THE RELATIONSHIP BETWEEN CANNABIS LEGALIZATION AND U.S. TRAFFIC FATALITIES

By

Victoria Paige Mosby

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Supervisor: Sergey Lychagin

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Abstract

This study expands on the current empirical literature on the relationship between recreational and medical cannabis legalization and traffic fatalities across states in the United States. The methodology used in this study is panel data regression with time and state fixed effects for 50 states from the years 2008 to 2020 with data from the United States Department of Transportation's National Highway Traffic Safety Administration. The empirical findings of this study point to a negative relationship between the legalization of cannabis with traffic fatalities. However, the addition of the unemployment rate suggests an increase between all types of legalization and traffic fatalities.

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Introduction

Cannabis legalization has been a trending topic in the United States, Canada, and the European Union for the past decade and has not been without controversy. While still illegal at the federal level in the United States (US) and in the European Union as of June 2023, states, and member states, respectively, have sought to change the legalization status. While there is a desire for states to legalize and regulate cannabis, there is still much to be learned about its effects and how local or federal governments can implement effective policies.

Cannabis, sometimes referred to as 'marijuana,' refers to derivatives of the *Cannabis sativa* plant. Two of the main substances, or cannabinoids, that come from cannabis are cannabidiol (CBD) and tetrahydrocannabinol (THC), the former is known for its medicinal properties, and the latter is the primary agent responsible for producing a psychoactive effect ("Cannabis (Cannabis) and Cannabinoids: What You Need To Know" n.d.). It is this psychoactive substance that is outlawed in many regions as the extent of the effect of THC on cognitive functioning is still being researched[1]. Meanwhile, also part of the Cannabis sativa plant albeit a distinct species (specifically Cannabis sativa Linn), hemp has extremely low amounts of THC ("Hemp" n.d.) and therefore it does not produce a psychoactive effect (CBD can be found in both varieties). Unlike cannabis containing THC, hemp is legal and regulated in the European Union and the United States.

Recreational cannabis legalization is when a state permits the use of individuals to consume cannabis without the need of approval from a healthcare individual, as opposed to medical legalization which still requires evaluation from a doctor, or decriminalization which removes the possession of, or consumption of, cannabis from a criminal to a civil infraction ("Cannabis Overview" n.d.).

[1] From here on, I will refer to cannabis containing THC as cannabis and that will trace amounts as hemp. The focus in this paper is cannabis containing psychoactive properties.

According to the United States Drug Enforcement Administration, cannabis is listed as a Schedule 1 drug, signifying that there is yet an accepted medical use and that there is a high potential for abuse of cannabis ("Drug Scheduling" n.d.). The World Health Organization (WHO) cites cannabis as the most consumed and trafficked drug with a consumption of approximately 2.5% of the global population ("Cannabis" n.d.). Despite this lack of understanding, laws around cannabis have been rapidly changing.

One policy that remains cryptic in the United States is the law regarding driving under the influence, more specifically drugged driving. The WHO highlights the physical limitations of cannabis use highlighting that it hinders psychomotor performance and can even compromise the ability to use complex machinery for as long as 24 hours. WHO also acknowledges that the risk of vehicle accidents increases when individuals drive after consumption("Cannabis Overview" n.d.).

As more states change their policy on cannabis, is there a difference between medical and recreational cannabis legalization on the impact of traffic fatalities? What policies should states be considering before adopting new cannabis laws? Are there other potential insights to be gathered from legalization in other countries and states?

To capture the variation across states and over time that may not be observable, I run a fixed effects regression similar to a model developed by Ruhm in his iconic piece on alcohol policies and traffic fatalities. I consider the population and the unemployment rate of each state to better understand the number of traffic fatalities and any economic trends that may influence traffic fatalities or consumption of cannabis, such as a recession (where driving or consumption might decrease unrelated to policies enacted).

Current literature on cannabis and road safety points to a decrease in traffic fatalities in MCLS however, there is an increase in RCLS which may hint that the private versus public consumption of cannabis may impact the number of impaired drivers behind the wheel. My

findings show a negative relationship between recreational and medical cannabis with traffic fatalities, yet with the addition of the unemployment rate, it shows a slight positive though not significant association.

In Chapter 1, covers the background including the historical context of laws and policies in the institutional setting followed by a literature review. Chapter 2 covers model specification. Then, Chapter 3 covers the results, discussion, policy recommendations and the conclusion.

Chapter 1: Background

Description of Institutional Setting

Global Context

Uruguay and Canada are the only two countries that have permitted the cultivation, production, consumption, and regulation of cannabis. More than half of the states in the United States have legalized recreational cannabis and several more have adopted a medical cannabis program. Member states in the European Union, namely Germany has voiced its intention to develop a cannabis program. In both the United States and in the European Union, states that adopt cannabis laws are in direct violation of federal laws causing a discrepancy between local and federal law enforcement. Understanding the global context of cannabis laws can provide insights into the markets of an emerging sector, as well as dynamics between states and federations or supranational unions, international research or legal frameworks, and public health strategies.

