

2019

# An Investigation of Recreational Marijuana Laws and Traffic Fatalities

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AN INVESTIGATION OF RECREATIONAL MARIJUANA LAWS AND TRAFFIC FATALITIES

by  
Darby Todd

A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford  
May 2019

Approved by

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## ABSTRACT

DARBY TODD: An Investigation of Recreational Marijuana Laws and Traffic Fatalities  
(Under the direction of Michael Belongia)

This thesis investigates whether the implementation of a recreational marijuana law in Colorado is associated with a change in traffic fatalities. This thesis utilizes Colorado state-level data in regression analysis with a menu of dependent traffic fatality variables from the Fatality Accident Reporting System data. The only significant relationship found is between the implementation of the recreational marijuana law and marijuana-related traffic fatalities, where the law is found to be largely and positively related with marijuana-related traffic fatalities. However, this paper can draw only limited conclusions owing to the lack of a counterfactual and the short period of post-implementation data available.

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## LIST OF ABBREVIATIONS

FARS	Fatality Accident Reporting System
MML	Medical Marijuana Law
MMLs	Medical Marijuana Laws
RML	Recreational Marijuana Law
RMLs	Recreational Marijuana Laws
ARF	Alcohol-Related Traffic Fatalities





## 1.1 Introduction

The first wave of marijuana legalization, for both medicinal and recreational usage, has swept the United States. Currently, thirty states and the District of Columbia (D.C.) have legalized medicinal marijuana, and nine states and D.C. have legalized recreational use of marijuana. The specific law enacted for these jurisdictions, as well as the year of adoption, are shown in the table below. Out of these jurisdictions, ten have legalized both medical and recreational use of marijuana. It can be noted that laws permitting the use of medical marijuana were passed as early as 1996 whereas the first legislation of recreational use occurred only in 2012.

**Table 1: All States with Medical Marijuana Laws (MMLs) and Recreational Marijuana Laws (RMLs) Status and Year of Approval**

STATE	MML	MML Year	RML	RML Year
AK	Yes	1998	Yes	2014
AZ	Yes	2010	No	
AR	Yes	2016	No	
CA	Yes	1996	Yes	2016
CO	Yes	2000	Yes	2012
CT	Yes	2012	No	
DE	Yes	2011	No	
D.C.	Yes	1998	Yes	2014
FL	Yes	2016	No	
HI	Yes	2000	No	
IL	Yes	2013	No	
LA	Yes	2017	No	
ME	Yes	1999	Yes	2016
MD	Yes	2003	No	
MA	Yes	2012	Yes	2016
MI	Yes	2008	No	

STATE	MML	MML Year	RML	RML Year
MN	Yes	2014	No	
MT	Yes	2004	No	
NV	Yes	2000	Yes	2016
NH	Yes	2013	No	
NJ	Yes	2009	No	
NM	Yes	2007	No	
NY	Yes	2014	No	
ND	Yes	2016	No	
OH	Yes	2016	No	
OK	Yes	2018	No	
OR	Yes	1998	Yes	2014
PA	Yes	2016	No	
RI	Yes	2007	No	
VT	Yes	2004	Yes	2018
WA	Yes	1998	Yes	2012
WV	Yes	2017	No	

Politicians, media outlets, and the public at large have claimed that legalized use of marijuana would have effects varying from the highly negative to the positive. Discussion of legalization has tended to focus on several concerns about its potentially negative effects. For example, many have conjectured that legal access to marijuana will lead to increased use of hard drugs, such as heroin or methamphetamine. Recent studies have revived this “gateway drug” theory<sup>1</sup>. For example, a Columbia University study found that rats given alcohol were more likely to request cocaine and that the alcohol strengthened the effects of cocaine. Conversely, if cocaine was given first, rats were no more or less likely to request alcohol than the rats not given cocaine, and cocaine did not affect alcohol potency. Thus, this study reinvigorated the theory that some drugs lead to other, more potent drug use. In addition, critics of legalization have conjectured that the readily available access to marijuana and the ability to advertise will take advantage of addicts by exploiting their addictive behaviors. This exploitation is like the strategy of the tobacco and alcohol industry to increase profits from those with substance abuse problems<sup>2</sup>. Alternatively, proponents of legalization have argued that, in addition to any benefits from medical use, states may benefit from increased tax revenue and job creation. For example, it has been estimated that New York City could benefit as much as \$336 million in tax revenue from marijuana sales<sup>3</sup>. These judgments, however, have lacked any evidence to support them. In search of such evidence, economists have begun to take a hard look at the data to investigate what the impacts of marijuana might be. With the accumulating base of state-level data, investigation of some of these issues has become possible.

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<sup>1</sup> Quenqua, Douglas. “A Comeback for the Gateway Drug Theory?” *The New York Times* (December 07, 2017). Accessed March 24, 2019.

<sup>2</sup>Lopez. “The Case against Marijuana Legalization.” *Vox* (November 14, 2018). Accessed March 24, 2019.

<sup>3</sup>Barnett, Chip. “NYC Stands to gain \$330M a Year if State Legalizes Marijuana Sales.” *Bond Buyer*, vol 390 issue 34911(May 26 2018): 1.

Although an expanding body of research on the impacts of medicinal marijuana laws on alcohol and other substances exists, the recent passage of recreational marijuana laws in nine states permits research into these impacts as well. Because the data for post-legalization of recreational use are available only from 2012, there are relatively few studies that have investigated the consequences of its use apart from any effects associated with medical use. This paper contributes to the literature on the impacts of recreational marijuana by focusing on the impact of the legalization of recreational marijuana on alcohol-related traffic fatalities. If, for example, people substitute the use of marijuana for alcohol, and marijuana impairs driving to a lesser degree than alcohol, traffic fatalities could decline. If, however, marijuana impairs driving more than alcohol or leads, via the “gateway theory”, to use of stronger drugs, traffic fatalities could increase. These questions, and others, will be investigated in what follows.

## **1.2 Literature Review**

This section provides background on economic studies that analyze the use of alcohol, the use of marijuana, and the cumulative impact of their use on the whole population as well as the young specifically. The discussion also elaborates on the study that motivates the topic of this paper: the association between the legalization of recreational marijuana use and variants of traffic fatalities.

Anderson, Hanson, and Rees (2013) investigated the impact of the passage of medical marijuana laws on alcohol-related traffic fatalities<sup>4</sup>. Their study utilized the exogeneity of the passage of medicinal marijuana laws to determine if the passage caused a decrease in alcohol-

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<sup>4</sup> Anderson, D. Mark, Benjamin Hansen, and Daniel I. Rees, “Medical Marijuana Laws, Traffic Fatalities, and Alcohol Consumption,” *The Journal of Law and Economics* 56, no. 2 (May 2013): 333-369.

related traffic fatalities. With the law's passage, people that had been using alcohol to self-medicate now could choose to use prescribed marijuana instead. If these substances are substitutes and if marijuana impairs less than alcohol, there should have been a decrease in alcohol-related traffic fatalities as people substituted their alcohol use with marijuana. The researchers concluded that the passage of medical marijuana laws was associated with a statistically significant reduction in the number of alcohol-related traffic fatalities, of almost nine percent. The most noticeable difference occurred on evenings and weekends. This finding is consistent with the idea that people would tend to consume more alcohol in their non-working hours. Also, the researchers noticed that the legalization of medicinal marijuana was found to be associated with a reduction in beer sales. The reduction in alcohol-related traffic fatalities and beer sales after medicinal marijuana legalization is consistent with one possible effect of legalizing the use of marijuana. Unlike the current paper, however, the authors did not distinguish why they selected the age specific groups of traffic fatalities (they used 15-19, 20-39, and 40 & older).

It is important, however, to investigate whether the change in fatalities is similar across age groups because, potentially, the people who use medical marijuana represent a different group than those who use marijuana recreationally. For example, people who use medical marijuana take it as doctor prescribed medication while recreational use of marijuana is for "fun". Those self-medicating with alcohol may substitute medical marijuana, and thus, decrease the amount of alcohol-traffic fatalities. Those who use marijuana recreationally may substitute their use of alcohol for marijuana, but they may also decide to partake in both substances together. If this is the case, then the passage of recreational marijuana laws may not create a reduction in the number of alcohol-related traffic fatalities. Alternatively, if recreational use of

marijuana impairs driving less than the use of alcohol, substitution between the two could lead to a reduction in the number of fatalities as it did in the studies of medical marijuana use. Focusing on a distinction between the two motivations of marijuana usage will permit testing of whether the two groups behave in similar or different ways. Furthermore, investigating this distinction will add to the limited research on the impact of recreational use of marijuana on alcohol consumption in the younger segment of the population. This paper will focus on this group because, potentially, the younger members of the population are more likely to experiment with marijuana and change their substance of choice. The National Institute on Drug Abuse, for example, states that teens may use drugs to “fit in”, enjoy the high, distract from stress, enhance performance, or experiment with a novelty<sup>5</sup>. Therefore, there may be a greater impact on the reduction of alcohol-related traffic fatalities in the younger group versus older members of the population.

Other studies also have investigated assorted effects associated with the recreational use of marijuana. Williams and Mahmoudi, for example, conducted an experiment in Australia in 2004 focusing on the economic relationship between alcohol and cannabis<sup>6</sup>. After reviewing the results of a nationwide survey in which two-thirds of respondents indicate polysubstance use rather than substitution between marijuana and alcohol, they presume that alcohol and recreational marijuana are economic complements. This possibility is bolstered by the negative correlation between marijuana consumption and the implementation of a Blood Alcohol Concentration (BAC) fine. BAC refers to the concentration of alcohol in one’s bloodstream, and the national standard is that driving with a BAC of 0.08% results in a DUI. Their regression

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<sup>5</sup> National Institute on Drug Abuse. “Why Do Adolescents Take Drugs?” *NIDA* (January 2014). Accessed March 24, 2019.

