Behavioral Impact of Graduated Driver Licensing on

Teenage Driving Risk and Exposure

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Abstract: The literature on teenage driving indicates that teenagers are at elevated risk for motor vehicle crashes. Starting in 1996, states have responded to these concerns by adopting graduated driver licensing (GDL) policies to reduce traffic hazards for teenagers. Previous literature evaluating the impact of graduated driver licensing (GDL) policies has demonstrated their effectiveness on reducing teenage involved fatal crashes. However, much remains unanswered: Why do they work? How do they work? Will the initial effects erode? How might they be improved? The difficulty in answering questions have been due to the unavailability of good estimates of how many teenage drivers are on the roads at any given time, and how that varies with the GDL policies. To fill this gap, we assess whether these policies achieve favorable results by improving teenage driving behavior, or by influencing the amount of teenage driving. We estimate a structural model that separately identifies the amount of teenage driving and the riskiness of teenage driving relying on data from two-car crashes and the information contained in the relative numbers of crashes between two teenagers, two adults versus a teenager and an adult. The relative amount of teenage driving and teenage driving risk are related to the GDL policies as well as other state-year level driving related laws and demographic information using a two-level hierarchical modeling framework. The primary data source is the State Data System, a universe of all police reported accidents (fatal and non-fatal) during 1990-2005 for a select number of states that provide the data. We find that the GDL policies have reduced the number of 15-17 year-old accidents by limiting the amount of teenage driving rather than by improving teenage driving. The most significant reduction in teenage driving is estimated to occur during night time, and in weekends. Stricter GDL policies, especially those with night-time restrictions have been significantly more effective in limiting teenage driving. Our preliminary results indicate that GDL policies do not have a statistically significant long-term impact on improving driving and making teenagers become better drivers.

Key Words: Teenage Driving, Traffic Safety, Graduated Driver Licensing

This research is supported by RO3 HD052547-01 by the National Institute of Child Health and Human Development. We thank Seth Seabury, David Loughran, Paul Heaton, and participants at the University of Minnesota Division of Health Policy and Management work-in-progress seminar for invaluable feedback. We thank Rory Austin of the Department of Transportation for facilitating access to the State Data System and Susan Baker and her co-authors, as well as Thomas Dee and Kitt Carpenter for sharing with us their data on state GDL laws and other driving related state laws. Heidi O'Connor at the University of Minnesota has provided excellent research assistance in preparing the State Data System files.

I. Introduction

…"By reducing the risk exposure of teenage drivers and allowing them time to mature before we give them the keys and unlimited use of the car, we will increase the likelihood that they will safely make it through their early driving years. And by creating safer teen drivers today, we also are helping them become safer, more responsible young adult drivers tomorrow…"[1]

Starting in 1996, states have adopted graduated driver licensing (GDL) policies to reduce traffic hazards for teenagers. These policies introduce three distinct licensing stages and various restrictions for each stage. The first stage is the "learner's permit stage" that requires supervised driving, restrictions on driving at high risk situations (night-time and with teen passengers). It enforces zero tolerance policy for alcohol and for violations by teen drivers who drive without a seat belt. Furthermore, it demands that the driver maintains a clean driving record with no motor vehicle crashes. If the requirements of the first stage are satisfied, the driver advances to the "intermediate license stage" that allows unsupervised driving during daylight hours, but maintains the supervision restriction on night driving with teen passengers. The intermediate stage still enforces the zero tolerance and clean driving record requirements. The final stage is the "full licensure" that removes all the restrictions. Over the last eight years, nearly every state has introduced a GDL policy. However, the GDL policies vary significantly across states in their level of restrictions.

Previous literature evaluating the impact of graduated driver licensing (GDL) policies of the 1990s has demonstrated the policies' effectiveness on reducing teenage involved fatal crashes. However, much remains unanswered: Why do they work? How do they work? Will the initial effects erode? How might they be improved? The difficulty in answering questions above have been due to the unavailability of good estimates of how many teenage drivers are on the roads at any given time, and how that varies with the GDL policies. The Nationwide Personal Transportation Surveys collect self-reported vehicle miles traveled (VMT) data for drivers of all ages but there are two major problems with these surveys. First, the sample sizes are too small to produce reliable geographical estimates for the age group of interest. Second, the surveys are collected only every five years and therefore, the surveys could not capture the variation in the number of drivers due to states' adoption of the GDL policies at any given year.

This paper contributes to the GDL literature by investigating the behavioral impact of GDL policies on teenage driving risk and on the amount of teenage driving separately. We also examine whether states that implement stricter GDL policies achieve more favorable results. Finally we evaluate whether GDL policies have a long term effect. Our estimation is based on a structural model, similar to Levitt and Porter (2001), and relies on data from two-car crashes, and the information contained in the relative numbers of crashes between two teenagers, two adults versus a teenager and an adult. These crash frequencies are modeled as a function of the teenage driving exposure and driving risk, both relative to those of adults. Next the relative amount of teenage driving and teenage driving risk are related to the GDL policies as well as other state-year level driving related laws and demographic information. The model is estimated jointly in a two-level hierarchical modeling framework. The primary data source is the State Data System, a

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[1] From the National Highway Traffic Safety Administration's "Saving Teenage Lives: The Case for Graduated Driver Licensing".

universe of all police reported accidents (fatal, injury and property damage) for 12 states[2] that provide the data. The study period is 1990 to 2005.

We find that the GDL policies have reduced the number of 15-17 year-old accidents by limiting the amount of teenage driving rather than by improving teenage driving. The most significant reduction in teenage driving is estimated to occur during night time, and weekends. Stricter GDL policies, especially those with night-time restrictions have been significantly more effective in limiting teenage driving. Moreover, our preliminary results indicate that GDL policies do not have a statistically significant long-term impact on improving driving and making teenagers become better drivers.

II. Related Literature

The literature on teenage driving indicates that teenagers are at elevated risk for motor vehicle crashes. In 2003, teenagers (ages 13-19) accounted for 10% of the U.S. population, and 13% of motor vehicle crash deaths. In 2001, motor vehicle crashes were the top reason for death among the teenagers. 41% of the female teenage fatalities and 34% of the male teenage fatalities resulted from a motor vehicle crash. [3] Various studies have attributed this increased risk level to factors such that teenagers have little driving experience, tend to drive at riskier times (nighttime), and usually carry other teenage passengers in their car, leading to a distracting environment for the driver.[4]

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[2] Arkansas, California, Florida, Illinois, Maryland, Michigan, Missouri, Montana, New Mexico, Pennsylvania, Virginia, Washington

[3] Insurance Institute for Highway Safety, Fatality Facts, 2003.

[4] Chen, et al (2000), Doherty et al (1998), , Jonah (1986), Jonah and Dawson (1987), Preusser, Ferguson and Williams (1998), Romanowicz and Gebers (1990), Ulmer, Williams and Preusser (1997), Williams (2003)

Over the last 11 years, the states have responded to these concerns by adopting GDL programs, previously implemented in Australia, New Zealand, and several Canadian provinces. These policies consist of three licensing stages: beginner, intermediate, and full licensure. The teen drivers have to satisfy the requirements of each stage to advance to the next stage. The first two stages include requirements on the minimum number of supervised driving, and restrictions on high-risk situations (night-time and with teen passengers). The main motivations of these policies include expanding the learning process, reducing risk exposure, improving driving proficiency and encouraging safe driving.