Currently four types of current cannabis supply models. The market model which is taxed, and the supply is commercial, has many licensed growers and retail stores which can be found in Alaska, California, Colorado, Maine, Massachusetts, Nevada, Oregon, and Washington. Secondly, is a government supply type which signifies that the government can limit the number of growers and outlets. Alternatively, some states, Washington D.C., and Uruguay permit self-cultivation which constitutes no tax and no retail outlets. Finally, social clubs are

groups of individuals that cultivate cannabis in a collective which also incurs no tax or retail. Currently Uruguay employs government supply, self-cultivation, and social clubs. Washington D.C. only has self-cultivation. The state of Washington, however, does not permit home grow (EMCDDA).

Uruguay

Uruguay became the first country to legalize cannabis in December 2013("| Parlamento UY" n.d.). As of 2018, one year after the introduction of cannabis in pharmacies, eight of 19 regions in Uruguay have pharmacies that sell cannabis to approximately 18,981 registered users (the actual number of registered is higher but not all of them make purchases) of the 3.5 million people that live in the country. Upon registration, users must select one of three supply mechanisms: growing at home, joining a social club, or purchasing (“Uruguay Reports on Regulated Cannabis Growing and Sales | Www.Emcdda.Europa.Eu .

Canada

Despite the use of the word ‘marijuana’ which comes from the Mexican term, the increase in cannabis usage has been in Western Europe, Australia, and North America (“Cannabis” n.d.). Canada passed legislation that allowed the consumption of cannabis in October 2018 (Government of Canada 2018a). Much like the United States, provinces decide the limits of cannabis sales, the location of stores, and can set further restrictions on possession limits, public consumption locations, and personal cultivation. Unlike the U.S., cultivation is regulated at the federal level to ensure product safety.

Canada’s implementation of cannabis also included regulations against impaired driving. Police use sobriety and saliva tests roadside, blood testing and evaluation by a drug recognition expert (not medically trained). The first offense can result in a $1000 fine with the possibility of up to 10 years in prison. A second offense results in a minimum of 30 days in prison with a maximum of 10 years. The third offense is a minimum of 120 days in prison. It is illegal in Canada to consume cannabis in a car even when parked (Government of Canada

2018a). To ensure traffic safety, Canada has implemented a threshold for the concentration of THC in the bloodstream for drivers. They even have a differing severity scale, those with a THC concentration of 2 and 5 ng are punished less severely than those above 5 ng. Although Canada experienced an increase in impaired driving within the first year after legalization, it could be due to the expansion of policing that led to a rise in the rate in 2019 (Government of Canada 2018a). However, it could also be due to a general increase in consumption or attitudes.

The government of Canada conducted a survey that explored the behaviors of drivers. Of the group that had consumed cannabis within the past 12 months, 14% claimed that they had at some point gotten behind the wheel within 4 hours after consuming cannabis. Of this group, nearly one- third stated having done this within the past month. There was also a slight increase within the past three years of a passenger in a car with someone who had used cannabis within 2 hours of driving nearly 30% ("Canadian Cannabis Survey 2022: Summary" 2022). This shows the increasing trend for cannabis consumption and the prevalence of cannabis even while driving.

In 2017, Canada saw nearly 3,500 substance-impaired driving incidents. One year after passing recreational legalization of cannabis, Canada saw an increase drug-impaired driving, up 43% (Government of Canada 2018b). In the United States Repository & Open Science Access Portal found that 56% of drivers involved in serious or fatal accidents tested positive for at least one drug in 2020 (United States. Department of Transportation. National Highway Traffic Safety Administration. Office of Behavioral Safety Research 2021). Additionally, a survey conducted by the National Roadside Survey discovered that nearly 20 percent of drivers that were surveyed tested positive for performance hindering substances (Berning, Compton, and Wochinger, n.d.). The surveys also pointed out that between 2007

and the 2014, there was nearly a 50% increase of drivers who tested positive for cannabis ("Drug-Impaired Driving | NHTSA" n.d.).

The United States

The topic of states' rights has a long history in the US. Even at the turn of the 20th century, advocates against alcohol proposed a constitutional amendment forbidding its manufacturing, sale, and consumption. Ultimately, this led to the creation of the 18th amendment, alcohol prohibition, with approval from three-fourths of the states. Two decades later it was repealed, and again with the approval of the states, ratified in the 21st amendment, ending prohibition. Both movements highlight the potential that states have in influencing national policies and how cultural attitudes can change over time.

Between the mid-1800s until 1942, cannabis was listed as a remedy for several ailments in the *United States Pharmacopeia* until California outlawed it for recreational use in 1913, followed by the rest of the states just before the onset of the Marijuana Tax Act. With the Marijuana Tax Act, it was discontinued as a medicinal remedy (Medicinal Cannabis (Bridgeman and Abazia 2017)). Again, the initial wave of cannabis legalization originated in California with the Compassionate Use Act, or Proposition 215. Proposition 215 was an initiative passed in 1996 allowing the use of cannabis for medical purposes ("Cannabis | MBC" n.d.). The creation of this law resulted in a conflict between federal authority and states' rights that is still prevalent today.