<sup>6</sup> Williams, Jenny, and Parvin Mahmoudi. “Economic Relationship Between Alcohol and Cannabis Revisited.” *Economic Record* 80, no. 248 (March 2004): 36–48.

analysis indicates that the consumption of marijuana is sensitive to the price of alcohol, and when the price of alcohol rises, the consumption of marijuana decreases. Furthermore, they explain that policies which make alcohol use more expensive, such as higher taxes on purchases or more costly fines for BAC over the legal limit, also will decrease the purchase of cannabis. Consequently, these policies contribute to a reduction in the use of cannabis. One potential shortcoming of this study is that the authors extrapolate the price of marijuana from police reports of undercover purchases. This could be problematic because the reports lack standardization and often report missing data; as such, the data limitations could result in altering the paper's conclusions. While the United States is comparable in many ways to Australia, the authors limit data inferences to households in Australia.

Cameron and Williams (2001) also conducted research in Australia concerning the relationships among alcohol, marijuana, and cigarettes as substitutes or complements<sup>7</sup>. They noted from their survey data that alcohol and marijuana had a stronger relationship than marijuana and cigarettes. Interestingly, their study finds that decriminalization of marijuana usage only increased the probability of marijuana use in youth up to the 20 through 24-year-old age group by 3.2 percentage points. The study also explained that instead of increasing the usage of marijuana, decriminalization is associated with lengthening the time that older groups participated in marijuana usage. For example, if a thirty-year-old was participating in marijuana use, the user would typically give it up in the next few years. When, however, the economic costs of use decrease, such as a reduction in fines for illegal marijuana possession or a reduction in jail time if caught, users extend their usage for perhaps a decade before ultimately quitting use

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<sup>7</sup> Cameron, Lisa, and Jenny Williams. "Cannabis, Alcohol and Cigarettes: Substitutes or Complements?" *Economic Record* 77, no. 236 (March 2001): 19.

of marijuana. The researchers also estimate that a 10 percent increase in the price of alcohol increases the probability of cannabis use by 4.17 percentage points and that a 10 percent increase in the price of cannabis reduces the probability of being a smoker by 1.32 percentage points. Although this paper utilized quarterly marijuana price data from the Australian police to track price sensitivity, the authors compensated for missing data by averaging quarterly data to create an annual average price. Their price data reaffirmed previous research findings that marijuana use is price sensitive. The authors also provide one caveat to their results: because decriminalization only occurred in South Australia, the authors note their results could potentially be the result of a unique population of Australians rather than the impact of decriminalization.

Chaloupka and Laixuthai (1997) looked at the United States population's youth and asked if this subgroup substitutes marijuana for alcohol<sup>8</sup>. Their study relied on data from System to Retrieve Information from Drug Evidence (STRIDE), Fatality Analysis Reporting System (FARS), and seniors in high school with the assistance of the Monitoring the Future surveys that collect confidential (parents will never know) responses. The authors expected lower economic costs of use of marijuana would result in less alcohol consumption if they are substitutes. For example, their model finds that the decriminalization of marijuana is negatively associated with the consumption of alcohol. This result implies that a decrease in the cost of marijuana use is associated with a decrease in the consumption of alcohol. Ultimately, the researchers conclude that high school seniors consider alcohol and marijuana substitutes. With only senior survey data, however, they could not generalize their conclusion for all youth. Furthermore, they did

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<sup>8</sup> Chaloupka, Frank J., and Adit Laixuthai. "Do Youths Substitute Alcohol and Marijuana? Some." *Eastern Economic Journal* 23, no. 3 (Summer 1997): 253.



note that it is possible that their results only reflect that specific generation's changing attitudes rather than the long-term youth habits of alcohol and marijuana consumption because they had Monitoring the Future survey data only for a limited time period, 1982 and 1989.

O'Hara, Armeli, and Tennen (2016) examined the relationship between alcohol and marijuana use among college students<sup>9</sup>. Students took a survey on coping habits prior to completing the month-long reporting of daily usage of alcohol and marijuana. They recognized, *ex-ante*, two groups of college students exist with different substance use habits. The students' usage differed by the individual's weak use of substances to cope with their problems or strong use of substances to cope with their problems. Students who relied on substances heavily to relieve stress tended to exhibit a substitution effect for alcohol and marijuana. Students who did not use substances to cope, however, tended to use alcohol and marijuana together, demonstrating a complementary relationship. This result suggests that in addition to price, other behavioral factors could influence consumption for college students. A higher tax on alcohol, for example, would result in a decrease in the consumption of alcohol and marijuana for students who use the substances together. However, students who use alcohol as a coping mechanism would substitute marijuana for alcohol. The authors also noted that across both usage tendencies college males used more substances than females. Apart from suggesting that gender also influences substance use, these results highlight the need to look at smaller subgroups to understand the relationship between marijuana use and alcohol use among young adults.

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<sup>9</sup> O'Hara, Ross E., Stephen Armeli, and Howard Tennen. "Alcohol and Cannabis Use among College Students: Substitutes or Complements?" *Addictive Behaviors* 58 (July 2016): 1-6. Accessed January 1, 2019.

Although these studies offer valuable background to the general subject of legalizing the use of marijuana, it is worth highlighting the data limitations of these experiments. For example, many utilize state population data to compute a population control variable. This means that these studies use census data, which are compiled only every ten years. Census data, therefore, create a trend line that fails to account for the influxes and outflows of population change over the interim of the ten years. In their models, this could create an effect that does not actually exist if the rest of their data set is counted daily, weekly, or monthly.

Another similar weakness in many of these papers is the inclusion of STRIDE data and of price data from High Times magazine. Although these data allowed papers on the U.S. population to use data on the price of marijuana, these data often contain missing values or are sparse. Moreover, STRIDE data are available for only 19 cities. Finally, the approximation of price loses accuracy the farther from the city one gets. The paper by Chaloupka and Laixuthai (1997) attempts to account for the accuracy of the data by denoting counties as a “poor match” if more than fifty miles away from a city with data. Next, the authors average available prices to account for missing quarterly data and then take the midpoint of the dollar value range of prices. The inherent shortcomings in calculating price data in this manner may alter the ultimate results. High Times, a magazine devoted to topics on marijuana, also offers data on marijuana prices. The magazine collects reported prices by their readers and produces a price index based on the average price of user submission. Thus, if marijuana users from one locale submit most of the reports with a specific price they paid that is unique to their region, this could bias the High Times pricing.

Although these papers have shortcomings, these shortcomings stem primarily from a lack of consistent and robust data for empirical investigation. Nonetheless, the papers offer a solid

foundation on the topic of consequences of marijuana use and whether it serves as a substitute or complement to the use of alcohol. The questions these papers do not answer guide the research that follows. Specifically, this study contributes to the literature on the effects of legalizing marijuana by investigating how the use of marijuana influences traffic fatalities among young drivers. By replicating the earlier studies with different data, this paper also tests the robustness of their conclusions.

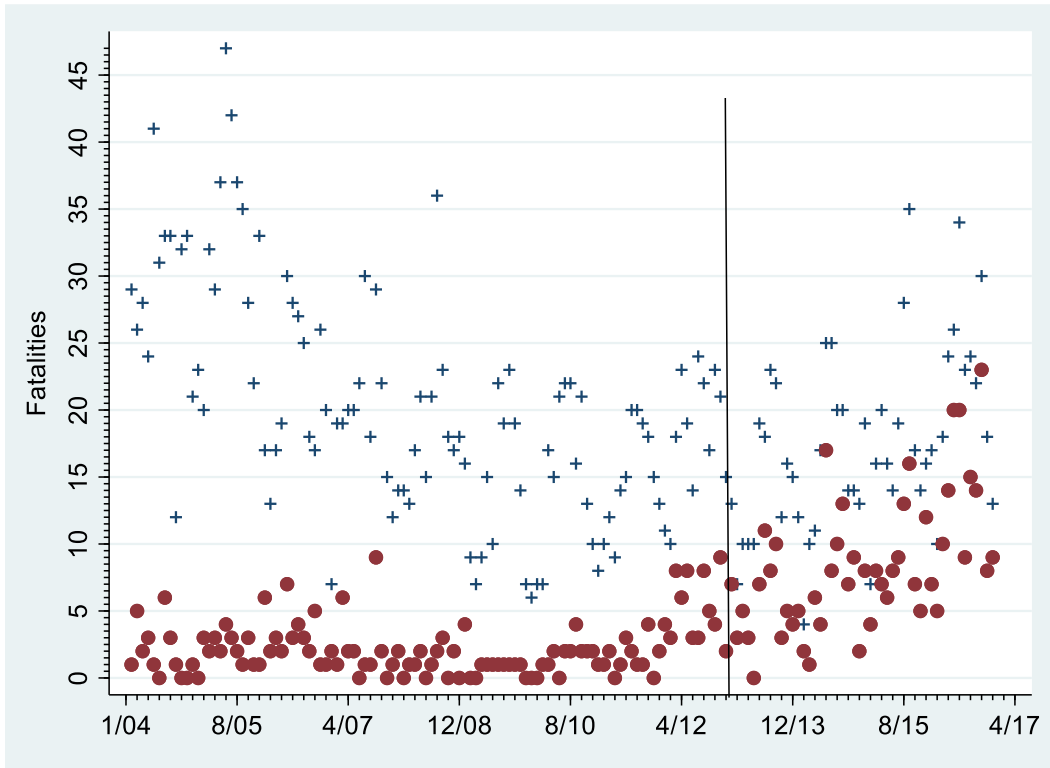
## 2.1 Methodology

Around the time of implementation of Recreational Marijuana Laws (RMLs), some trends begin to change. These changes make this investigation interesting as it seeks to ask whether the passage of the law truly affects traffic fatalities among different sub-groups of the population. This paper focuses on the RML passage and data for the state of Colorado. This state was chosen because more post-implementation data are available for it relative to other states that passed RMLs. Washington and Colorado were the first states to pass RMLs, in 2012 (see table 1 for reference of other states). Colorado has more, readily-available state-level data. As time passes and the post-RMLs period lengthens, similar studies will be possible for other states.

