in 15- to 17-year-old drivers' fatal crashes following the introduction of GDL were largest for young White drivers, followed by African-Americans and Asians, however there was no significant reductions in Hispanic drivers' crashes (Romano, Fell et al. 2011). Whether this is due to differing average ages of licensure between racial and ethnic groups is unknown.

Requiring some form of graduated licensing program to be completed by all novice drivers is recommended. Several international jurisdictions necessitate that all novice drivers complete a form of GDL prior to receiving a regular license (Organisation for Economic Co-operation and Development and European Conference of Ministers of Transport 2006; Senserrick 2007); however, further research is necessary to identify the elements that would be required in the U.S. context.

The body of literature examining the effects of GDL has focused on 16- and 17-year-old drivers. This population is distinct from drivers aged 18 years and older on multiple dimensions. For example, GDL requirements that may be relatively straightforward for 16- and 17-year-old drivers to fulfill, such as completing a minimum number of supervised driving hours with a parent, may be more difficult for those aged 18 years or older, who are at a different life stage and may no longer reside with their parents. Maryland's GDL program, which requires an extended learner permit period for all novice drivers, represents one approach that could be considered. This research demonstrated significant reductions in 18-year-old drivers' possible injury/PDO crashes in that state following the introduction of GDL; however, it is unknown whether additional requirements or restrictions would result in the same or a larger crash reduction.

Longitudinal state crash and licensure records that allow the linkage of an individual's crashes with age at licensure and GDL stage would permit the identification of crash types for which drivers who have not completed GDL (i.e., were licensed at age 18 or older) are at greater risk. Comparing 18-year-old drivers' crash involvement between teens who are licensed through GDL and teens in the same state not licensed until age 18 following implementation of GDL, will identify the unique crash risks for novice drivers licensed for the first time at age 18. Based on these data, GDL programs for novice drivers aged 18 years and older could be designed, implemented and evaluated.

As a public health intervention, GDL forgoes efforts to provide specific, detailed training to individuals directly, but exerts its influence through modifying the environment by restructuring of the driver licensing system. The principle of environmental modification is not new to the field of public health or injury prevention, and can be found in the design of motor vehicles and roadways (Hemenway 2009) and beyond the field of road safety, to the prevention of unintentional poisoning through package and label design (Schneider 1977). Unlike changes in engineering and design, GDL modifies the driving environment through redesigning the licensing system to make the initial learning period safer for inexperienced drivers by specifying the conditions wherein that experience can be gained.

Extending the application of this principle to mitigating the elevated crash risk of older drivers has recently been proposed where the licensing environment for drivers above a certain age (e.g., 70 years) could be modified to accommodate declining cognitive and physical capabilities (Redelmeier and Stanbrook 2012). With this approach, a full driver’s license defaults automatically to a restricted license that allows seniors to continue to drive only under relatively favorable driving conditions. Under this system, older drivers’ continued licensure is contingent on demonstrating competency to drive. Moreover, an opt-out rather than opt-in approach to licensing is congruent with existing safety policies for aviators, vaccination programs for children and commercial driver testing.

The goal of this dissertation was to advance the existing body of knowledge of the effect of each GDL component on 16- to 17-year-old drivers’ crashes, and the effect of GDL on 18-year-old drivers’ crashes. A distinctive feature of this research was the use of natural experiments in GDL policy implementation, and an analytical method that controlled for pre-existing trends in crashes. Despite the limitations of a small study sample and subset of crashes, we established that an extended learner license and strict passenger restrictions are associated with declines in 16- and 17-year-old drivers' fatal crashes. Our findings suggest that the effectiveness of GDL programs in reducing crashes may not be due to the individual contribution of each component, but the synergy that results from multiple GDL components operating within a comprehensive GDL program. Furthermore we observed that 18-year-old drivers possible-injury/PDO crash rates increased in Michigan and declined in Maryland, which is consistent with the presence of an 'offset effect' that incorporates the crashes of novice 18-year-old drivers. Requiring novice drivers of all ages to complete some form of graduated licensing is recommended. Further research is required to identify the elements of a GDL program that would be most effective in reducing crashes in this population of new drivers.

REFERENCES

Chen, L. H., S. P. Baker and G. Li (2006). "Graduated driver licensing programs and fatal crashes of 16-year-old drivers: A national evaluation." Pediatrics **118**(1): 56-62.

Dahl, R. E. (2008). "Biological, Developmental, and Neurobehavioral Factors Relevant to Adolescent Driving Risks." American journal of preventive medicine **35**(3, Supplement): S278-S284.

Ericsson, K. A. (2005). "Recent advances in expertise research: a commentary on the contributions to the special issue." Applied Cognitive Psychology **19**(2): 233-241.