Currently, in the United States, the latest federal mandate change on cannabis is the 2018 Farm Bill, or the Agriculture Improvement Act of 2018, effectively removing hemp as a controlled substance, allowing for cultivation and production ("Hemp" n.d.). Although this marked a prominent change in the United States drug policy, states as well as EU member states have further pushed for changes for cannabis containing a higher percentage of Δ9-tetrahydrocannabinol (THC).

There are over 212, 159,000 drivers in the United States (United States. Department of Transportation. Bureau of Transportation Statistics 2019). There remains a heterogeneity between states on the legalization of cannabis. Across the United States, some states have adopted laws that grant adult use over a certain age, which will be referred to as RCLS (recreational cannabis law states). Conversely, states that do not permit the use without a medical provider will be referred to as medical cannabis law states (MCLS). States that have no public cannabis access program are Idaho, Nebraska, and Kansas. Other states have developed medical cannabis only laws, some have simply decriminalized cannabis use, and a few have still outlawed the possession and consumption of it.

In the United States, to date, only in Idaho, Wyoming, Kansas, and South Carolina is cannabis fully illegal without decriminalization. Additionally, North Carolina, District of Columbia, and Nebraska have decriminalization however, cannabis is still illegal.

According to the National Organization for the Reform of Marijuana Laws, nearly every state has adopted some form of legalization such as allowing low-THC (11) or medical cannabis (39 + U.S. territories) usage with doctors' oversight. States which have medical legalization and decriminalization include New Hampshire in 2013, Maryland and Minnesota in 2014, North Dakota and Ohio in 2016, and Mississippi in 2020. States in which medical is legal but in which it is not decriminalized are Arkansas, Florida, Louisiana, and Pennsylvania in 2016, West Virginia in 2017, Oklahoma and Utah in 2018, and South Dakota in 2020[2].

To date, approximately 22 states have legalized recreational cannabis, including: Colorado and Washington in 2012, Alaska and Oregon in 2014, California, Nevada, Maine, and Massachusetts in 2016, Vermont and Michigan in 2018, Illinois in 2019, Arizona, Montana, New Jersey, South Dakota2[3] in 2020, New York, Virginia, New Mexico,

[3] South Dakota's Supreme Court has since tried to reverse legalization.

Connecticut in 2021, and Rhode Island, Maryland, and Missouri in 2022. Recreational legalization entails that local governments can govern the cultivation, production, and sale of cannabis and that individuals need not obtain permission from a medical doctor for purchases ("Legalization" n.d.).

While states have begun to change their policies, a question that naturally emerges is whether there is an underlying variation in the consumption of cannabis. Has allowing access to cannabis increased its consumption? According to a survey conducted in 2018, the percentage of adults that reported consuming cannabis within the past 30 days increased from the previous year across all age groups. Between 2016 and 2018, the percentage of adults in California exposed to secondhand smoke increased from 21.5 to 39.9% More notably, in 2018 over 12 million adults in the U.S. stated that had driven under the influence of cannabis in the past 12 months. This is a 47% increase since 2014. Between 2013 and 2017 there was an increase of 4 percentage points of drivers in California who tested positive for cannabis that was involved with fatal accidents (CPHD 2020). With this information in mind, it is vital for policymakers to understand the effects that cannabis consumption can have on drivers.

The European Union

Currently, in the United States, the latest federal mandate change on cannabis is the 2018 Farm Bill, or the Agriculture Improvement Act of 2018, effectively removing hemp as a controlled substance, allowing for cultivation and production ("Hemp" n.d.). Although this marked a prominent change in the United States drug policy, states as well as EU member states have further pushed for changes for cannabis containing a higher percentage of Δ9-tetrahydrocannabinol (THC).

Currently no national government in Europe supports the recreational use of cannabis though proposals have been presented in recent years. Laws regarding punishment for cannabis among member states are varied; more than one third of countries do not permit prison time in special circumstances and others advise against imprisonment. Every country

punishes impaired driving. However, the use of saliva testing is not ubiquitous and for legal action many countries require blood testing (EMCDDA).

In the Netherlands, despite the existence of Dutch coffeeshops, locations that sell and where people can consume cannabis, the personal possession and sale of cannabis is still punishable according to national law though tolerated (EMCDDA). In recent years, some regions in Spain tried to create legislation for cannabis social clubs, where people could cultivate their one allotted cannabis plant together with others, but the Spanish Supreme Court ruled it out stating that the collaboration of such an organization would be "considered drug trafficking" (EMCDDA).

Hemp, however, is legal and cannabis products used for industrial or medicinal purpose are permitted (the latter is based on the member state), except for consumption via smoking which no country allows.

As of May 2023, Germany has announced plans of developing legislation on cannabis reform highlighting the need for European countries and the United States to fully understand its impact ("Germany's Two-Step Plan to Legalize Cannabis – DW – 04/14/2023" n.d.).