Figure 1 highlights the trend shift in Colorado of drug use overall and specifically marijuana use. Colorado passed its RML in November of 2012, which corresponds to a little after April 2012 on this graph. The blue pluses, representing total drug-related traffic fatality deaths each month, start dropping from highs in 2004 but begin to rise again near the passage of the new recreational marijuana law, implementation denoted by the vertical line. The red dots, which represent marijuana-related traffic deaths, show that they are a small share of total fatalities. Their incidence changes very little until approximately April 2012, when they start to escalate dramatically; specifically, they increase from an average of less than five marijuana-related traffic fatalities a month in January 2012 to an average of ten marijuana-related traffic fatalities a month by 2016. Although this trend shift does not demonstrate causation, it does

illustrate why it is worthwhile to investigate whether a causal link exists between the adoption of RMLs and higher numbers of drug-related traffic fatalities.

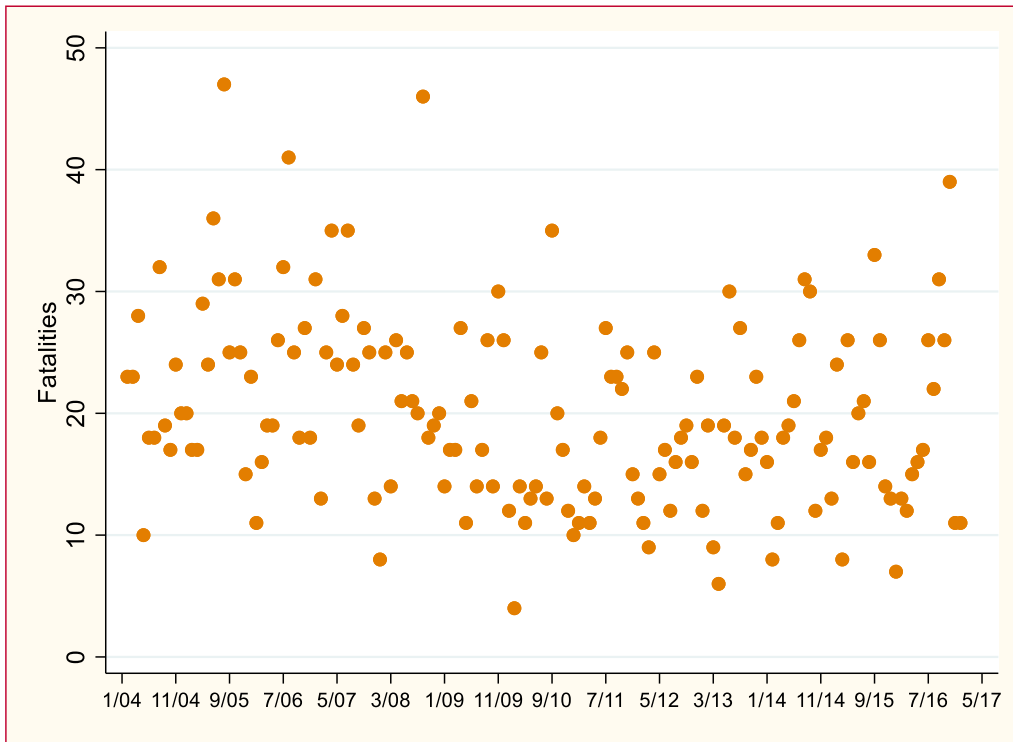
**Figure 1: Comparison of the Change in Drug and Marijuana-related Traffic Fatalities Pre and Post Colorado RML Implementation, Monthly Data from 2004-2016<sup>10</sup>**



<sup>10</sup> The blue pluses represent the number of monthly drug-related traffic fatalities in Colorado, and the red dots represent the number of monthly marijuana-related traffic fatalities in Colorado.

Although any shift in trend from figure 2 is not so clear for alcohol-related traffic fatalities, it still is worthwhile to investigate whether there is an association with RMLs. Alcohol-related traffic fatalities served as the primary dependent variable of interest in the earlier investigations of medical marijuana laws, and the authors of these studies speculated that new studies based on RMLs would find similar results showing RMLs also are associated with a decrease in alcohol-related traffic fatalities. Therefore, alcohol-related traffic fatalities (ARF) were selected as the dependent variable to test the hypothesis that RMLs would affect traffic fatalities the same way that MMLs had.

**Figure 2: Monthly Alcohol-related Traffic Fatalities in Colorado, from 2004-2016**



## 2.2 General Form of the Model

To test several hypotheses, the following general linear regression was estimated:

$$(1) \ln(Y) = a + \beta_1 RML + \beta_2 Textban + \beta_3 Lnalctax + \beta_4 Lnunemp + \beta_5 Lngasgasohol + \varepsilon.$$

This is the general model, and from this model, other variants are derived to test related hypotheses. In addition to a constant term, two dummy variables are included to represent the date of Colorado's passage of the RML law (RML) and another to represent the date when Colorado passed its law to ban texting while driving (Textban). Each takes a value of zero prior to the passage of the respective laws and a value of one afterward. The equation's error term is assumed to be normally distributed and similarly unrelated. The equation also includes terms thought to have an influence on ARF.

$Lnalctax$  is the natural log of alcohol taxes collected in Colorado, which tracks the percentage increase or decrease in alcohol tax revenues. This variable is meant to account for variations in alcohol consumption and serves as a proxy for alcohol consumption, for which data were not available. Using an alcohol taxation variable assumes that the increase in monthly liquor sales, as evidenced by the increase in taxes paid, reflects the months with increased alcohol consumption.

Similarly, the volume of travel needed to be controlled. The variable  $Lngasgasohol$  is the natural log of gas and gasohol gallons consumed, which serves as a proxy to track the amount of travel on the roads in Colorado. These fuels were selected because they capture common drivers. Data on diesel and aviation fuel gallons sold also were available, but these fuels represent groups such as commercial driving and planes, not relevant to this research. The assumption made to use gas and gasohol gallons sold as a proxy was that the volume of cars on the road would be

associated with miles driven. Controlling for car travel was necessary because it is likely more cars on the road results in more accidents. The peak season for travel appears to be summer.

The variable Lnunemp is the natural log of the unemployment of the monthly number of unemployed in Colorado. Studies have indicated that people who are unemployed are more likely to drink alcohol<sup>11</sup>. Increased alcohol consumption would be associated with increased alcohol-related traffic fatalities. Furthermore, unemployment, following the business cycle, is cyclical and will vary over time. Therefore, it is necessary to control for unemployment so that the change in alcohol-related traffic fatalities is related to the RML implementation, not variations in unemployment.

This paper chose to specify continuous variables in logs because it wanted to look at how the percentage change in independent variables resulted in a percentage change in the dependent variable, traffic fatalities. This paper also uses logs because the paper (Anderson 2013) which investigated medical marijuana also used a log specification. Furthermore, a log-log model made for cleaner interpretations because the percentage change makes more interpretative sense than a model without logs that would say an increase in a unit of an independent variable could correspond with a partial increase in the number of traffic fatalities.

Before proceeding to the estimation of the model, table 2 offers descriptive statistics for each variable including the number of observations, the mean, standard deviation, and the minimum and maximum values. The variables with high variations such as gas and gasoline gallons consumed, the number of unemployed, and variants of traffic deaths are expected to vary across the business cycle or across seasonal differences for example.

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<sup>11</sup> Popovici, Ioana, and Michael T. French. "Does Unemployment Lead to Greater Alcohol Consumption?" *National Center for Biotechnology Information* (April 2013). Accessed February 3, 2019.



**Table 2: Summary Statistics of Each Variable**

	<b>Obs</b>	<b>Mean</b>	<b>Std. Dev.</b>	<b>Min</b>	<b>Max</b>
<b>RML</b>	156	0.321	0.468	0	1
<b>Textban</b>	156	0.545	0.5	0	1
<b>Gas</b>	150	1.84e^8	1.28e^7	1.60e^8	2.19e^8
<b>Unemp</b>	156	155977.2	50328.42	84230	243221
<b>Drugdeath</b>	156	19.372	8.024	4	47
<b>Regfatals</b>	156	103.385	32.826	39	190
<b>Marijdeath</b>	156	4.141	4.394	0	23
<b>YouthDrug</b>	156	4.987	2.801	0	13
<b>Alcinvol</b>	156	20.077	7.791	4	47
<b>YouthAlc</b>	156	8.103	5.256	0	26
<b>Regfatals</b>	156	0.321	0.468	0	1

Correlations between variables are reported below. Table 3 includes variables already defined as well as others that will be used in alternative specifications of the model.

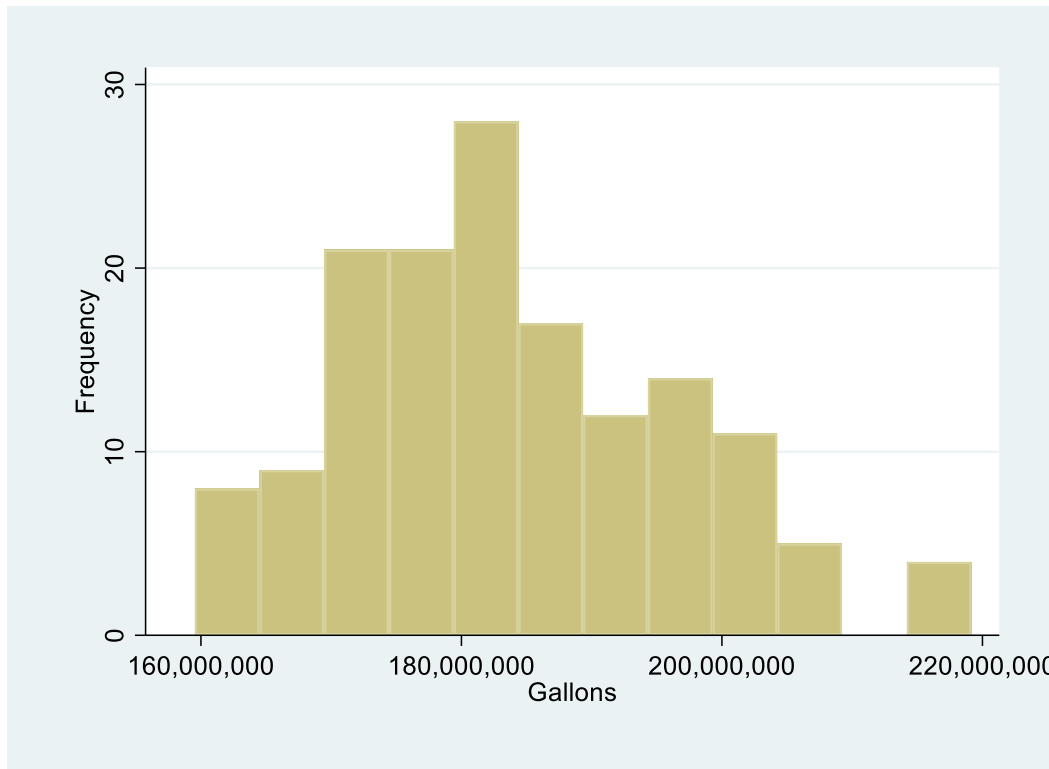
Multicollinearity appears to be present. It is noteworthy, for example, that the correlation between a texting ban and RMLs is high, the correlation of marijuana-related traffic fatalities(lnmarijdeath) and RMLs is high, as is the correlation between alcohol-related traffic fatalities (lnalcinvol) and drug-related traffic fatalities(lndrugdeaths).