The National Committee on Uniform Traffic Laws and Ordinances has developed an optimal system based on the suggestions of the Insurance Institute for Highway Safety. This model recommends a minimum age of 16 for acquiring a learner's permit, at least 6 months duration with the permit and 30-50 hours of supervised driving. It suggests that the intermediate stage extend until age 18, and restrict driving starting at 9 pm or 10 pm, while allowing a maximum of one teen passenger. Currently most states have some form of a GDL policy, but there is significant variation in their implementation. Some states have introduced all elements of the suggested model, but some have introduced only a few components. Moreover, states vary in terms of their enforcement. For example, some states do not allow the police to stop young drivers for violating night driving or passenger restrictions.

Studies to date have primarily focused on understanding the impact of GDL policies on outcomes such as teenage fatalities and teenage crash involvement focusing on 15-17 year olds, or 16-year olds. Based on this literature, there is little doubt that GDL reduces young driver crashes as well as deaths and injuries that result. In the United States, earlier studies have examined the effects of GDL policies in a particular state. For example, Ulmer et al (1999) study Florida, Shope et al (2001) study Michigan, and Foss et al (2001) study North Carolina. These three studies report reductions of 9%, 25% and 57% in the crash rates of 16 year-olds respectively. McKnight and Peck (2002) provide an excellent review of GDL related research for specific countries (Sweden, Ontario, Quebec, Nova Scotia, New Zealand) and states (California, Ohio, Connecticut, Florida, Kentucky, Louisiana, Michigan). The general conclusion is that overall crash rates of 16/17 year-olds decline.

More recently, Shope (2007) and Hedlund et al (2006) provide a comprehensive review of studies that evaluate GDL since 2002. The recent studies typically take a more comprehensive and systematic approach. Eisenberg (2003) uses state-by-year panel data between 1982-2000 to mainly study drunk-driving laws, but attributes 4% of the reduction in fatal crash rates involving 16-20 year olds to GDL policies of the states. Dee et al (2005) also use state-by-year panel data from the FARS, and primarily focus on the period of significant adoption of the GDL policies between 1990-2002. They report at least a 5.6% reduction in fatal crash rates involving 15-17 year olds, and note that larger crash reductions were achieved in states with more restrictive policies. Chen et al (2006) rely on the same data and find approximately 20% reduction in the 16-year-old drivers' fatal crash involvement rates in states with comprehensive GDL policies. Morrisey et al (2006) apply the same data and framework to rural areas and report 8% reduction in teenage fatalities among 15-17 year olds on rural roads. Baker et al (2007) study injury crashes as well as fatal crashes and find 11% reduction in fatal crash involvement, and

19% reduction in injury crash involvement of 16-year olds. Reductions reach up to 40% for both fatal and injury crashes in states with stricter GDL policies. Morrisey et al (2006) differentially study the GDL impact on the number of teenage fatalities in crashes that occur at night-time as well as in crashes with passengers present. Their results suggest a reduction in night-time fatalities 10-12%, but this finding has weak statistical power. Restrictions of GDL policies on the number of passengers do not seem to have a strong impact on reducing the number of teen driver fatalities, but they reduce the number of passenger fatalities.

The common limitation of all the previous literature is the limited evidence they provide on how these reductions are achieved. In particular these studies do not effectively control for the GDL's behavioral effect on the number of teenagers on the road. It is possible that GDL policies limit the amount of teenage driving by imposing minimum age requirements into the learner's phase, by restricting night-time driving and/or driving with passengers. On the other hand, they may increase the amount of teenagers on the road by increasing the required number of supervised and unsupervised hours driven in learner and intermediate stages. Similarly, the presence of GDL policies might signal safer driving environment and parents might look more favorably to allowing their teens become younger drivers and take on the road more frequently. If GDL policies are very effective in limiting the amount of teenage driving, then observed reductions in teenage involved crashes may be simply due to this behavioral change rather than any improvement in teenage driving skills and driving risk. On the other hand, if GDL policies increase the amount of teenagers on the road, the observed crash reductions could be due to even larger reductions in teenage driving risk.

Most studies tackle the relative reduction in teenage driving rate by using indices such as "per licensed driver" and "per capita". For example, they find that per capita crash rates decline up to 30% for 16 year olds, and half or more of this figure results from decreases in the proportion of drivers who are licensed since the length of the learner stage is increased. However, per-capita rates and licensed drivers are not good measures. The 16-17 year old population does not change significantly within a state, making it difficult to interpret the effectiveness of the GDL policy using within state variation in the adoption of GDL policy. The annual number of young licensed drivers is not ideal either since before GDL, there were only two types of licenses (permit or full license), while after GDL, there are different license types one can have, and people change these license types by month.[5]

III. GDL Policies in the U.S.

Currently most states have some form of a GDL policy, but there is significant variation in their implementation. Baker et al (2007) dichotomize the main components of the GDL policies similar to suggestions of the Insurance Institute for Highway Safety (IIHS). The IIHS tracks GDL policies in the U.S. since 1996, and list detailed descriptions. We obtained the data on state GDL laws from Baker et al (2007)[6] who have verified the data with the state government web sites and made editions to reflect changes in GDL programs. Table 1 lists these important components and presents variation across state-year observations regarding the characteristics of the GDL policies for all states

[5] Foss R.D. (2002): Discussion paper for Mcknight and Peck (2002)

[6] Data on state GDL laws were compiled by Drs. Susan P. Baker, Li-Hui Chen, Ghohua Li, of the Johns Hopkins Bloomberg School of Public Health, in a project funded by the AAA Foundation, and were provided by the AAA Foundation for Traffic Safety.

(column 1) and for the 12 states used in the analysis (column 2). In all states, only 12% of the policies require a minimum age of 16 for obtaining a learner's permit, but most of them (76%) require at least 6 months of holding the learner permit before being able to advance to the intermediate stage. About half of the GDL policies (55%) require at least 30 hours of supervised driving during the learner stage. In the intermediate stage, only 17% of the policies put a curfew on driving after 10 pm at night, while 89% have some form of night-time driving restriction (for example after midnight). About 40% restrict driving in the presence of more than one teenage passenger. The variation in the 12 states used in the analysis is similar to the U.S.-wide variation, more restrictive in some aspects such as minimum holding periods and required supervised driving, while less restrictive in some others such as curfew after 10 pm and passenger restrictions.

The Insurance Institute of Highway Safety (IIHS) rates each state as "Good", "Fair", "Marginal", or "Poor" based on their licensing system. All states with an intermediate licensing stage are rated at least "Marginal". Table 2 lists the IIHS criteria for its ratings. Following this scoring system together with the annually updated components of the GDL policies presented in Table 1, we constructed scores and ratings for each of the state-year observations. Figure 1 presents the number of states with each rating over time across the U.S. As the figure shows, adoption of GDL policies dramatically increases over time. While more states implement "Fair" GDL policies than "Good" policies for all years, the number of states with "Marginal" GDL policies decreases over time, suggesting that states move toward stricter policies. By 2005, all states except for six

(Arizona, Kansas, Kentucky, Montana, North Dakota and Oklahoma) have implemented a GDL policy.[7]

IV. Benchmark Model and Methodology

IV.2. Overview

The primary structural parameters of interest are the relative crash risks and the relative exposure between two age groups: teens and adults. We adopt a methodology similar to Levitt and Porter (2001) application on identifying the risks posed by drunk drivers separately from the number of drunk drivers on the road using data on fatal crashes. The identification relies on two-car crashes, and the information contained in the relative counts of teen/teen, teen/adult, and adult/adult crashes. There are only certain relative risks and exposures that would make a particular collection of crash counts plausible. If many of the accidents involve teen/teen collisions then either the teen relative risk is high or there are many teens on the road relative to adults. The counts of teen/adult and adult/adult crashes can be used to identify how much the number of teen/teen crashes depends on risk and how much depends on exposure.