Literature Review

In "Alcohol Policies and Highway Vehicle Fatalities", Ruhm explores various types of alcohol policies and the implementation of beer taxes on highway vehicle fatalities between 1982 and 1988 in the United States. Using a fixed-effects regression which estimates minimum age drinking laws, beer taxes, and other policies on traffic fatalities, he shows that each policy employed reduces fatalities considering differences across the states. Although this paper explores the relationship between alcohol, beer taxes, and traffic fatalities, the design is ideal for exploring the connection between cannabis and traffic fatalities. Instead of looking at policies implemented as cannabis is relatively new, we can look at the types of legalization to see whether there is an underlying trend across all types or whether the types of legalization make a difference.

Many articles have been written discussing the medical effects of cannabis. Additionally, there have been some preliminary studies that have only included a few states for a few years. Given that the number of states legalizing cannabis is growing, I would like to analyze the effects across many states over a longer period and differentiate between medical and recreational cannabis to see if there is a difference in outcomes between these two types of policies.

Medical Cannabis

Several papers have been written on the topic of legalizing medical cannabis. As stated by the European Monitoring Centre for Drugs and Drug Addition (EMCDDA), that even within the European Union some cannabis products have been tolerated for medical use (EMCCDA). Legalizing medical cannabis would mean that individuals could access cannabis products with a prescription of a doctor typically for ailments such as pain or nausea.

States that do not permit the use without a medical provider are North Dakota, Minnesota, South Dakota, Utah, Oklahoma, Louisiana, Mississippi, Alabama, Arkansas, West Virginia, Kentucky, Ohio, Pennsylvania, New Hampshire, Florida, and Hawaii. I will refer to these states as medical cannabis law states or MCLS. Throughout the studies, a general trend shows that states which previously had no cannabis laws and adopted some form of medical cannabis saw no significant increase, even a decrease in traffic fatalities across the United States. There have been numerous studies employing various methodologies, analyzing different states or jurisdictions, and focusing on different time periods.

Anderson et al (2013) conducted research employing data from the Fatalities and Accident Report System (FARS) in the United States. The research focused on individuals between the ages of 15 and 60 between 1990 to 2010. The motivation behind this study was to examine the association between medical cannabis legalization and traffic fatalities, citing that motor vehicle death is the leading cause of death among those between 5 and 34 in the United States.

The authors utilized data from FARS, to analyze blood drug tests and even socioeconomic variables to ascertain that medical legalization led to an eight to 11 percent decrease in traffic fatalities for states that adopted medical cannabis laws compared to states that did not for the first full year after legalization. The authors note the impact from alcohol consumption is greater on traffic fatalities than medical cannabis. They also conclude that the effect of the legalization of medical cannabis is "strongest among young adults," even when the median age of cannabis patients is greater than 40.

The methodology used in this study is ordinary least squares estimates yet, when state specific time trends were included, the decrease in traffic fatalities were no longer significant. Using a model with the log of the total fatalities as the left-hand variable, the authors controlled for the unemployment rate, income, miles driven, as well as included binary variables such as zero tolerance laws, speed limit over 70MPH (miles per hour), hands free laws[4], and texting ban. This literature gives a well-rounded perspective on medical cannabis and alcohol laws; however, it does not rule out mechanisms for why cannabis has a smaller impact than alcohol.

Salomonsen-Sautel et al (2014) further expanded on the FARS data, picking up not only blood but also urine analysis of drivers involved in fatal crashes in Colorado and 34 control states between 1994 and 2011 with the first dispensary in Colorado having opened in July 2009. The authors used linear regression, generalized least squares methods to conclude that there was a significant trend change in Colorado, but there was no significant change in other states that had implemented medical cannabis laws. The main limitations of this study are that only fatal traffic accidents were analyzed, versus all accidents. Additionally, it is unclear whether the results can be generalized to other states. The authors did discover that

[4] Hands free laws – drivers are prohibited from driving with an electronic device in their hands

drivers testing positive for cannabis in Colorado increased after the introduction of commercial dispensaries and it is not seen in control states.

Unlike Salomonsen-Sautel et al (2014), Masten and Guezburger (2014) discovered an increase in traffic fatalities in California, Hawaii, and Washington when employing a time series analysis with an auto-regressive integrated moving average. The authors looked at 12 (originally 14, two were excluded) states with medical cannabis laws and had 37 control jurisdictions from 1992 until 2009. The other nine states that had adopted MCL did not see an increase in traffic fatalities.

While the authors discovered that there was an increase in cannabinoid prevalence in a few states, that did not hold true for the other states that had implemented MCL. What they discovered was an increase, however, they were only for one-time changes suggesting that this type of policy did not create new users over time. While the authors did look at the level of cannabinoids in the blood of drivers in non-legalized states, the testing across states is not standardized and therefore the results may not be precise.