**Table 3: Correlation Matrix**

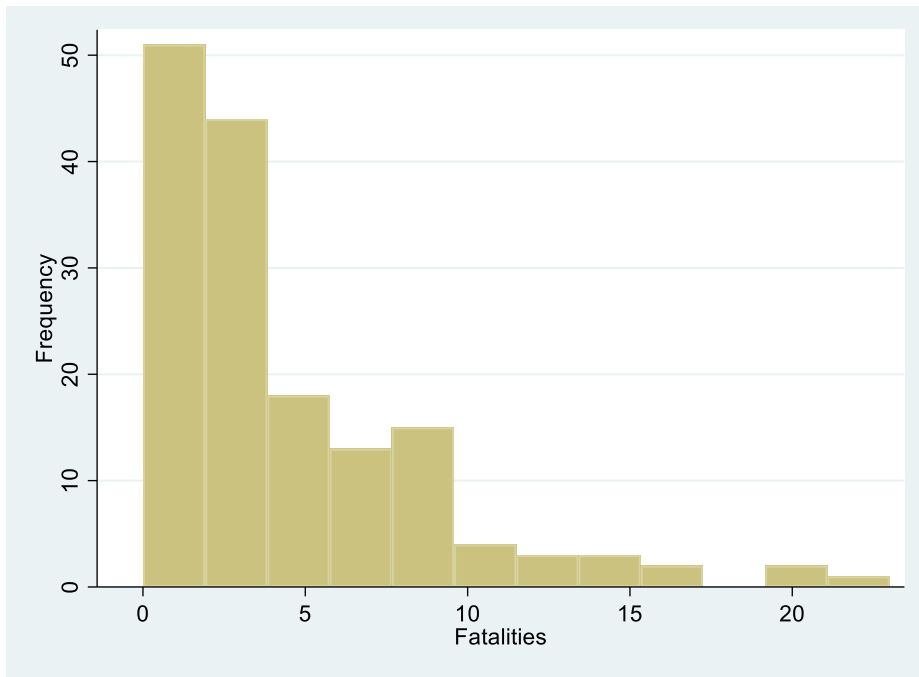
	<b>RML</b>	<b>Textban</b>	<b>Ln-GasGasohol</b>	<b>Ln-Unemp</b>	<b>Ln-DrugDeaths</b>	<b>Ln-MarijDeaths</b>	<b>Ln-YouthDrug</b>	<b>Ln-Alcinvol</b>	<b>Ln-YouthAlc</b>
<b>RML</b>	1								
<b>Textban</b>	0.618	1							
<b>LnGasGasohol</b>	0.373	0.243	1						
<b>LnUnemp</b>	-0.274	0.365	-0.277	1					
<b>LnDrugDeaths</b>	-0.112	-0.316	0.492	-0.353	1				
<b>LnMarijDeaths</b>	0.678	0.486	0.494	-0.316	0.258	1			
<b>LnYouthDrug</b>	-0.104	0.2	0.311	-0.217	0.631	0.131	1		
<b>LnAlcinvol</b>	-0.122	-0.342	0.364	-0.266	0.637	0.088	0.425	1	
<b>LnYouthAlc</b>	-0.09	-0.244	0.216	-0.169	0.4134	0.043	0.316	0.73	1

One last way to examine the data is through the distribution of the data of each variable. The ideal would be the normal distribution. A few variables deviate from this. Marijuana deaths are heavily skewed right. Unemployment is symmetrical. Youth drug deaths also are skewed right. One potential explanation for the heavily skewed right data is that for most of the observation period, July 2004 through October 2012, recreational marijuana was not legalized. This could explain why the data are skewed to fewer deaths rather than a normal distribution. If this paper were written later, with more observations, the data might be distributed more normally. What follows are histograms of the distributions of each variable.

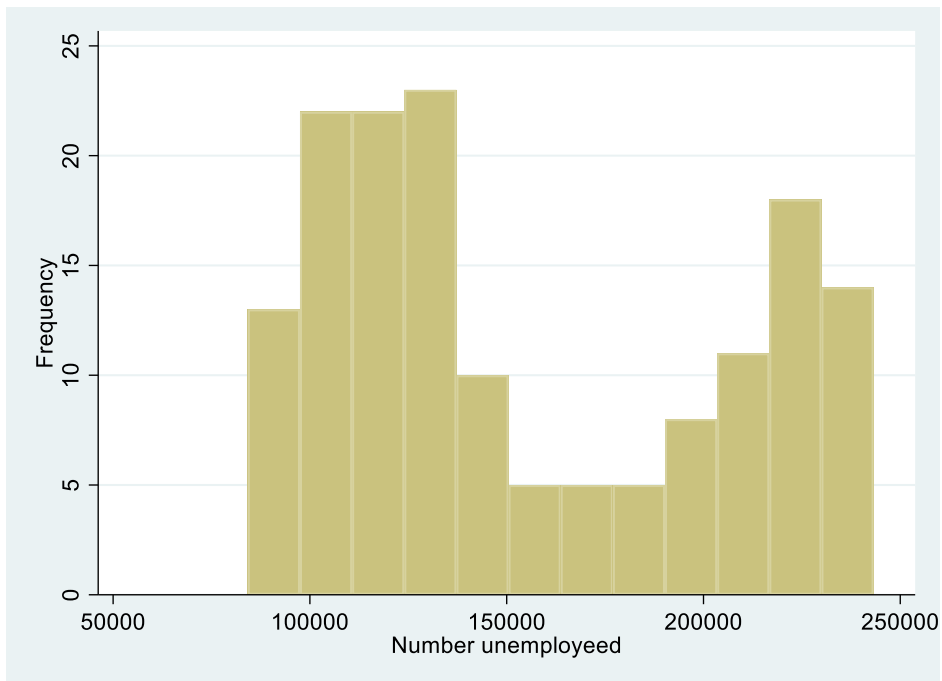
***Figure 3: The Distribution of Monthly Gasoline and Gasohol Gallon Consumption in Colorado from July 2004- 2016***



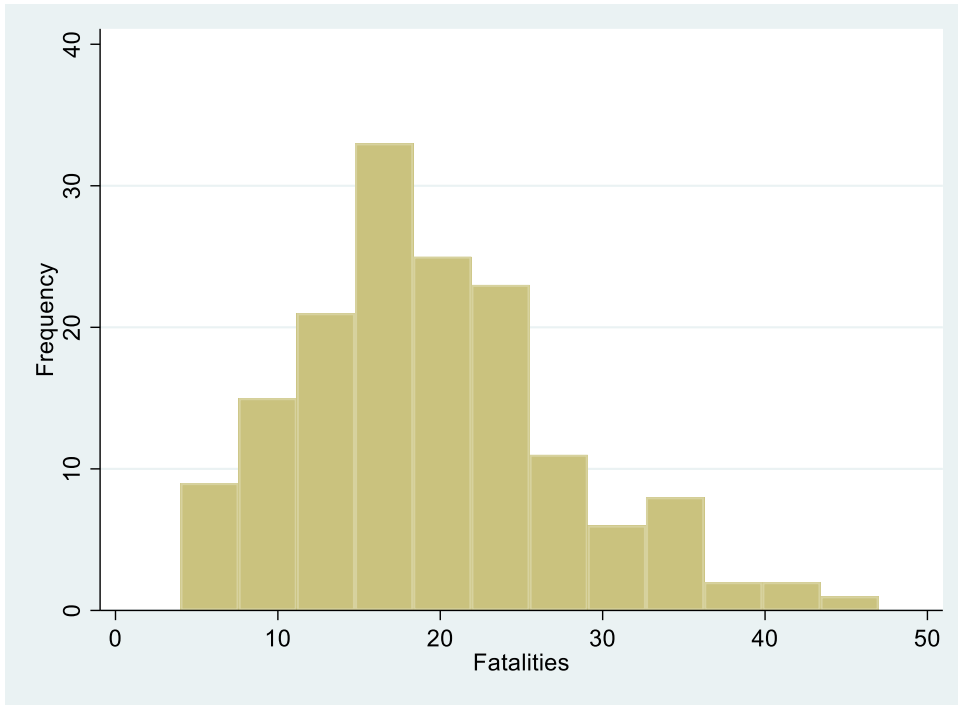
**Figure 4: The Distribution of Monthly Marijuana-Related Traffic Fatalities from 2004-2016**