Let *I* be an indicator that equals one if two cars interact with the potential for a crash to occur and zero otherwise. For any two drivers of type *i* and *j*, Levitt and Porter assume that drivers are equally mixing on the road so that the number of interactions of a driver's interaction with other drivers is independent of the driver's type. Specifically,

$$\Pr(i, j \setminus I = 1) = \Pr(i \setminus I = 1)\Pr(j \setminus I = 1)$$

[7] Our analysis excludes Hawaii, Washington D.C., and Alaska as do other studies in this field.

where $\Pr(i \setminus I = 1) = \frac{N_i}{N_{Total}}$ with N_i denoting the number of drivers of type i on the road, and N_{Total} denoting the sum of drivers of all types on the road.

Equal mixing requires that there is no "clumping" of drivers in space or time; it will be violated if, for example, adult drivers are more likely to interact with other adult drivers for each mile driven, perhaps because they frequent the same locations or drive at the same times of day. The equal mixing assumption is likely valid for a fine enough partition of space and time but will be violated if clumping occurs as the level of aggregation increases. We conduct analyses to investigate the sensitivity of our results to this assumption.

Let θ_T and θ_A represent the probabilities that a teen and an adult driver causes a two-car accident respectively. The probability of a crash (C) given that two cars interact with the potential for a crash is $P(C=1|I=1, i, j) = \theta_i + \theta_j - \theta_i\theta_j$. Since possibility that both drivers cause an accident is small, the product $\theta_i\theta_j$ can be dropped. From this probability calculation and the equal mixing assumption we can construct a multinomial likelihood for the counts of teen/teen accidents, teen/adult accidents, and adult/adult accidents. While neither the individual accident rates, θ_T and θ_A, nor the rates of driving exposure, N_T and N_A, are identifiable, Levitt and Porter (2001) show that the relative accident rate, $\theta = \frac{\theta_T}{\theta_A}$, and the relative exposure, $N = \frac{N_T}{N_A}$, are identifiable from just the two car accident data yielding the likelihood in (1)

$$(C_{TT}, C_{TA}, C_{AA}) \sim \text{Multinomial}\left(N_T, \left[\frac{N^2\theta}{1+N(1+\theta)+N^2\theta}, \frac{N(1+\theta)}{1+N(1+\theta)+N^2\theta}, \frac{1}{1+N(1+\theta)+N^2\theta}\right]\right) \quad (1)$$

where C_{ij} are the observed counts of each of the three types of accidents: between two teenage drivers, a teenage and an adult driver, and two adult drivers respectively. [8]

IV.3. Evaluating the Impact of GDL Policies

In principle, for each state by year, one could estimate the relative accident rate, θ, and relative exposure, N, using the method described above. Next, these estimates could be used as dependent variables and regressed on state GDL policies as well as other state-year varying covariates. Levitt and Porter use this two-stage analysis to assess the impact of alcohol policies on drunk driving, although they do account for the potential measurement error on the estimated dependent variables. If the measurement on the left-hand-side variable has a common variance across all observations, this correction would not be necessary, but since θ and N are estimated for each state-year pair based on a different number of crash observations, the variance of the measurement error potentially varies by state-year.

We instead take a joint-estimation approach that is not subject to the problem mentioned above, and is also more efficient. In particular, we construct a hierarchical model building off of the likelihood in (1) with second level regression models of the form

[8] Levitt and Porter (2001) provide details of the crash probabilities.

$$\log(\theta_{s,t}) = \mathrm{GDL}_{s,t}\gamma^{(\theta)} + X_{s,t}\beta^{(\theta)} + \eta_t^{(\theta)} + \alpha_s^{(\theta)} \qquad (2)$$

$$\log(N_{s,t}) = \mathrm{GDL}_{s,t}\gamma^{(p)} + X_{s,t}\beta^{(p)} + \eta_t^{(p)} + \alpha_s^{(p)} \qquad (3)$$

In (2) and (3), $\mathrm{GDL}_{s,t}$ represents the presence of a GDL policy and its characteristics depending on the specification. The $X_{s,t}$ represents state specific characteristics that vary over time such as the presence of other driving related policies and other macro level variables such as the share of teenage population. The η_t and α_s represent year and state fixed effects to control for time specific and state specific factors unobserved to the researcher. Following Bertrand et al. (2004), we cluster standard errors at the state level to account for the potential presence of serial correlation.

We use the logarithmic link since we believe that the factors on the right side of the equations likely have multiplicative effects on the relative risks and relative exposures. We estimate (1), (2) and (3) jointly using maximum likelihood estimation in a hierarchical set-up.

For notational ease, equations (2) and (3) specify the unit of observation to be a state-year pair. In practice, our benchmark models expand this framework and allow for θ to vary by state-year-night-time as well as by state-year-night-time and weekend. Similarly, the unit of variation for N is specified to be state-year-hour-weekend.

IV.3. Data

We extracted data on the number of two-vehicle crashes by driver type-combinations - two teens, a teen and an adult and two adults- from the State Data System(SDS), 1990-2005 for each state, year, hour and weekend/weekday observations. Unfortunately not all states report on the State Data System, and some that do report do not make the data available for research use. Of the 22 states that make the data available, 12 states responded favorably to our data request. Table 3 reports data availability and GDL adoption of the 12 states used in the analysis.

We define teen drivers as those between ages 15-17 (age cohorts directly impacted by GDL policies), and adult drivers as those older than 18. The SDS data is very similar to the Fatal Analysis Reporting System (FARS) data used extensively by previous research on traffic safety. It provides information on all persons involved in a police reported crash (age, gender, etc) as well as detailed information on the crash (location, time, road type, road conditions, number of vehicles involved etc) and on all the vehicles involved (make, model, year).

The FARS data seems advantageous as it is available for all states. However, FARS reports only fatal crashes and thus does neither have the sufficient sample size for accidents between two teen drivers 15-17, nor for accidents between a 15-17 year-old and a driver older than 18. Since our identification heavily relies on the differences of such interactions across driver types, we have decided to use the SDS data despite the fewer number of states.[9]

We use three different characterizations of the GDL policy. First, we use a binary variable indicating the presence of a GDL policy at a given year and state. Second, we examine GDL policies with night-time restrictions and those with no night-time restrictions. Third, we distinguish GDL policies based on the IIHS rating as discussed earlier. In each case, we allow the GDL effect to vary either by state-year-night, and or

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[9] Levitt and Porter (2001) provide details of the need for sufficient number of observations of each crash type for estimation purposes.

by state-year-night-weekend for the relative teen crash risk θ. The relative number of teens on the road, N, is allowed to vary by state, year, hour, and weekend.

As state specific controls in the estimation of (2) and (3), we use a set of variables related to the presence of additional driving-related state policies for each year. Similar to Dee (2002), Eisenberg (2003), and Dee et al (2005), we use binary variables that indicate whether it is illegal per se to drive with a blood alcohol concentration of 0.08 ; whether the state has a “zero-tolerance” law[10] and whether there is a license revocation policy.