(Santaella-Tenorio et al. 2020) further expanded on the timeframe of MCLS looking at traffic fatalities across the entire 50 states from 1985 until 2014. The authors took into consideration the supply mechanisms within these states looking at the role of dispensaries. The data was comprised of over 1.2 million observations and segmenting drives in three age groups: below 24, 25 to 44, and above 45 years of age. Like Anderson et al, the authors found that states with medical cannabis laws had lower rates of traffic fatalities compared to states that did not for 7 of the states including California, Oregon, Washington, Colorado, Nevada, New Mexico, and Arizona. However, there was an increase for Rhode Island and Connecticut. In their hybrid model, which included immediate and trend effects, California and New Mexico saw gradual increases. This is in opposition to the findings of Masten and Guezburger which cited that California, Hawaii, and Washington had an increase compared to the other

MCLS. Additionally. dispensaries present had a significant reduction in adults aged 25 to 44, however, for the rest of the population the results were not significant.

Utilizing the blood test in the FARS data, the authors ran multilevel regressions with state-level random intercepts determining that causal relationships cannot be established. While there was a long period of data prior to the inception of the first medical cannabis law in California, the periods post legalization were relatively short for some of the states, neglecting potential lags.

In conclusion of the medical cannabis studies, further examination post period could be implemented. Perhaps there could be further exploration on the state of California as authors could not agree on whether there was an increase or decrease and the mechanisms behind the potential increase/decrease for this state were unclear. While these studies consider MCLS they do not differentiate between medical only and medical and decriminalization states which could be a factor in the lack of uniformity in their results.

Recreational Cannabis

Recreational cannabis legalization began in the United States with Colorado and Washington in 2012. Uruguay became the first country to legalize cannabis in 2013 and Canada became the second country in 2018. Recreational legalization refers to the allowance of individuals to obtain cannabis from legal sources without the need to go through a medical provider.

(Lane and Hall 2019) examined the impact of legalized recreational cannabis on traffic fatalities in neighboring states between 2009 and 2016. Looking at RCLS, in this case Colorado, Washington, and Oregon, and their neighboring states, they utilize a generalized least squares regression, pooling the coefficients and standard errors, and account for seasonal variations. Monthly fatality rates per million individuals were taken from CDC WONDER, RoadSafetyBC, as well as census data.

Their findings suggest an increase in traffic fatalities (step increase per million) however, it accompanied by a trend reduction. Comparing RCLS to non-legalizing states, there was a temporary increase in traffic accidents that can spill over into other states.

Despite the results, economic factors, other forms of substance consumption and cultural or political attitudes were not considered during this research. Additionally, the relatively small sample size, the exclusion of Idaho, and neighboring states becoming legalizing states (as was the case with Oregon) hinder the quality of the conclusion. As Idaho is one of the only states in which cannabis entirely remains illegal, excluding it from the study may bias the result. In addition to states studied, another aspect to note is that the access to cannabis after legalization may be suppressed as states had yet to implement operational dispensaries. Further research is needed on this and as more states legalize recreational cannabis, results may change.

Aydelotte et al (2019) perform a difference-in-differences study to look at the relationship between recreational cannabis and traffic fatalities in the United States between 2007 and 2017. This study was limited to Colorado and Washington as well as limited to fatal traffic accidents meaning it neglected some states where recreational cannabis was also legalized. In looking at Colorado and Washington the analysis found that there was a positive association between traffic fatalities with recreational legalization however, the results were not significant. Moreover, the data showed that there was statistical significance when considering the opening of commercial dispensaries. This is in direct opposition with the study by Santaella-Tenorio which found that there was a reduction in fatalities with the presence of dispensaries under medical legalization.

Borst et al (2020) examined traffic fatalities between 2010 and 2018 using data from San Diego County's trauma centers. The authors leveraged blood and urine samples to obtain information about THC and alcohol presence in patients. They ran multivariate logistic, linear,

binomial logistic, and time-series regression analysis to determine that cannabis concentration levels were higher in post-periods and concluded patients obtained more serious injuries. While data was obtained from these trauma centers, there is still no threshold for cannabis consumption while driving. Additionally, there was variation in testing between the centers. The information in this study may be particularly helpful to the healthcare industry which may want to make additional arrangements in anticipation for recreational legalization. However, the biggest drawback from this study is the lack of standardization which not only undermines the validity of the results, but it also highlights the inconsistencies across the United States in drug testing policies.

(Lensch et al. 2020) conducted a study on the recreational legalization of cannabis on traffic fatalities exploring the behaviors and attitudes of drivers. The authors employed Chi-squares tests to study drivers and passengers in the United States in states[5] that already had established legal sale dispensaries and states that had yet to implement dispensaries post legalization.

Obtaining data from self-reported web-based surveys they gathered information on attitudes related to driving, consumption, and frequency of cannabis use determining that there was a higher incidence in states that legalized cannabis within the last 30 days and the last 12 months. The authors note that when segmenting by frequency of consumption, states with sales and significantly lower rates and their attitude towards taking protective driving measures was higher compared to states without sales. The study found that drivers believed that driving drunk was more dangerous than driving high.