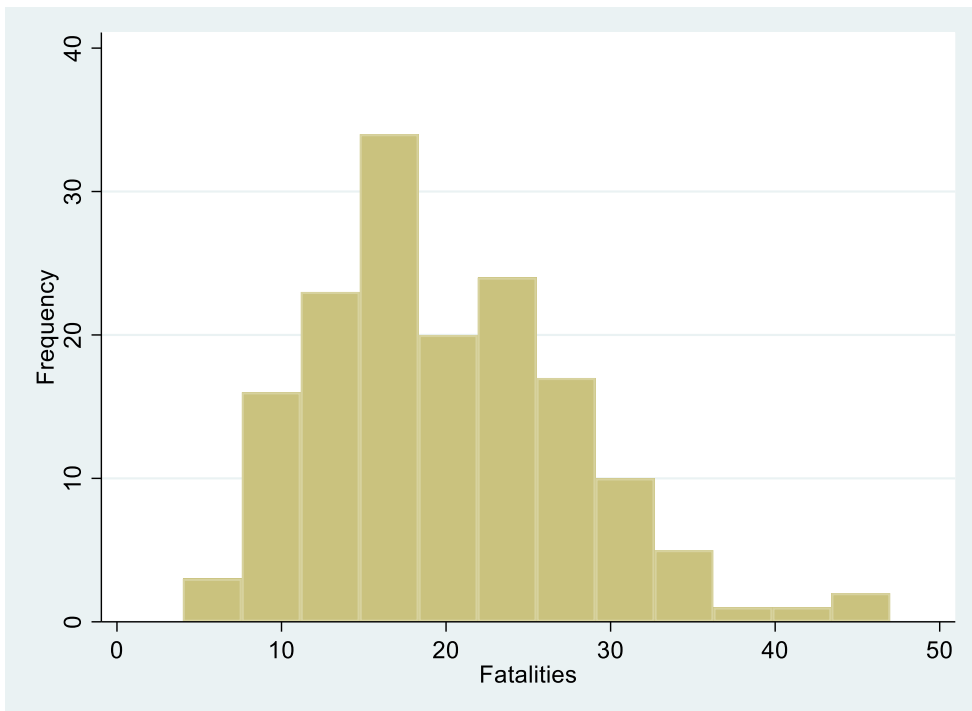
**Figure 5: The Distribution of Monthly Number of Unemployed in Colorado from 2004-2016**



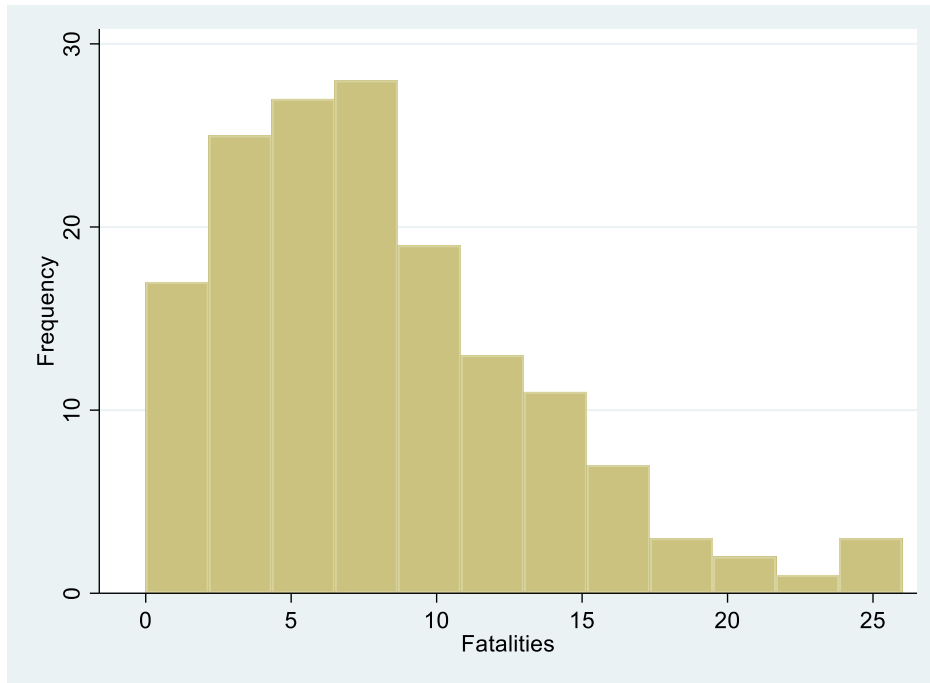
**Figure 6: The Distribution of Monthly Drug-Related Traffic Fatalities from 2004-2016**



**Figure 7: The Distribution of Monthly Alcohol-Related Traffic Fatalities from 2004-2016**



**Figure 8: The Distribution of Monthly Alcohol-Related Traffic Fatalities Among Drivers Age 15-25 from 2004-2016**



**Figure 9: The Distribution of Monthly Drug-Related Fatalities Among Drivers 15-25 from 2004-2016**

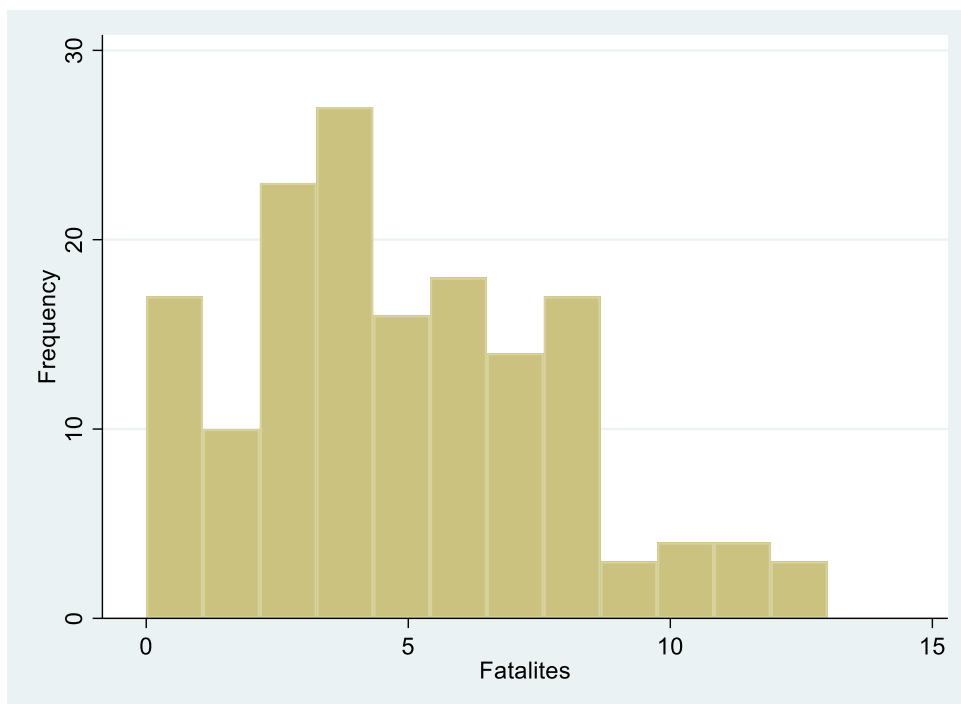


Figure 10, which shows alcohol tax revenue by month, suggests for the inclusion of a variable to control the monthly variation in consumption. The holiday months of November and December show peak tax collection times; the data also reveal a smaller peak during the summer. To look solely at increases in alcohol-related traffic fatalities from the implementation of a recreational marijuana law, without consideration of monthly fluctuations in alcohol use, increases the possibility of attributing traffic fatalities to the incorrect underlying influence. To this end, the estimated models include a variable that controls for alcohol consumption.