Table 4 reports summary statistics of the crashes by crash type as well as other state laws by state-year observations. On average SDS states have 99,000 two-car crashes annually, and about 10% of these crashes occur at night-time (between 9 pm-5 am), and a third of the night-time crashes occur during the weekend. Fatal crashes make up about 0.4% of total crashes while injury crashes constitute 27% and property damage accidents account for the majority with 67%. [11]

Among all two-car accidents, 88,320 (89%) involve two adult drivers, 10,074 (10%) involve one-teen and one adult driver, and about 714 (1%) involve two teen drivers. This suggests that overall 11% of the two car accidents involve at least one teenage driver between ages 15-17. If we restrain the analysis to fatal crashes, only 1 crash in a state-year observation on average involves two teen drivers, and 33 involve a teen and an adult, highlighting the argument earlier on why we chose to estimate the model using all crashes in SDS instead of just relying on fatal crashes provided in FARS.

[10] Zero tolerance laws make it illegal to drive with a positive BAC if the driver is under legal drinking age.

[11] Other injury severity types not reported here include “potential injury”, “complaint of pain”, “no visible injury”, “unknown injury” etc.

Overall, majority of SDS states have other driving related laws that may influence relative teenage driving risk and prevalence. 78% of the observations have a license revocation law, 54% have a BAC under 0.08 policy, and 74% have zero tolerance laws.

V. Results

We start with a reduced form investigation of the relationship between the number of accidents with teenage involvement and the GDL policies. Table 5 presents negative binomial regression of the number of two-car crashes with at least one teen driver on GDL policies, and GDL policy interactions with night-time observations. The specifications also control for other driving related laws, teenage population, indicators for weekend, weekend and night-time observations, hour fixed effects, year fixed effects and state fixed effects. The first specification in Table 5 characterizes the presence of the GDL policy with a binary variable, while the second specification specifies indicator variables for good, marginal and fair GDL policies with the reference category of no GDL policy. Both specifications allow for GDL's effect to differ in day-time versus night-time observations with night-time defined as between 9 pm-5 am. Panel (A) reports coefficient estimates while Panel (B) reports coefficient estimates for GDL interactions with night-time observations and presents Wald tests. The results in both specifications indicate that GDL does not have a statistically significant effect on teenage involvement in accidents that occur during the day-time, but significantly reduces teenage involvement in night-time observations. On average, presence of a GDL policy reduces number of night-time two-car accidents with at least one teen driver by 14%, while GDL policies that are rated "Good" result in a corresponding reduction of 32%.

Having illustrated that GDL policies are influential in reducing teen involvement in accidents, at least significantly during the night-time, we move on to our primary question: are such reductions due to GDL's impact on improved teen driving, or its impact on limited teenage driving? Table 6 presents three different models that estimate parameters of slightly modified equations (2) and (3), the "risk equation" and the "prevalence equation" respectively. In the risk equation, the dependent variable can be viewed as $\log(\theta)$, teens' likelihood of causing an accident relative to adults. The prevalence equation specifies the number of teens on the road relative to adults, $\log(N)$, as the dependent variable. As discussed earlier, these two equations are estimated simultaneously embedded in a hierarchical maximum likelihood framework which specifies probabilities of observing crashes by two teens, one teen and an adult and two adults.

The first model includes a binary indicator to represent the presence of GDL policy, and allows for its differential effect by day-time and night-time. The first column in the first specification, (1a), presents estimates of the risk equation, and suggests no statistically significant impact of GDL on relative teenage driving behavior. The second column (1b) corresponds to the prevalence equation and the coefficient on GDL represents a 5% statistically significant reduction in the relative number of teens during day-time observations. Panel (B) at the bottom of the table presents GDL's impact on night-time observations, wherein we add the coefficient on GDL and the coefficient on GDL's interaction with night-time. We find a 16% reduction in the relative number of teens on the road during night time with a p-value of 0.

The second model identifies different effects of GDL policies with night-time restrictions versus those with no night-time restrictions. As we showed that GDL's primary influence is on teen prevalence during night-time, we should expect to see a stronger reduction in the number of teens during night-time in states with GDL policies that restrict night-time driving. As column (2b) outlines, GDL policies with no night-time restrictions do not influence the relative number of teens on the road, neither during day-time nor during night-time. GDL policies with night-time restrictions, on the other hand, reduce relative teen prevalence during day-time by 5% and during night-time by 16%. The 5% reduction during day-time is most likely due to the fact that GDL policies with night-time restrictions tend to be more restrictive policies in general. The finding that such policies reduce night-time driving by even more supports the hypothesis that night-time restrictions by themselves play an important role. As before, neither the policies with night-time restrictions nor those without them have any impact on relative teenage risk.

The third model differentiates GDL policies by their IIHS rating and identifies the impact of good, fair, and marginal policies relative to the reference category of no GDL policy. This model also allows for different impact during day-time and night-time. Regardless of the policy's rating, we find no influence on the relative teen prevalence of GDL during day-time. However, during night-time, the good GDL policies reduce relative teen prevalence by 56% (with the p-value 0.03), the fair GDL policies reduce it by 13% (with the p-value 0.06), and the marginal GDL policies have no statistically significant effect. Again, we find no statistically significant effect of any kind of GDL policies on relative teenage risk, neither during day-time nor during night-time.

Table 7 repeats the same analysis as Table 6, except the models differentiate the GDL effect by weekend and night-time observations together. Qualitatively and quantitatively the results are consistent with those reported in Table 6, with only slightly larger magnitudes of the GDL effects. For example, good and fair GDL policies reduce relative teenage prevalence by 59% and 13%.

We also investigated whether certain types of accidents were driving the results. We repeated our analysis in Table 6 for non-fatal crashes (property damage, injury andother) and for property damage-only crashes separately. Table 8 reports these results: for both types of crashes, we obtain results consistent with those across all accident types, shown in Table 6. This suggests that neither type of crashes dominates the average effects we find. The relatively small sample size of fatal crashes and of injury-only crashes (in particular with regards to accidents that involve two teenage drivers) limited our ability to separately analyze such types of crashes.

V.1. Robustness Analysis

In this section, we present our robustness analyses. The first approach assesses the sensitivity of our results to a critical assumption of our model. The second approach conducts a counterfactual exercise to test the validity of our specifications.

V.1.1 Equal Mixing Assumption

In the heart of our model is an assumption that drivers are equally mixing on the road so that there is no “clumping” of drivers in space or time. As discussed earlier, it will be violated if, for example, adult drivers are more likely to interact with other adult drivers for each mile driven, perhaps because they frequent the same locations or drive at the same times of day. The equal mixing assumption is likely valid for a fine enough partition of space and time but will be violated if clumping occurs as the level of aggregation increases. Our benchmark specification's unit of observation is a state-year-hour-weekend, which we believe to be a small enough partition of space and time.

We conduct a sensitivity analysis to assess whether our results are sensitive to different units of observation. In particular, we repeat our joint estimation of (1), (2) and (3) allowing for different restrictions on the units of observation over which "equal-mixing" is imposed. We consider state-year-night-weekend, and state-year-night as alternative units of observations. For example, state-year-night-weekend assumes equal mixing only within a given state-year pair, night and weekend status. Formally, we restrict the relative crash risk θ to be the same for a given state-year-night observation, but we allow the relative exposure N to vary by state-year-night-weekend.