Windle et al (2021) explored the relationship between cannabis legalization and deaths from motor vehicle collisions in the United States. Study was funded by the Canadian

[5] Only six states at the time of the study had implemented a recreational retail market: Alaska, California, Colorado, Nevada, Oregon, and Washington.

Institutes of Health Research to analyze the association between recreational cannabis legalization and fatal traffic collision rates for Canadian policy. Using data from Embase, MEDLINE, PsycINFO, SafetyLit, ProQUest, and FARS with an interest group of 7[6] states and a control group of 10 states between the years of 2007 and 2018, the authors concluded that there was an increase however, the increase was not significant after the first year. More specifically, they found that national recreational of cannabis in the United States may increase traffic fatalities by 4,843 annually, or 308 for Canada. A secondary analysis was performed to look at when commercial cannabis dispensaries opened however, the authors did not find significant results with this.

Although the authors included cannabis-specific impaired driving laws, zero tolerance, per se limits on THC concentration levels to reveal an increase in fatalities in the first year post recreational legalization using Poisson regression and meta-analysis estimates, this study was an observational study and the jurisdictions differed among the states. The study did not include states that legalized cannabis in 2019 or after. The limitation that I see with this analysis is the relatively small number of states as only 10 are implemented in a control group and some had a relatively short legalization period. Additionally, the distinction between the onset of the legalization period and the initiation of operational dispensaries could have been further explored.

(Tefft and Arnold 2021) studied drivers involved in fatal crashes in Washington using the blood drug test in the FARS data with a pre-period from January 1, 2008, to December 5, 2012, and a post-period from December 6, 2012, until December 31, 2019. The authors utilized logistic regression and marginal standardization to conclude that there was an increase

[6] The states of interest included Alaska, California, Colorado, Maine, Massachusetts, Michigan, Nevada, Oregon, Vermont, Washington, and the District of Columbia.

in the proportion of drivers that tested positive for THC and an increase in the overall concentration of THC in the blood.

The biggest contribution here is that the authors used imputation to validate the differences between testing for cannabis in the same way that has been used before for blood alcohol levels. Secondly, they also accounted for drivers that did not have a valid license, had a previous DUI, or had previous license suspension. However, in this study data was missing for 49% of the observation for THC, 45% for other drugs and 44% of the time for alcohol and there was no comparison for states that had not legalized cannabis recreationally. Those whose THC status was known (regardless of whether it was positive or negative) died nearly three-quarters of the time where those whose status was unknown was only 17%. In their findings results were consistent with other research showing that there was an increase in crashes, fatalities, or insurance claims. On the other hand, the authors point out that the estimates of fatalities increasing is unlikely unless there was also an increase of crashes that did not involve cannabis after legalization.

(Benedetti et al. 2021) studied cannabis policy changes and use among adolescents in Europe. Taking data from the European school Survey Project on Alcohol and other Drugs (ESPAD) they find that out of 13 European countries from 2001 – 2014, had an impact on adolescents. The difference-in-differences method was utilized looking at policies such as: removing the prison sentence for minor offenses, reducing maximum prison sentence, facilitating closure of minor cases, increasing the non-prison penalty, and increasing the prison penalty. Authors concluded that no policy change contributed to a decrease in the frequent use of cannabis group nor in the perception of availability among frequent users. However, some policies related to an increase in cannabis use, and some policies that implemented harsher policies were associated with decreasing in the perceived cannabis use and availability of cannabis.

Kilmer et al (2022) provides a look into context of Uruguay, the initial country that legalized cannabis in 2013. The authors analyze the different types of supply mechanisms using ordinary least squares regression to examine the association between them. Using quarterly government data between 2013 and 2019, and economic and demographic characteristics they found that there was not a statistically significant correlation between the number of registrations and crashes (all crashes not just fatalities). There was, however, a positive and statistically significant difference between the number of home growers and traffic accidents that resulted in injuries. This literature provides empirical analysis on the policies that governments can implement in the design of distribution or supply of cannabis.

While further evidence in needed for recreational cannabis as the period post-legalization is rather short, there does appear to be an increase overall of traffic fatalities, at least initially with the introduction of operational dispensaries. Perhaps further exploration of supply mechanisms in the North American context could provide valuable insights for policymakers. There is also a greater need to understand the behavior and attitudes of groups in the United States and Europe about cannabis.

Data

In this study, I will take data from the U.S. Department of Transportation's National Highway Traffic Safety Administration from the years 2008 to 2020 to see the relationship between cannabis legalization and traffic fatalities in the US. The variables of interest in this data set are the states (51 when District of Columbia is included), year, month, day of the week, drunk driving, weather, and fatalities. For traffic fatalities, I combined the total number of fatalities by state for a given year then multiplied by 1000 and divided by the state population to account for differences in population across states.

To monitor changes in unemployment and population, I downloaded data from the U.S. Department of Labor, Bureau of Labor Statistics between 2008 and 2020 looking at the unemployment rate and population per state.