**Figure 10: The Monthly Tax Dollars Collected from Colorado Alcohol Taxes from 2004-2016**

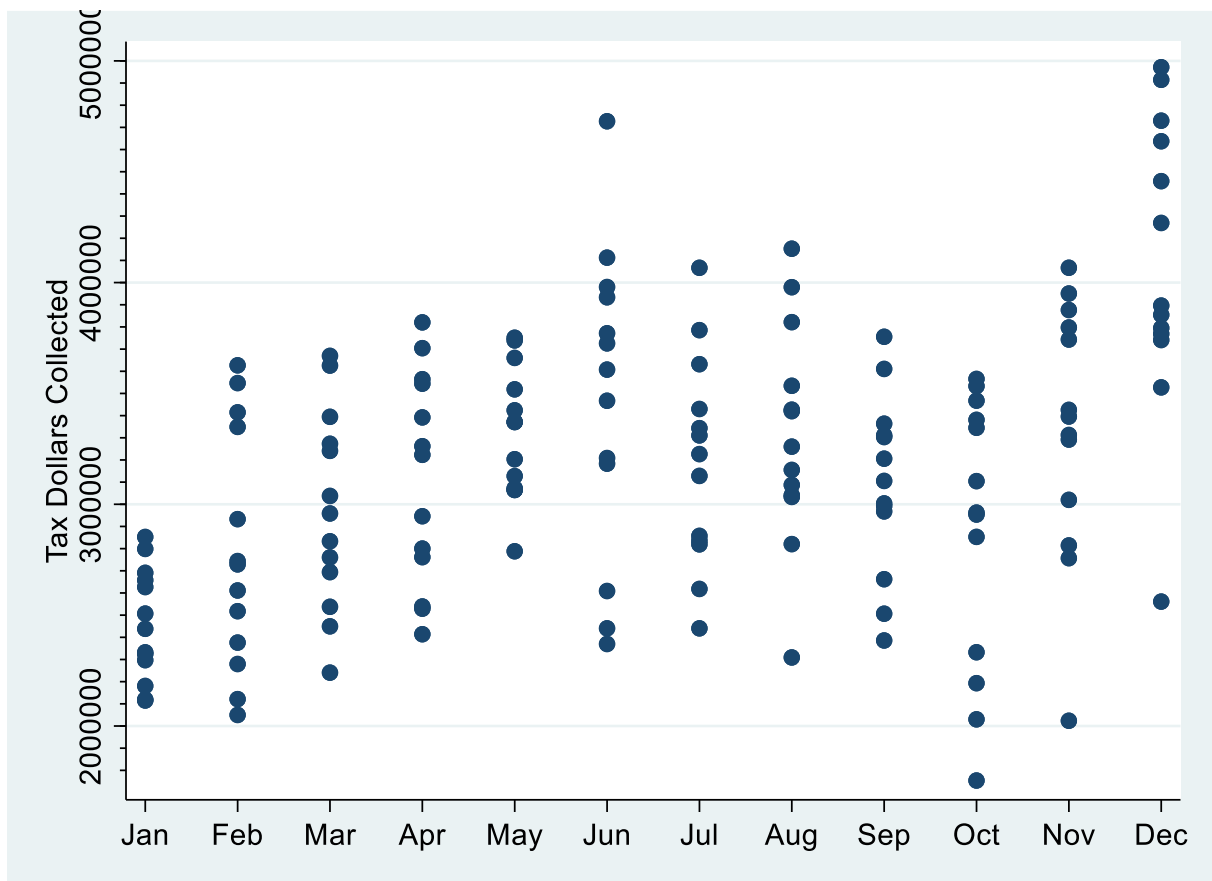
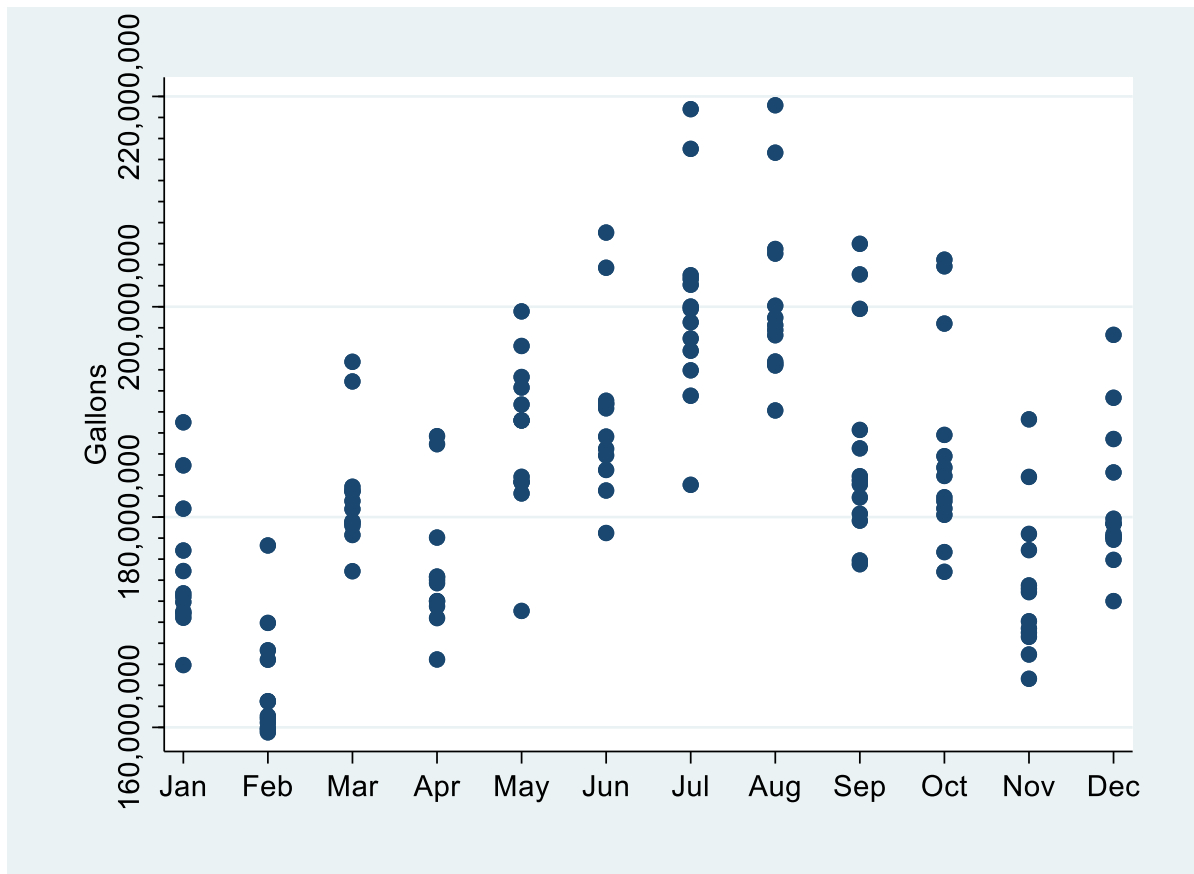


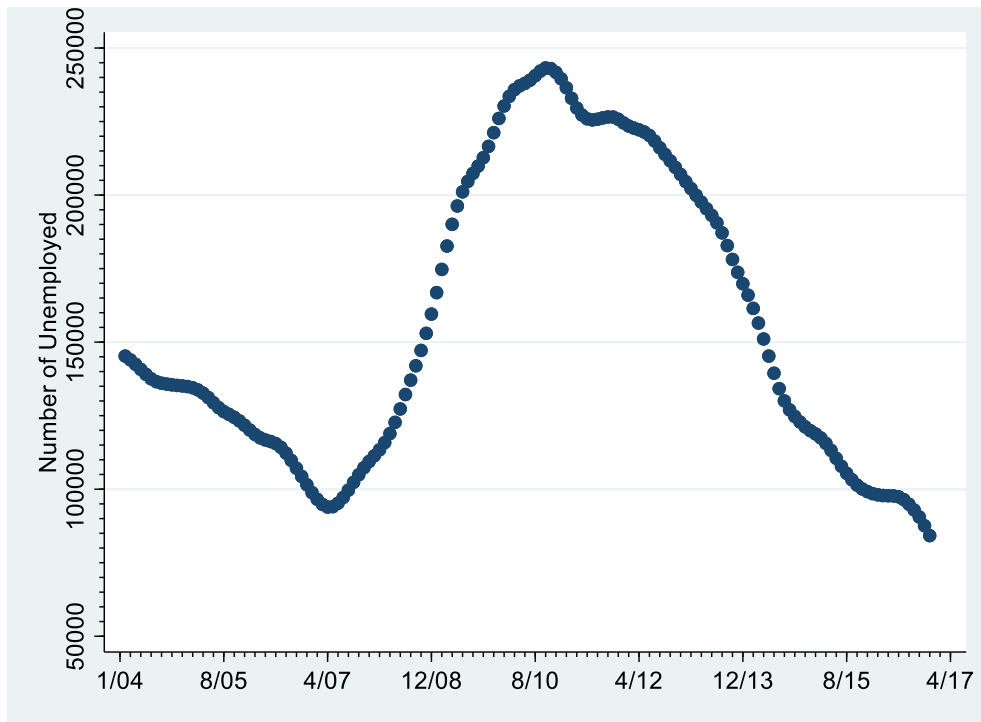
Figure 11, which shows gas and gasohol consumed by month, suggests the inclusion of a variable to control for the monthly variation in travel. The summer months show peak gas and gasohol consumption. To look solely at increases in alcohol-related traffic fatalities from the implementation of a recreational marijuana law, without consideration of monthly fluctuations in travel, increases the possibility of attributing traffic fatalities to the incorrect underlying influence. To this end, the estimated models include a variable that controls for variation in travel.

**Figure 11: The Monthly Colorado Gallons of Gas and Gasohol Consumed from July 2004-2016**



A variable for unemployment was also added to the regression. Although unemployment may seem unrelated to marijuana and alcohol use, studies show that becoming unemployed corresponds with higher usage of alcohol<sup>12</sup>. Evidence on marijuana use during unemployment, however, is not available. Because the unemployment numbers fluctuate over time, the variable tries to account for increases in alcohol consumption associated with unemployment such that alcohol-related fatalities associated with this phenomenon are not incorrectly associated with the passage of RMLs. Figure 12 shows the variations in unemployment from 2004-2017 in Colorado with the large spike associated with the 2008-2009 recession; the unemployment numbers slowly return to lower levels as the economy recovers from the Great Recession. By controlling for unemployment, the regression accounts for the possibility of increased drinking associated with rising unemployment.

**Figure 12: Colorado’s Number of Unemployed Monthly from 2004-2016**



<sup>12</sup> Popovici, Ioana, and Michael T. French. “Does Unemployment Lead to Greater Alcohol Consumption?” *National Center for Biotechnology Information* (April 2013). Accessed February 3, 2019.



A variable (youth) was created to define an age group encompassing those between age 15 and 25-year-olds. This age range was selected because 15 is the earliest that Colorado permits young drivers to get learners permits and 25 is the age when one becomes a less risky driver according to many insurance companies. Thus, 25 is the “magic” safer driving age because at 25, insurance premia start to drop barring any prior car accidents. This variable then was used to construct two new dependent variables for other variants of the baseline model: youth drug-related traffic fatalities and youth alcohol-related traffic fatalities.

The alcohol-related traffic fatalities dependent variable was selected because that was the original dependent variable used in the Anderson, Hanson, and Rees (2013) research that inspired this thesis. The menu of dependent variables then was expanded to include drug-related traffic fatalities to examine if the passage of a recreational marijuana law increased drug-related traffic fatalities. This is a relevant question to ask as one tries to assess the impact of the Colorado RML passage. It should be noted that, however, the assumption that allowed for large quantities of marijuana data is that products of marijuana such as hashish and hash oil, more concentrated forms, were considered marijuana. Also, for the FARS<sup>13</sup> data, it was necessary to aggregate thousands of individual police reports on traffic fatality accidents to monthly data.

A potential problem with these specifications is that the variable, alcohol-related traffic fatalities, takes a value equal to the crash fatalities if anyone in the car had consumed alcohol and anyone (not necessarily the driver) died in the accident. Because police reports indicate if someone died and at least one person involved in the crash had consumed alcohol, this variable is created by summing the number fatalities of incidents involving alcohol in a month to create a

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<sup>13</sup> FARS refers to the Fatality Accident Reporting System that collects data for every state in the United States from police reports of traffic accidents involving fatalities.

monthly total. Drug accidents were treated in the same manner to generate a variable of drug-related traffic fatalities. The underlying assumption used to set up these variables was that the presence of alcohol and drugs played a role in the accident even if the driver was not using substances.

### 3 Equations and Results

By way of summary, the estimated regressions do not show that the passage of recreational marijuana laws results in an increase of alcohol-related traffic fatalities. They also do not show that the passage of RMLs results in an increase of drug-related traffic fatalities or that RMLs are associated with youth. Nonetheless, the results are suggestive of how passage of RML affects other behaviors. The results of each individual regression will now be reviewed more extensively.