Table 9 reports our original estimation that differentiates GDL by its IIHS rating allowing N to vary by state-year-hour-weekend (our original specification) as well as the two new specifications that use a different unit of observation. Estimates are very similar across the board with GDL policies having no impact on relative teenage risk, and good GDL policies reducing the night-time relative teen prevalence by 53%-56%, and fair GDL policies reducing it by 13%-16%. The new specification that varies the unit of observation by state-year and night is the most restrictive, while our original specification with variation across state-year-hour-weekend is the least restrictive. The similarity in estimates between these two specifications increase our confidence that further relaxing the assumption from our original specification will likely not lead to significantly different findings.

V.1.2 Counterfactual Analyses

As mentioned earlier, our benchmark specifications classify teen drivers as those between ages 15-17 (age cohorts directly impacted by GDL policies), and adult drivers as those older than 18. We conduct counterfactual analyses defining the younger age group broader, as those between ages 15-19, which includes 18 and 19 years-olds not subject to the restrictions of the GDL policies in a given state-year pair.

Our benchmark specifications have consistently shown a reduction in relative teen prevalence during night-time, especially in states with stronger GDL policies, and those with GDL policies that restrict night-time driving. By defining the teen drivers as those between ages 15-19, we test whether our specifications predict an equal sized GDL effect on relative teen prevalence at night-time although they should predict a smaller effect.

Table 10 compares our benchmark model with the alternative. In both specifications, GDL has no effect on relative teen risk. Moreover, we observe that the magnitude of GDL effect on teen prevalence during night-time reduces significantly in the second specification that uses a broader definition of teens. In particular, good GDL policies reduce night-time relative teens on the road by 12% while fair GDL policies reduce it by 5%. Corresponding declines in the original specification are 56% and 13% respectively.

V.1.2 Dynamics

We have shown that GDL policies do not have significant influence in on the driving risk of the teenagers between ages 15-17, but rather achieve observed reductions in teen accidents and fatalities through restricting the amount of teenage driving, especially at night-time. A very interesting question then is whether driving under GDL restrictions results in a cohort of drivers that have reduced risks in the future although the effects during the very teen years might not be large.

Another side of the token is a question proposed by Dee et al (2005) - whether the GDL regulations shift risky driving to older teens by disallowing them to mature through risky behavior while they are 15-17. They focus on 18-20 year olds and for each state-year pair, they estimate whether the presence of a GDL policy three years prior has a negative impact on the traffic fatalities of this age cohort. They find a negative, but statistically insignificant effect, and conclude that such issues should be revisited in the future when more GDL constrained cohorts advance to full licensure, and additional FARS data become available.

We are currently conducting analyses to understand the long-run effects of GDL restrictions by replicating Dee et al (2005) approach above while separately identifying the impact on risk exposure and on crash risk instead of on total traffic fatalities (results not reported in this draft). In particular, for each 18-20 year old cohort in a given state-year pair, the GDL covariate vector in (2) and (3) consists of a binary variable indicating the presence of a GDL policy three years prior.

For example, within a state that adopts GDL in 1998, we are essentially comparing the crash risks of 18-20 olds in 1998 with the crash risks of 18-20 year olds in 2002 where the former group was definitely not exposed to GDL, but the latter was definitely exposed.[12]Across two states, one with GDL in 1998 and one without it, we would be comparing the crash risks of 18-20 year olds in 2002 to examine whether the state with

[12] 20 year olds in 2002 were 16, and thus subject to GDL implemented in 1998.

the GDL has lower 18-20 year old crash risk after controlling for observable differences across states.

A more refined approach could compare an age group that barely missed being subject to GDL to another age group that was the first cohort to be subject to GDL. In each state with a GDL policy, we could follow a cohort of drivers defined by the implementation date of the GDL. For example, California implemented a program in 1998. As a result drivers who had turned 16 in 1997 likely had already been fully licensed by 1998, while those youths turning 16 in 1998 were subject to GDL restrictions. By 2002, both groups have unrestricted licenses, differ by only one year of driving experience, are at similar stages in life, with the exception that the 20 year-olds were exposed to GDL restrictions for up to two years while the 21 year-olds were not. We continue this comparison in 2003-2005 to determine whether the GDL exposure has long-term effects on accident risks.

One procedure would be to use the data only for the defined cohort, compute maximum likelihood estimates from (1) and test whether $\theta_{s,t}$ differs from 1.0. The power of this test would be limited since it depends on having a large number of crashes involving 20- and 21-year-olds. To increase the power we could compute $\theta_{s,t}$ comparing 20 year-olds to 22 and older and also compute $\theta_{s,t}$ comparing 21 year-olds to 22 and older. For both 20- and 21-year-olds we could compute the risks relative to a common group, but having the larger reference group increases the sample size of crashes. We will investigate the feasibility of implementing this refined approach with our data availability.

Our preliminary investigation of this question of long-term GDL effects uses a reduced form approach. In particular, we limit our sample to all crashes by 18-25 year-olds, and identify the number of drivers that were exposed to a GDL policy when they were between ages 15-17. For example, a 20 year-old driver who gets involved in an accident in California in 2004 was 16 years-old in 2000, after California's adoption of the GDL in 1998, and thus was exposed to GDL. On the other hand, a 25 year old driver in an accident in California the same year would be 19 years-old in 1998, and thus not subject to GDL when s/he was younger. Similarly, for each state-year pair, we identify the population of 18-25 year-olds that were subject to GDL. For example if GDL was passed in 1998, and we are examining the accidents in 1998, none of the 18-25 year-old population would be exposed to GDL. If, on the other hand, we are examining the accidents in 2000, 18 and 19 year-olds in 2000 would have been exposed to GDL as they were 16 and 17 respectively when the GDL passed.

Table 11 presents two separate models that relate accident rate of 18-25 year-olds to their propensity to be exposed to GDL when they were younger. The first model estimates

$$\frac{\#\,Accidents_{st}^{18-25}}{Population_{st}^{18-25}} = \lambda \frac{\#\,Exposed\_to\_GDL^{18-25}}{Population_{st}^{18-25}} + \beta X_{st} + \eta_{st} + \alpha_{st} + \varepsilon_{st}$$

where the dependent variable is the accident rate of 18-25 year old drivers (normalized by the population of 18-25 year-olds in the state-year pair), and the key regressor is the share of 18-25 year-old population that is exposed to GDL. If GDL exposure improves driving, total accident rates of the 18-25 year-olds should decrease as more of them are exposed to GDL. Other regressors include other driving regulations, state and year fixed effects. As

Table 10, column (1) presents, we do not find a statistically significant association between GDL exposure rate and accident rate of this population.

We take an additional step to exploit the information on the number of accidents caused by the GDL exposed versus not. For each state-year pair, we construct two cohorts: one corresponding to the GDL exposed and the other to the unexposed 18-25 year-olds. We estimate

$$\frac{\#\,Accidents_{st,GDL\_Exposed}^{18-25}}{Population_{st,GDL\_Exposed}^{18-25}} = \lambda GDL\_Exposed_{st} + \beta X_{st} + \eta_{st} + \alpha_{st} + \varepsilon_{st}$$

where $GDL\_Exposed_{st}$ is a binary indicator for whether the observation corresponds to the GDL exposed cohort for state s and year y. Some state-year pairs may have only an exposed or an unexposed cohort. For example, Florida adopted GDL in 1996, and thus all drivers between ages 18-25 in Florida during 2004 have been exposed to GDL. Similarly, for all state-year observations pre-GDL adoption years, we only observe the GDL-unexposed population. Column (2) in Table 11 estimates the equation above and finds that the GDL exposed population has a lower accident rate, but this effect is not statistically significant.