From the Fatalities Analysis Reporting System, I will explain the following coding:

Year: 20XX

Month: 1 – January, 2 – February, 3 – March, etc, If the month is unknown then month is 99.

Day: The first day of the month is 1, the second is 2, etc. If the day is not reported, then it is listed as 99.

Day of the week: Sunday is 1, Monday is 2, etc. if the day is unknown then it is listed as 9.

Hour: FARS uses military time therefore midnight is 0 until 11PM is 23; if unknown then 99.

Minute: 0 – 59, 99 Unknown

Drunk_dr is the number of drunken drivers involved in the fatal accident.

Weather: a 1 indicated clear weather, 2 stands for rain, 3 is sleet or hail, 4 is snow, 5 is fog, smog, smoke, 6 represents sever crosswinds, 7 is blowing sand, soil, dirt, 8 stands for other, 10 is for cloudy weather, 11 represents blowing snow, 12 is freezing rain, 98 is not reported and 99 is unknown. There is no 9 indicated in this sequence National Highway Traffic Safety Administration).

Summary Statistics

Variable	N	Mean	Std. Dev.	Min	Pctl. 25	Pctl. 75	Max
STATE	561	29	16	1	16	42	56
YEAR	561	2015	3.2	2010	2012	2018	2020
MONTH	561	1.1	0.35	1	1	1	5
DAY	561	4.7	6.1	1	1	6	31
DAY_WEEK	561	3.9	2.1	1	2	6	7
HOUR	561	12	13	0	4	17	99
DRUNK_DR	561	0.4	0.5	0	0	1	2
WEATHER	561	6.2	17	1	1	5	99
POP	561	6278499	7082167	563626	1752074	7164228	39437610
LOGPOP	561	15	1	13	14	16	17
RATE_UN	561	5.8	2.3	2.1	3.9	7.3	14
TOTAL_FATALS	561	887274	2143287	210	42586	730711	12487060
FATAL_RATE	561	0.12	0.046	0.024	0.086	0.15	0.28
TYPELEG	561	2.7	1.8	1	1	4	6
REC	561	0.43	0.5	0	0	1	1
MEDDEC	561	0.14	0.34	0	0	0	1
MEDONLY	561	0.18	0.38	0	0	0	1
DECONLY	561	0.059	0.24	0	0	0	1
ILLEG	561	0.078	0.27	0	0	0	1
DRUNK_BI	561	0.39	0.49	0	0	1	1

The variables in this data are state, or the state ID that the National Highway Traffic Safety Administration uses for classification, year which ranges from 2010 to 2020, month ranging from 1 (January) to 12 (December), day ranging from 1 to 31 corresponding to the

days of the month, day of the week from 1 (Sunday) to 7 (Saturday), hour uses military time from 00 (midnight) to 23 (11PM).

The variables for recreational, medical & decriminalization, medical only, decriminalization only, illegal, and drunk driving binary are all binary variables. Typeleg is a factor variable ranging from 1 to 6 categorizing the states according to legalization i.e., 1 is recreational, etc.

There are a few states that have adopted low THC laws, permitting CBD. As these states are not directly dealing with THC, the psychoactive substance, I have decided to simply reclassify them as illegal given that cannabis with THC is still outlawed and as I do not see reason to measure the traffic fatalities on a non-cognitive altering chemical.

Figure 4 shows the population of the states in 2015. As can be seen California, Florida, Illinois, New York, and Texas have the highest populations. Due to this uneven distribution, I take the log population for my regression.

Figure 5 shows a series of boxplots of the traffic fatality rates of states grouped by legalization type for 2015. Looking at this graph, the traffic rates are not uniform. Instead, what we see is that the medical only group has a much higher median and smaller range than the other types. Illegal has the second highest median.

Figure 6 represents the traffic fatality rate of the states by group and considers its population size, or bubble in 2015. The larger the bubble, the greater the population. From this graph, it is not as clear to see the distribution of fatality rates by legalization type.

In Figure 7, the boxplots correspond to the unemployment rate of states by legalization type in 2015. Unlike the in Figure 5, the ranges for the unemployment rate are relatively similar with the recreational states having a slightly higher median unemployment rate.

Chapter 2: Model Specification

The regression equation could be described as:

$$Yit = \beta Xit + \gamma Zit + \alpha i + \epsilon it$$

Where *i* and *t* stand for the state and year, respectively. The Y*it* denotes traffic fatalities in state *i* during year *t*. Whereas X*it* stand for the controls, in this case, weather, drunk driving, unemployment etc. Z*it* represents the different types of cannabis legalization in state *i* during year *t* specifically recreational, medical and decriminalization, medical only, decriminalization only, or illegal. αi represents the individual, or in this case, state, fixed effects. ϵit is the error term with state fixed effects.