#### 3.1 Equation 2

Equation 2 can be written as:

$$(2) \ln(\text{alcohol-related traffic fatalities}) = a + \beta_1 RML + \beta_2 Textban + \beta_3 Lnalctax + \beta_4 Lnunemp + \beta_5 Lngasgasohol + \varepsilon$$

Equation 2 estimates the impact of RMLs on alcohol-related traffic fatalities. The primary null hypothesis is that RMLs do not affect alcohol-related traffic fatalities and  $\beta_1$  equals zero. The alternative hypothesis is that RMLs are associated with alcohol-related traffic fatalities and  $\beta_1$  is not zero. The decision to specify a  $\beta_1$  that does not equal zero in the alternative hypothesis is driven by the conflicting evidence on whether marijuana impairs driving less than alcohol and therefore tends to reduce driving fatalities or, alternatively, use of marijuana impairs driving more than alcohol through its use alone or its use in combination with other drugs. The null will be rejected if a two-sided t-test at an alpha level of 0.05 is statistically significant.

The null hypothesis for  $\beta_2$  is that texting bans do not affect alcohol-related traffic fatalities and  $\beta_2$  equals zero. The alternative hypothesis is that texting bans are negatively associated with alcohol-related traffic fatalities and  $\beta_2$  is negative. Texting bans would be expected to be associated with decreased distracted driving and thus decreased traffic fatalities. The null will be rejected if a one-sided t-test at an alpha level of 0.05 is statistically significant.

The null hypothesis for  $\beta_3$  is that alcohol taxes collected do not affect alcohol-related traffic fatalities and  $\beta_3$  equals zero. The alternative hypothesis is that alcohol taxes collected are positively associated with alcohol-related traffic fatalities and  $\beta_3$  is positive. Alcohol taxes collected reflect gallons of alcohol consumed in Colorado, and if increased alcohol consumption is associated with increased alcohol-related traffic fatalities, then more taxes should be associated with an increased number of alcohol-related traffic fatalities. The null will be rejected only if a one-sided t-test at an alpha level of 0.05 is statistically significant.

The null hypothesis for  $\beta_4$  is that the number of people unemployed in Colorado does not affect alcohol-related traffic fatalities and  $\beta_4$  equals zero. The alternative hypothesis is that the amount of people unemployed is positively associated with alcohol-related traffic fatalities and  $\beta_4$  is positive. If people who are unemployed consume more alcohol than others, then increases in unemployment should be associated with an increased number of alcohol-related traffic fatalities. The null will be rejected if a one-sided t-test at an alpha level of 0.05 is statistically significant.

The null hypothesis for  $\beta_5$  is that the amount of gas and gasohol gallons bought in Colorado does not affect alcohol-related traffic fatalities and  $\beta_5$  equals zero. The alternative hypothesis is that the amount of gas and gasohol gallons bought positively is associated with alcohol-related traffic fatalities and  $\beta_5$  is positive. If the number of cars traveling on the road and

the amount of gas and gasohol gallons bought is associated, then increases in road travel would lead to more traffic fatalities. The null will be rejected if a one-sided t-test at an alpha level of 0.05 is statistically significant.

**Table 4: All Equation Variants**

VARIABLES	(2) Inalcivol	(3) Inyouthalc	(4) Indrugdeaths	(5) Inyouthdrugdeath	(6) Inmarijdeath
RML	0.006 (0.115)	0.032 (0.187)	-0.166* (0.099)	-0.305 (0.189)	0.556*** (0.200)
Textban	-0.404*** (0.120)	-0.551*** (0.192)	-0.258** (0.107)	-0.177 (0.187)	0.747*** (0.168)
Ingasgasohol	2.924*** (0.455)	3.125*** (0.903)	3.784*** (0.445)	3.602*** (0.785)	2.927*** (0.735)
Inalctax	0.020 (0.196)	0.215 (0.317)	-0.038 (0.169)	0.160 (0.293)	-0.321 (0.304)
Inunemp	0.063 (0.153)	0.130 (0.256)	-0.171 (0.127)	-0.249 (0.242)	-0.914*** (0.210)
Constant	-53.534*** (9.380)	-62.063*** (17.337)	-66.333*** (8.707)	-66.357*** (15.582)	-39.568*** (14.392)
Observations	150	150	150	150	150
R-squared	0.332	0.144	0.455	0.193	0.581

Robust standard errors in parentheses, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

The results for equation 2 shown above in the column listed as (2), from table four, indicate that there is no significant association between RMLs and alcohol-related traffic fatalities; the  $\beta_1$  coefficient is not significantly from zero. The texting ban and the natural log of gas and gasohol gallons sold are both statistically significant and take the sign to be expected. The texting ban would decrease accident fatalities, and the increase in the volume of traffic would increase accident fatalities. This model explains 33% of the variation in alcohol-related traffic fatalities.

### 3.2 Equation 3

Another variant of the baseline model, equation 3, estimates the association between RMLs and youth-alcohol-related traffic fatalities. Equation 3 can be written as:

$$(3) \ln(\text{youth alc related traffic fatalities}) = a + \beta_1 RML + \beta_2 \text{Textban} + \beta_3 \text{Lnalctax} + \beta_4 \text{Lnunemp} + \beta_5 \text{Lngasgasohol} + \varepsilon$$

The primary null hypothesis is that RMLs do not affect youth-alcohol-related traffic fatalities and  $\beta_1$  equals zero. The alternative hypothesis is that RMLs decrease youth-alcohol-related traffic fatalities and  $\beta_1$  is negative. The null will be rejected only if a one-sided t-test at an alpha level of 0.05 is statistically significant. All other betas,  $\beta_2$  through  $\beta_5$ , are included in the model for the same reasoning behind equation 2.

The results of this estimation, reference table 4 column listed as (3), indicate that RMLs and the youth-alcohol-related traffic fatalities appear to have no association. As for equation 2, the texting ban and the amount of gas and gasohol gallons consumed both are statistically significant and with their coefficients being the hypothesized negative and positive signs respectively. This version of the model, however, explains only 14% of the variance in the youth-alcohol-related traffic fatalities. One possible explanation for the smaller R-squared is that less data is available for youth-alcohol-related traffic fatalities.

### 3.3 Equation 4

Equation 4, another variant of the general model, estimates the association between RMLs and drug-related traffic fatalities.

Equation 4 can be written as:

$$(4) \ln(\text{drug related traffic fatalities}) = a + \beta_1 RML + \beta_2 \text{Textban} + \beta_3 \text{Lnalctax} + \beta_4 \text{Lnunemp} + \beta_5 \text{Lngasgasohol} + \varepsilon$$

The primary null hypothesis is that RMLs do not affect drug-related traffic fatalities. The alternative hypothesis is that RMLs increase drug-related traffic fatalities and  $\beta_1$  is not zero. A  $\beta_1$  not equal to zero was chosen in the alternative hypothesis because there are two potential relationships between RMLs and drug-related traffic fatalities. There is a positive relationship between increased availability of marijuana and drug-related traffic fatalities, where the increased availability increases overall drug usage. Alternatively, similar to the previous discussion of alcohol and marijuana, marijuana may impair driving less than harder drugs, such as heroin, and the decreased cost of use of marijuana post-legalization will lead some people to substitute their drug of choice (contrary to the “gateway” drug theory). This would lead to a negative relationship between increased availability of marijuana and drug-related traffic fatalities. The null will be rejected only if a two-sided t-test for an alpha level of 0.05 is statistically significant. While this regression focuses on the association between RMLs and drug-related traffic fatalities, other independent variables were included in the model following the same logic described earlier. The results, reference table 4 column listed as (4), suggest that there is no significant association between RMLs and drug-related traffic fatalities. This is interesting because one would speculate that increased access to marijuana would affect drug-related traffic fatalities. This does not appear to be the case which would bolster arguments to support the passage of RMLs since they do not appear to affect other drug usage, at least as far as the impact of drug use on driving fatalities. The other variables in the equation take the expected signs except for the unemployment measure. This variable is, however, not significantly different from zero.

While this paper does not directly investigate the potential substitute vs. complement implications of RMLs, the findings of no association between drug deaths and RMLs offers some implicit conclusions. If the passage of RMLs are not associated with an increase in drug-related traffic fatalities, this would tend to indicate that marijuana does not function as a complement for other drug usage. Why? Because more drug usage would lead to increased impairment while driving which would lead to increased traffic fatalities.

Interestingly, this paper also can draw implicit conclusions about the “gateway drug” argument. If marijuana is a gateway drug, one would expect to see an association with the passage of RMLs in Colorado and increased drug-related traffic fatalities as increasing numbers of people become marijuana users, and subsequent hard drug users. Potentially, this lack of an increase in drug-related traffic fatalities could be explained by the “gateway drug” theory if it takes a considerable time period before a user switches from marijuana to harder drugs. In this case, one would expect to see increases in drug-related traffic fatalities if the data covered a longer time interval.

### 3.4 Equation 5

Equation 5, reference table 4 column listed as (5), estimates the association between RMLs and youth-drug-related traffic fatalities. Equation 5 can be written as:

$$(5) \ln(\text{youth drug related traffic fatalities}) = a + \beta_1 RML + \beta_2 Textban + \beta_3 Lnalctax + \beta_4 Lnumemp + \beta_5 Lngasgasohol + \varepsilon$$

The primary null hypothesis of interest is that RMLs do not affect drug-related traffic fatalities among young drivers. The alternative hypothesis is that RMLs are associated with drug-related traffic fatalities among young drivers and  $\beta$  is not zero. The null will be rejected only if a two-sided t-test for an alpha level of 0.05 is statistically significant.



The results indicate no significant association between RMLs and drug-related traffic fatalities among people age 15-25 years of age. This is worth future investigation with a larger data sample because the results could have been influenced by the limited number of drug-related traffic fatalities among youth in Colorado. It would be interesting for researchers to repeat this regression with a broader scope than one state and a richer data set. As more time passes since the implementation of RMLs, more states will have adequate data to be included in regression analysis of any association between RMLs and drug-related traffic fatalities among youth.