However, as we mentioned, these are only preliminary findings, and the findings may be subject to bias due to our clumping of a very heterogeneous mix of ages 18 to 25 year-old together. A more precise approach that we will pursue would be to separately investigate GDL exposure effects on ages 18-20, 21-23, 24-25 and so on.

VI. Conclusion

This paper investigated the causal mechanisms through which state GDL policies have been achieving favorable results in reducing accident rates and fatalities of 15-17 year old novice drivers. In particular, we have focused on whether GDL policies reduce relative teenage driving risk, or relative teenage driving prevalence. Using a structural model, we find that the latter is primarily responsible for reducing the observed number of teen crashes. The reductions in relative teenage prevalence are estimated to primarily occur during night-time, due to restrictiveness of the GDL policies during night-time driving. More restrictive GDL policies and those with night-time restrictions achieve greater reductions in teen driving prevalence during the night. We also conducted some preliminary analyses to investigate whether the GDL exposed teens become better drivers in the future. Reduced form regression analyses did not provide any evidence of a significant relationship between exposure to GDL when 15-17 year-old and probability of getting involved in an accident when 18-25 year-old. However, much remains to be done to investigate this question further.

There are many states that have not yet adopted GDL policies with strict night-time or passenger restrictions. Our findings make a case for more restrictive GDL policies for 15-17 year-old drivers. Our research also points out the need for re-thinking how GDL policies can be improved to have an impact on better teenage driving.

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Table 1: Variation in Components of GDL policies, Conditional on GDL presence

		All States	12-States used in the analysis
Learner Stage			
	Minimum Age of 16	12%	9%
	Minimum Holding Period of 6 months	76%	82%
	Minimum 30 Hours of Supervised Driving	55%	69%
Intermediate Stage			
	Minimum Age of 16.5	11%	9%
	No unsupervised driving after 10 pm	17%	0%
	Any restriction on unsupervised driving	89%	91%
	No unsupervised driving with >1 passenger <20	40%	36%
Final Stage			
	Minimum Age of 17	69%	79%

Table 2: IIHS Criteria for Ranking GDL policies

	Components	IIHS points
Learner's Entry Age		
	minimum age of 16	1
Learner's Holding Period		
	min. 6 months	2
	3-5 months	1
	less than 3 months	0
Practice Driving Certification		
	min. 30 hours	1
Night Driving Restriction		
	not allowed after 9 pm	2
	not allowed after 10 pm	1
Passenger Restriction		
	1 or less underage passanger	2
	1-2 passengers	2
	3 passengers or more	0
Duration of Restrictions		
	min. unrestricted license age minus the min. intermediate license age is more than 12 months	1

Good systems score at least 6 points; **Fair** systems 4-5 points; **Marginal** systems 2-3 points; **Poor** Systems <2 points

Figure 1: GDL Policies and Ratings across the U.S.

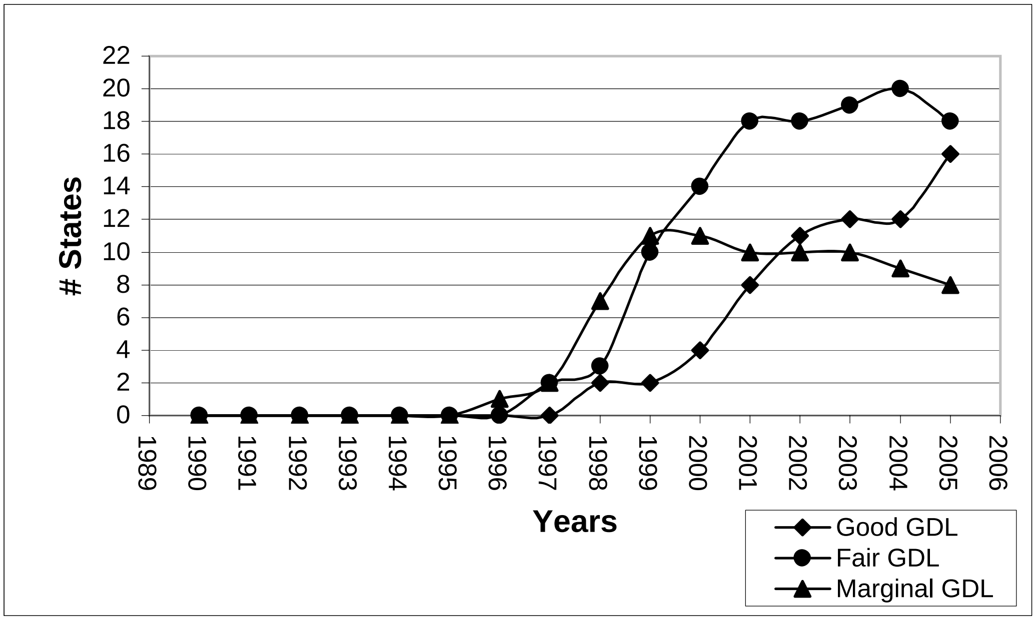

Table 3: GDL Policies and Data availability for the 12 states used in the analysis

States	Years of Data Availability	Year of GDL Adoption	IIHS Ranking	Notes
AR	1998-2005	2002	Marginal	
CA	1991-2004	1998	Good	
FL	1991-2004	1996	Marginal	in 2000 changed to Fair
IL	1991-2003	1998	Marginal	
MD	1991-2005	1999	Marginal	in 2005 changed to Good
MI	1991-2005	1997	Fair	
MO	1991-2005	2001	Marginal	
MT	1994-2005	no GDL until 2005		adopted GDL in 2006
NM	1990-2005	2000	Good	
PA	1991-2005	1999	Fair	
VA	1991-2004	1999	Fair	in 2001 changed to Good
WA	1999-2005	2001	Good	

Notes:

1. Illinois, 1996 is not used in the analysis since it contains only "state maintained road crashes" (page B-2 of user manual)

2. Washington 1999-2000 are not used in the analysis since they contain only "state route crashes" (page 4 of user manual)

Table 4: Summary Statistics for State-Year Observations

		Mean	Std. Dev.	Min	Max
Total Two-Car Crashes					
	All	99109	71882	8835	270693
	Night-time	9928	7123	651	25736
	Night and Weekend	3630	2637	232	9372
	Fatal	417	321	42	1201
	Injury	26912	14279	954	53652
	Property Damage-Only	66638	51090	7687	190581
	Two Teen Drivers	714	545	84	2098
	A Teen and an Adult Driver	10074	6903	1585	24898
	Two Adult Drivers	88320	65085	6878	250105
	Fatal, Two Teen Drivers	1	1	0	7
	Fatal, A Teen and an Adult Driver	33	23	2	102
	Fatal, Two Adult Drivers	383	299	36	1127
Other State Driving Laws					
	License Revocation Law	0.78	0.41	0.00	1.00
	BAC 0.08 Law	0.54	0.50	0.00	1.00
	Zero Tolerance Law	0.74	0.43	0.00	1.00
Population					
	18-85 year-old population	7017438	6173601	620371	26300000
	15-17 year-old population	387906	344692	40488	1568822

Notes:
1. Night-Time is characterized as 9 pm-5 am
2. There are 160 state-year observations

Table 5: GDL Policies and Number of Two-Car Crashes with Teen Drivers, Negative Binomial Regressions