Ericsson, K. A. (2006). An introduction to the Cambridge handbook of expertise and expert performance: its development, organization, and content. The Cambridge handbook of expertise and expert performance. K. A. Ericsson, N. Charness, P. J. Feltovich and R. R. Hoffman. New York, Cambridge University Press.

Foss, R. D. (2002). "Graduated Driver Licensing: What Works?" Discussion Paper." Injury Prevention **8, Supplement II**: ii36-ii38.

Gagne, R. M. and N. E. Paradise (1961). "Abilities and learning sets in knowledge acquisition." Psychological Monographs: General and Applied **75**(14): 1-23.

Hemenway, D. (2009). While We Were Sleeping: Success Stories in Injury and Violence Prevention. Berkely, University of California Press.

Karaca-Mandic, P. and G. Ridgeway (2010). "Behavioral impact of graduated driver licensing on teenage driving risk and exposure." Journal of Health Economics **29**(1): 48-61.

Keating, D. P. (2004). Cognitive and brain development. Handbook of adolescent psychology. R. Lerner and L. Steinberg. New York, Wiley

Keating, D. P. and B. L. Halpern-Felsher (2008). "Adolescent Drivers: A Developmental Perspective on Risk, Proficiency, and Safety." American journal of preventive medicine **35**(3, Supplement): S272-S277.

Lam, L. T. (2003). "Factors associated with young drivers car crash injury: comparisons among learner, provisional, and full licensees." Accident Analysis & Prevention **35**(6): 913-920.

Males, M. (2007). "California's graduated driver license law: Effect on teenage drivers' deaths through 2005." Journal of Safety Research **38**(6): 651-659.

Masten, S. V., R. D. Foss and S. W. Marshall (2011). "Graduated Driver Licensing and Fatal Crashes Involving 16- to 19-Year-Old Drivers." JAMA: The Journal of the American Medical Association **306**(10): 1098-1103.

Mayhew, D. R., H. M. Simpson, K. Desmond and A. F. Williams (2003). "Specific and Long-Term Effects of Nova Scotia's Graduated Licensing Program." Traffic Injury Prevention **4**(2): 91-97.

McCartt, A. T. and E. R. Teoh (2011). "Strengthening Driver Licensing Systems for Teenaged Drivers." JAMA: The Journal of the American Medical Association **306**(10): 1142-1143.

McCartt, A. T., E. R. Teoh, M. Fields, K. A. Braitman and L. A. Hellinga (2010). "Graduated Licensing Laws and Fatal Crashes of Teenage Drivers: A National Study." Traffic Injury Prevention **11**(3): 240-248.

Moeckli, J. and J. D. Lee (2007). The making of driving cultures, AAA Foundation for Traffic Safety.

Morrisey, M. A., D. C. Grabowski, T. S. Dee and C. Campbell (2006). "The strength of graduated drivers license programs and fatalities among teen drivers and passengers." Accident Analysis and Prevention **38**(1): 135-141.

National Highway Traffic Safety Administration. (2011). "SDS Overview." Retrieved 12th September, 2011.

Organisation for Economic Co-operation and Development and European Conference of Ministers of Transport (2006). Young Drivers: The Road to Safety. Paris, France.

Reason, J. (1998). "Achieving a safe culture: Theory and practice." Work & Stress **12**(3): 293-306.

Redelmeier, D. A. and M. B. Stanbrook (2012). "Graduated drivers' licences for seniors: reclaiming one benefit of being young." Canadian Medical Association Journal.

Rikers, R. M. J. P. and F. Paas (2005). "Recent advances in expertise research." Applied Cognitive Psychology **19**(2): 145-149.

Romano, E., J. Fell and R. Voas (2011). "The role of race and ethnicity on the effect of graduated driver licensing laws in the United States." Annals of Advances in Automotive Medicine **55**: 51-61.

Schneider, K. C. (1977). "Prevention of Accidental Poisoning Through Package and Label Design." Journal of Consumer Research **4**(2): 67-74.

Senserrick, T. M. (2007). "Recent developments in young driver education, training and licensing in Australia." Journal of Safety Research **38**(2): 237-244.

Shope, J. T. (2007). "Graduated driver licensing: Review of evaluation results since 2002." Journal of Safety Research **38**(2): 165-175.

Shope, J. T. and L. J. Molnar (2003). "Graduated driver licensing in the United States: evaluation results from the early programs." Journal of Safety Research **34**(1): 63-69.

Simons-Morton, B. and M. C. Ouimet (2006). "Parent involvement in novice teen driving: a review of the literature." Injury Prevention **12**(suppl 1): i30-i37.

Trempel, R. E. (2009). Graduated Driver Licensing Laws and Insurance Collision Claim Frequencies of Teenage Drivers. Arlington, VA, Highway Loss Data Institute