### 3.5 Equation 6

Equation 6, reference table 4 column listed as (6), estimates the association between RMLs on marijuana-related traffic fatalities. Equation 6 can be written:

$$(6)\ln(\text{marijuana related traffic fatalities}) = a + \beta_1\text{RML} + \beta_2\text{Textban} + \beta_3\text{Lnalctax} + \beta_4\text{Lnunemp} + \beta_5\text{Lngasgashol} + \varepsilon$$

The primary null hypothesis is that RMLs do not affect marijuana-related traffic fatalities. The alternative hypothesis is that RMLs increase marijuana-related traffic fatalities and  $\beta$  is positive. The null will be rejected only if a one-sided t-test for an alpha level of 0.05 is statistically significant.

Unlike the previous models, results from estimation of this model show the passage of RMLs have a statistically significant association with marijuana-related traffic fatalities. Interestingly, the magnitude of the coefficient of  $\beta_1$  is substantial, showing that implementation of the RML is associated with a 56 percent increase in the amount of marijuana-related traffic fatalities. The texting ban variable, however, is positive and significantly associated with marijuana-related traffic fatalities, and one would expect it to be negative as it was in previous

results. These results should encourage other researchers to investigate to see if they can replicate the results of the statistically significant association between RMLs and marijuana-related traffic fatalities while improving the regression to account more accurately for the effects of a ban on texting. The variables for unemployment and gas also are significantly associated with marijuana-related traffic fatalities.

## **4 Conclusion**

This paper sought to replicate and extend the results reported by Anderson, Hanson, and Rees (2013). They reported that the passage of marijuana laws is associated with decreases in alcohol-related traffic fatalities, whereas this paper did not. There are several reasons that may explain why this paper's results differ from previous inquiries. For example, studies based on the passage of medical marijuana laws (MMLs) had a much longer time period of post-implementation data available to them. Furthermore, the data available to the previous paper covered most states and gave the authors a much larger data set to work with. Also, the MMLs paper had a different model specification: they included more safety control variables for things such as seat belts or zero-tolerance laws and specified their model to include indicators for marijuana decriminalization, which this paper did not. As well, with their model, the authors utilized leads and lags in their regression estimation. This is another difference from this paper which did not. Finally, this paper, while taking a similar approach to the MMLs paper, diverges enough that the lack of association between RMLs and alcohol-related traffic fatalities could be a result of different specifications.

Several things that would have improved this paper include population control, uniform availability of marijuana in Colorado, a counterfactual capturing the no implementation trend, and data for additional states. A population variable would have been beneficial to control for the influxes and outfluxes of the state of Colorado. Unfortunately, the only available data, from the United States census, are estimated annually and would not fit with this paper's use of monthly data.

Although the uniform availability of marijuana in Colorado is not feasible, such a scenario would likely increase the precision of the model's estimates. Colorado legalized recreational marijuana in 2012, but the state left the discretion up to the counties on whether to permit recreational marijuana dispensaries. For example, GQ magazine reports that in 2014 seventy-five percent of dispensary licenses granted were in the city and county of Denver<sup>14</sup>. The Denver Post acknowledges the disparity of counties with recreational dispensaries and counties without dispensaries continued through 2016 as some places feel that recreational marijuana will hurt local county tourism dollars<sup>15</sup>. The challenge with the variety of dispensary permits and concentrations in certain locations is that variance in local access creates for higher opportunity costs for some potential recreational marijuana users than others. For example, if one lives in a dry county, it may take an hour drive to reach a location that is a permitted recreational marijuana dispensary. This added time increases the opportunity cost for recreational marijuana use for some counties. Therefore, this increased cost may result in fewer people using recreational marijuana, and thus, limiting the effect of RMLs. It would have been much more

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<sup>14</sup>Christian, Scott. "6 Things You Need To Know To Be a Colorado Weed Tourist." GQ (August 09, 2017). Accessed March 24, 2019.

<sup>15</sup> Aguilar, John, and John Aguilar. "Marijuana Gap Divides Colorado Towns That Sell Pot, Those That Don't." The Denver Post (October 02 2016). Accessed March 24, 2019.

beneficial if the RMLs implementation coincided with even distribution of recreational dispensaries across counties.

Data for additional states would have improved this paper. With only one state serving as a source of data, for example, the association between RMLs and marijuana-related traffic fatalities could be a “Colorado effect” instead of the RMLs effect. It is possible that there are unique attributes to the state of Colorado that manifested through its RML and marijuana-related traffic fatalities association. The inclusion of more states’ data would serve either to replicate the association between RMLs and marijuana-related traffic fatalities or confirm the “Colorado effect” explanation. Another benefit of the inclusion of more states is that a larger data set would be available for study. For example, the monthly total of fatalities for youth-alcohol-related traffic fatalities and youth-drug-related traffic fatalities in Colorado alone often was low or zero. The inclusion of more states would boost the numbers of driving fatalities associated with drug or alcohol use and offer better data for analysis.

A counterfactual would have improved this paper. This paper only looked at data for Colorado, and this is a severe limitation. Colorado offers pre- and post-RML treatment data; however, Colorado cannot demonstrate what would have happened to traffic fatality trends if no RML was implemented. By adding data on states similar to Colorado that never implemented RMLs, this paper would offer a counterfactual that would allow for better interpretation of the effects of RMLs. This approach is called a Difference in Difference analysis. This paper chose not to implement a Difference in Difference because of time constraints and limited state-level data for such a comparison.

While this paper does not include a counterfactual, a paper by Hansen, Miller, Weber (2018) investigates the impact of recreational marijuana laws on traffic fatalities in Colorado and

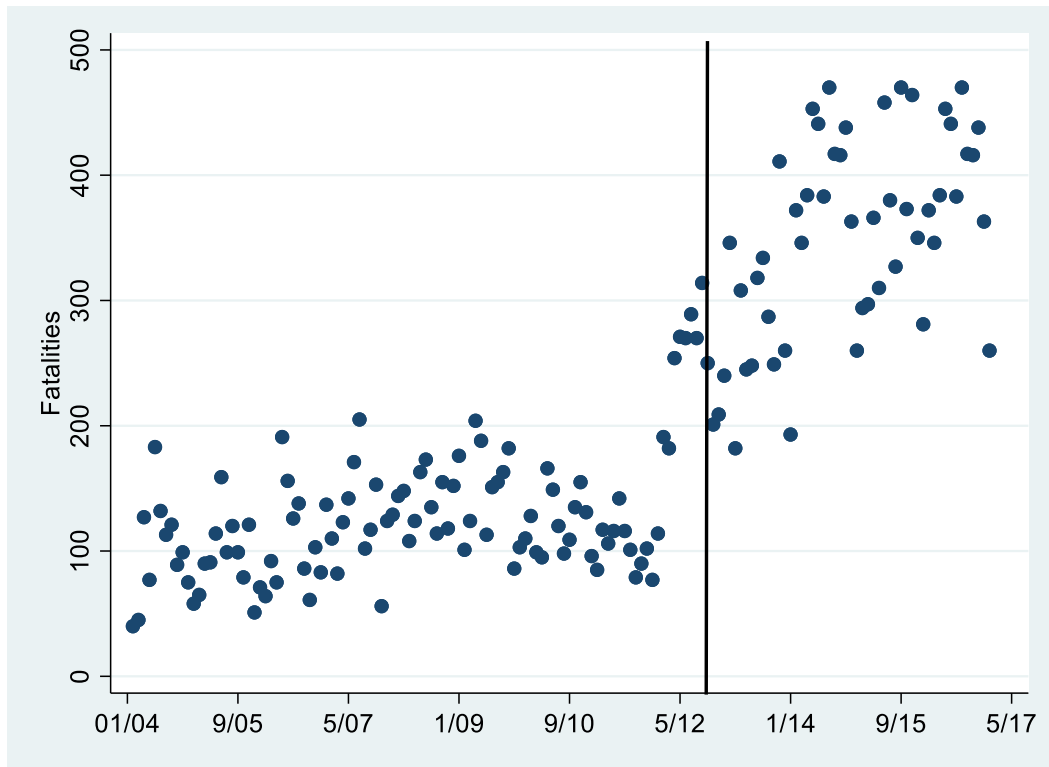
Washington, and the authors use a synthetic control approach to serve as a counterfactual<sup>16</sup>. Their synthetic controls, simulating no recreational marijuana law passage in Colorado and Washington, show increased marijuana-related traffic fatalities, alcohol-related traffic fatalities, and total traffic fatalities. This increase of fatalities casts doubts on if the implementation of a recreational marijuana law and an association with increased marijuana fatalities represent a causal relationship. To investigate further, this paper took FARS data for states that implemented neither an RML or MML and looked at the trend of marijuana-related traffic fatalities to see if it could supplement the marijuana-related traffic fatalities trend that the Hansen, Miller, Weber paper found with their synthetic control.

Figure 13 shows the increase in marijuana-related traffic fatalities over time for states without MMLs or RMLs, and the vertical line represents the date of legalization of recreational marijuana use in Colorado, November 2012. A rapid increase in marijuana-related traffic fatalities is clustered around November 2012. This paper conjectures that this increase may be related to either a change in preferences for marijuana use for all states or that recreational marijuana use legalization in some states lowers the cost of use in other states. For example, someone who lives in a non-legal use state could drive to a legal use state to purchase marijuana. This paper recommends that these lines of inquiry be investigated to determine what is driving the increase in marijuana-related traffic fatalities of the national trend.

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<sup>16</sup> Hansen, B., Miller, K., & Weber, C. "Early Evidence on Recreational Marijuana Legalization and Traffic Fatalities." *NBER* (March 16 2018). Accessed April 1, 2019.

**Figure 13: Comparison of the change in Monthly Marijuana-related Traffic Fatalities for all States without any Recreational or Medicinal Marijuana Laws, from 2004-2016**



Furthermore, this paper suggests that a reexamination of the implications of recreational-marijuana laws and traffic fatalities be explored later, after more data accumulation. Recreational use of marijuana in the earliest states was legalized less ten years ago, and Colorado state-level data are available only through 2016. This paper explores the relationship between Colorado's RML and traffic fatalities, but any conclusions about long-term impact would require more years of data.

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