Panel A: Coefficient Estimates				
	Dependent Variable: Number of Two-Car Crashes with at Least One Teen Driver			
	(1)		(2)	
	Coeff.	Std. Error	Coeff.	Std. Error
GDL	-0.04	(0.03)	-	
GDL×Night-Time	-0.10	(0.07)	-	
Good GDL	-		-0.10	(0.10)
Fair GDL	-		-0.09	(0.06)
Marginal GDL	-		0.01	(0.03)
Good GDL×Night-Time	-		-0.22 ***	(0.05)
Fair GDL×Night-Time	-		-0.04	(0.18)
Marginal GDL×Night-Time	-		-0.08	(0.08)
Log(Teen Population)	0.32	(0.47)	0.54	(0.38)
License Revocation Law	-0.14 **	(0.06)	-0.10	(0.07)
BAC 0.08 Law	0.03	(0.04)	-0.04	(0.06)
Zero Tolerance Law	-0.06	(0.05)	-0.07 **	(0.03)
Weekend	-1.29 ***	(0.06)	-1.29 ***	(0.06)
Weekend×Night-Time	1.16 ***	(0.08)	1.16 ***	(0.08)
Hour fixed effects	Included		Included	
Year fixed effects	Included		Included	
State fixed effects	Included		Included	
Number of observations	7,680		7,680	

Panel B: Estimates for Night-Time Observations				
	Coeff.	p-value	Coeff.	p-value
GDL on Night-Time Accidents				
GDL+GDL×Night-Time	-0.14 **	(0.04)		
Good GDL on Night-Time Accidents				
Good GDL+Good GDL×Night-Time	-		-0.32 ***	(0.00)
Fair GDL on Night-Time Accidents				
Fair GDL+Fair GDL×Night-Time	-		-0.13	(0.33)
Marginal GDL on Night-Time Accidents				
Marginal GDL+Marginal GDL×Night-Time	-		-0.07	(0.38)

1. Standard errors are clustered at the state level
2. ***, **, and * denote statistical significance at 0.01, 0.05, and 0.10 respectively

Table 6: Joint Hierarchical Maximum Likelihood Estimation - All Crashes- Allowing for Night-Time Interactions

	Panel A: Coefficient Estimates											
	Risk Equation (log(θ))		Prevalance Equation (log(N))		Risk Equation (log(θ))		Prevalance Equation (log(N))		Risk Equation (log(θ))		Prevalance Equation (log(N))	
	(1a)		(1b)		(2a)		(2b)		(3a)		(3b)	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
GDL	0.002	(0.06)	-0.05 **	(0.02)								
GDL×Night-Time	0.03	(0.07)	-0.11 **	(0.05)								
GDL without Night Restriction					0.11	(0.28)	-0.07	(0.12)				
GDL with Night Restriction					-0.02	(0.06)	-0.05 *	(0.03)				
GDL without Night Restriction×Night-Time					-0.004	(0.04)	-0.04	(0.07)				
GDL with Night Restriction×Night-Time					0.03	(0.07)	-0.11 **	(0.05)				
Good GDL									0.58	(0.39)	-0.44	(0.27)
Fair GDL									-0.05	(0.07)	-0.03	(0.05)
Marginal GDL									-0.16	(0.13)	0.08	(0.08)
Good GDL×Night-Time									-0.04	(0.06)	-0.12 ***	(0.04)
Fair GDL×Night-Time									0.02	(0.04)	-0.10 **	(0.04)
Marginal GDL×Night-Time									-0.01	(0.03)	-0.07 ***	(0.02)
Teen Pop./Adult Pop.	5.08	(20.40)	2.68	(6.8)	6.24	(21.97)	2.55	(7.39)	-30.00	(28)	23.34	(20)
License Revocation Law	-0.07	(0.23)	-0.05	(0.08)	-0.08	(0.24)	-0.05	(0.09)	-0.03	(0.08)	-0.03	(0.06)
BAC 0.08 Law	-0.08	(0.23)	0.16	(0.10)	-0.09	(0.23)	0.17 *	(0.10)	0.28 **	(0.12)	-0.09	(0.09)
Zero Tolerance Law	0.11	(0.26)	-0.03	(0.12)	0.12	(0.25)	-0.03	(0.11)	-0.03	(0.06)	0.02	(0.03)
Night-Time	-0.01	(0.04)			-0.02	(0.03)			0.02	(0.02)		
Weekend			0.09 ***	(0.02)			0.08 ***	(0.02)			0.09 ***	(0.02)
Weekend×Night-Time			0.14 ***	(0.02)			0.14 ***	(0.02)			0.14 ***	(0.02)
Hour fixed effects			Included				Included				Included	
Year fixed effects	Included		Included		Included		Included		Included		Included	
State fixed effects	Included		Included		Included		Included		Included		Included	
Number of observations	7,680 state-year-hour-weekend cells				7,680 state-year-hour-weekend cells				7,680 state-year-hour-weekend cells			
	Panel B: Estimates for Night-Time Observations											
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
GDL during Night-Time												
GDL+GDL×Night-Time	0.03	(0.77)	-0.16 ***	(0.00)								
GDL without Night Restriction during Night-Time												
GDL without Night Restriction + GDL without Night Restriction×Night-Time					0.11	(0.68)	-0.11	(0.36)				
GDL without Night Restriction during Night-Time												
GDL with Night Restriction + GDL with Night Restriction×Night-Time					0.01	(0.91)	-0.16 ***	(0.00)				
Good GDL during Night-Time												
Good GDL+Good GDL×Night-Time									0.54	(0.12)	-0.56 **	(0.03)
Fair GDL during Night-Time												
Fair GDL+Fair GDL×Night-Time									-0.03	(0.63)	-0.13 *	(0.06)
Marginal GDL during Night-Time												
Marginal GDL+Marginal GDL×Night-Time									-0.17	(0.13)	0.01	(0.92)

1. Standard errors are clustered at the state level
2. ***, **, and * denote statistical significance at 0.01, 0.05, and 0.10 respectively

Table 7: Joint Hierarchical Maximum Likelihood Estimation - All Crashes - Allowing for Night-Time & Weekend Interactions

	Estimates of GDL							
	Risk Equation (log(θ))		Prevalance Equation (log(N))		Risk Equation (log(θ))		Prevalance Equation (log(N))	
	(1)		(2)		(1)		(2)	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
GDL on Non-Weekend-Night-Time								
GDL	-0.008	(0.90)	-0.05	(0.18)				
GDL on Weekend-Night-Time								
GDL+GDL×Weekend-Night-Time	0.003	(0.95)	-0.17 ***	(0.00)				
Good GDL during Non-Weekend-Night-Time								
Good GDL					0.56	(0.15)	-0.44 *	(0.10)
Fair GDL during Non-Weekend-Night-Time								
Fair GDL					-0.06	(0.42)	-0.04	(0.44)
Marginal GDL during Non-Weekend-Night-Time								
Marginal GDL					-0.17	(0.16)	0.08	(0.31)
Good GDL during Weekend-Night-Time								
Good GDL+Good GDL×Weekend-Night-Time					0.6	(0.12)	-0.59 **	(0.03)
Fair GDL during Weekend-Night-Time								
Fair GDL+Fair GDL×Weekend-Night-Time					0.007	(0.93)	-0.19 ***	(0.00)
Marginal GDL during Weekend-Night-Time								
Marginal GDL+Marginal GDL×Weekend-Night-Time					-0.13	(0.20)	-0.04	(0.64)

1. Standard errors are clustered at the state level
2. ***, **, and * denote statistical significance at 0.01, 0.05, and 0.10 respectively
3. Each panel has 7,680 state-year-hour-weekend observations
4. State and Year fixed effects as well as weekend-night interaction are used in all specifications. Prevalance equation includes additional hour fixed effects.
5. Other driving related laws and the ratio of teen population to adult population are included as covariates in all specifications

Table 8: Joint Hierarchical Maximum Likelihood Estimation - Different Types of Crashes - Allowing for Night-TimeInteractions

	Estimates of GDL							
	All Non-Fatal Accidents				Property Damage-Only Crashes			
	Risk Equation (log(θ))		Prevalance Equation (log(N))		Risk Equation (log(θ))		Prevalance Equation (log(N))	
	(1)		(2)		(1)		(2)	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Good GDL during Day-Time								
Good GDL	0.58	(0.14)	-0.44 *	(0.10)	0.51	(0.22)	-0.40	(0.15)
Fair GDL during Day-Time								
Fair GDL	-0.05	(0.45)	-0.04	(0.47)	-0.05	(0.39)	-0.05	(0.27)
Marginal GDL during Day-Time								
Marginal GDL	-0.16	(0.19)	0.08	(0.31)	-0.14	(0.24)	0.07	(0.33)
Good GDL during Night-Time								
Good GDL+Good GDL×Night-Time	0.55	(0.12)	-0.56 **	(0.03)	0.46	(0.22)	-0.55 **	(0.04)
Fair GDL during Night-Time								
Fair GDL+Fair GDL×Night-Time	-0.03	(0.64)	-0.14 *	(0.06)	-0.04	(0.60)	-0.17 **	(0.02)
Marginal GDL during Night-Time								
Marginal GDL+Marginal GDL×Night-Time	-0.17	(0.13)	0.01	(0.93)	-0.15	(0.18)	-0.04	(0.61)

1. Standard errors are clustered at the state leve
2. ***, **, and * denote statistical significance at 0.01, 0.05, and 0.10 respectively
3. Each panel has 7,680 state-year-hour-weekend observations
4. State and Year fixed effects as well as weekend-night interaction are used in all specifications. Prevalance equation includes additional hour fixed effects.
5. Other driving related laws and the ratio of teen population to adult population are included as covariates in all specifications

Table 9: Joint Hierarchical Maximum Likelihood Estimation - All Crashes - Equal Mixing Assumption

	Estimates of GDL											
	All Accidents -Vary N by state, year, hour, weekend				All Accidents -Vary N by state, year, night, weekend				All Accidents -Vary N by state, year, night			
	Risk Equation (log(θ))		Prevalance Equation (log(N))		Risk Equation (log(θ))		Prevalance Equation (log(N))		Risk Equation (log(θ))		Prevalance Equation (log(N))	
	(1)		(2)		(1)		(2)		(1)		(2)	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Good GDL during Day-Time												
Good GDL	0.58	(0.14)	-0.44	(0.11)	0.51	(0.21)	-0.40	(0.14)	0.51	(0.21)	-0.40	(0.14)
Fair GDL during Day-Time												
Fair GDL	-0.05	(0.45)	-0.03	(0.47)	-0.05	(0.43)	-0.03	(0.44)	-0.05	(0.44)	-0.04	(0.43)
Marginal GDL during Day-Time												
Marginal GDL	-0.16	(0.19)	0.08	(0.31)	-0.15	(0.21)	0.08	(0.32)	-0.15	(0.21)	0.08	(0.32)
Good GDL during Night-Time												
Good GDL+Good GDL×Night-Time	0.54	(0.12)	-0.56 **	(0.03)	0.48	(0.18)	-0.53 **	(0.04)	0.48	(0.18)	-0.53 **	(0.04)
Fair GDL during Night-Time												
Fair GDL+Fair GDL×Night-Time	-0.03	(0.63)	-0.13 *	(0.06)	-0.03	(0.65)	-0.15 **	(0.03)	-0.03	(0.65)	-0.16 **	(0.03)
Marginal GDL during Night-Time												
Marginal GDL+Marginal GDL×Night-Time	-0.17	(0.13)	0.01	(0.92)	-0.16	(0.15)	-0.01	(0.93)	-0.15	(0.15)	-0.01	(0.92)

1. Standard errors are clustered at the state level
2. ***, **, and * denote statistical significance at 0.01, 0.05, and 0.10 respectively
3. Each panel has 7,680 state-year-hour-weekend observations
4. State and Year fixed effects are used in all specifications. Prevalance equation includes additional hour fixed effects for model (1). Models (1) and (2) include weekend-night interactions
5. Other driving related laws and the ratio of teen population to adult population are included as covariates in all specifications

Table 10: Joint Hierarchical Maximum Likelihood Estimation - All Crashes - Teens defined as the 15-19 Year Olds

	Estimates of GDL							
	Teen Definition is 15-17 Year-Olds				Teen Definition is 15-19 Year-Olds			
	Risk Equation (log(θ))		Prevalance Equation (log(N))		Risk Equation (log(θ))		Prevalance Equation (log(N))	
	(1)		(2)		(1)		(2)	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Good GDL during Day-Time								
Good GDL	0.58	(0.14)	-0.44	(0.11)	0.00	(0.60)	-0.06 **	(0.04)
Fair GDL during Day-Time								
Fair GDL	-0.05	(0.45)	-0.03	(0.47)	0.00	(0.33)	-0.02	(0.29)
Marginal GDL during Day-Time								
Marginal GDL	-0.16	(0.19)	0.08	(0.31)	0.00	(0.87)	-0.01	(0.55)
Good GDL during Night-Time								
Good GDL+Good GDL×Night-Time	0.54	(0.12)	-0.56 **	(0.03)	0.00	(0.15)	-0.12 ***	(0.01)
Fair GDL during Night-Time								
Fair GDL+Fair GDL×Night-Time	-0.03	(0.63)	-0.13 *	(0.06)	0.00	(0.65)	-0.05 *	(0.08)
Marginal GDL during Night-Time								
Marginal GDL+Marginal GDL×Night-Time	-0.17	(0.13)	0.01	(0.92)	0.00	(0.82)	-0.05	(0.11)

1. Standard errors are clustered at the state level
2. ***, **, and * denote statistical significance at 0.01, 0.05, and 0.10 respectively
3. Each panel has 7,680 state-year-hour-weekend observations
4. State and Year fixed effects are used in all specifications. Prevalance equation includes additional hour fixed effects for model (1). Models (1) and (2) include weekend-night interaction
5. Other driving related laws and the ratio of teen population to adult population are included as covariates in all specifications

Table 11: Preliminary Results for 18-25 year-old drivers

	(1) # 18-25 year-old Accidents/18-25 year old Population		(2) # 18-25 year-old Accidents/18-25 year old Population, by GDL exposed and Not	
	Coeff.	Std. Error	Coeff.	Std. Error
Share of 18-25 year old pop. exposed to GDL when 15-17 year old	0.012	(0.013)		
Indicator for GDL Exposed			-0.007	(0.009)
License Revocation Law	0.011	(0.007)	0.015	(0.016)
BAC 0.08 Law	-0.002	(0.002)	0.001	(0.006)
Zero Tolerance Law	-0.002	(0.002)	-0.002	(0.004)
Year fixed effects	included		included	
State fixed effects	included		included	
Number of observations	153 state-year pairs		209 state-year-GDL exposed cells	

Standard Errors are clustered at the state-level