I choose the fixed effects method to account for unobservable factors, while providing a precise estimate. Ruhm's paper on Traffic Fatalities and Beer Tax is an example literature on fixed effects, which is the ideal measure when dealing with heterogeneity and unobservable factors. However, as the fixed effects model assumes that some variables are constant across all states, it could provide biased estimates if the effects of the fixed variables vary across them. For this method to hold, the fixed variables must not vary across states, the error term must not be correlated with the fixed variables and there must not be multicollinearity among the independent variables.

My initial hypothesis is that there will be a difference between medical and recreational legalization on the traffic fatalities in the United States. Although establishing a medical program increases access to cannabis, it still must be consumed at home, thereby reducing the potential of driving under the influence. Living in a state that looks less favorably on cannabis may insinuate that there are greater legal risks associated with consumption which may or may not be a deterrent. Alternatively, if cannabis is a substitute for alcohol, which several papers have hinted towards, it may be that it reduces the potential for

people to consume alcohol in public settings thereby reducing traffic fatalities by decreasing the amount of driving under the influence altogether.

Chapter 3: Findings

Results

	Dependent variable:		
	FATAL_RATE		
	(1)	(2)	(3)
REC	-0.886***	0.521	0.522
	(0.320)	(0.437)	(0.437)
MEDDEC	-0.890***	0.560	0.561
	(0.330	(0.450)	(0.451)
MEDONLY	-0.712**	0.575	0.576
	(0.292)	(0.399)	(0.400)
DECONLY	-0.840**	0.598	0.599
	(0.327)	(0.446)	(0.447)
ILLEG	-0.581**	0.601	0.602
	(0.269)	(0.367)	(0.367)
WEATH_BI	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)
LOGPOP	0.060***	-0.028	-0.028
	(0.020)	(0.028)	(0.028)
RATE_UN		-0.002***	-0.002***
		(0.0004)	(0.0004)
DRUNK_BI			-0.0002
			(0.001)
Observations	561	561	561
R2	0.991	0.991	0.991
Adjusted R2	0.990	0.991	0.991
Residual Std. Error	0.013 (df = 508)	0.013 (df = 507)	0.013 (df = 506)
F Statistic	1,066.302*** (df = 53; 508)	1,089.053*** (df = 54; 507)	1,067.203*** (df = 55; 506)
Note:			*p<0.1; **p<0.05; ***p<0.01

On the left-hand side of my equation, I have the rate of traffic fatalities (per 1,000 people). This rate is created by totaling the number of fatalities per state within a given year, then dividing it by the population of the state and multiplying it by 1,000. On the right-hand side, I have incorporated variables relating to the current cannabis policies employed by the

states. Please note that each of these variables is binary and mutually exclusive i.e., a state will not belong to both medical only and medical and decriminalization. One caveat to note is that states may have originally belonged to medical and decriminalization before adopting recreational laws. While this may affect the precision of the results, I believe that an overall association can be concluded. Not included in this graph are the state coefficients, as I ran a regression with state fixed effects, and as the coefficients of the states are not interpretable.

In model 1, with a coefficient of 0.886 for it seems that a one-unit increase in recreational legalization decreases the fatality rate by 0.886 units per 1,000 people. States that have medical legalization and decriminalization laws see a decrease of 0.890 units per 1,000 people. States that do not have decriminalization laws but do have medical laws see a decrease of 0.744 units (per 1,000). States which have decriminalization laws but do not have a medical cannabis program see a decrease of 0.840 units (per 1,000). Finally, states which outlaw cannabis completely, have a decrease of .581 (per 1,000) compared to states that have some sort of cannabis law (decriminalization, medical, recreational, etc). States with medical only, decriminalization only, and where cannabis remains illegal are statistically significant at the 5% significance level. RCLS and states with both medical and decriminalization laws are significant at the 1% level. This is not in alignment with traditional literature. While MCLS have seen a reduction in traffic accidents (Anderson 2018, Santaella-Tenorio 2020), the results exhibited inconsistencies with some having no significant change (Salomonsen-Sautel 2014) and even some with an increase (Masten and Guezburger 2014) pointing to the complexity of this policy. Regarding the current empirical literature on RCLS, across the board there was a positive association between this policy and an increase in traffic accidents (Lane and Hall 2019, Aydelotte 2019, Windle 2021, Tefft and Arnold 2021). I have also included a control for weather, which is a binary variable with 0 indicating clear weather, and 1 indicating adverse weather conditions, and it not significant. There is also a control for population, which I have

already stated is a proxy for density. It is, however, statistically significant at the 1% level. The coefficient indicates that a 1% increase in the natural logarithm of population is associated with an expected increase of 0.060 units in traffic fatalities, holding all other variables constant.

Possible reasons why the unemployment rate may be changed the results drastically include the possibility that states with higher unemployment rates may have higher fatalities because more people are on the road, as opposed to at work. Additionally, states with higher rates of unemployment may also have a higher rate of blue-collar jobs that test for cannabis use discouraging workers from consuming while employed. Without adding more variables, it is difficult to isolate the exact mechanism behind this phenomenon.

In model 2, when I account for the unemployment rate, the coefficients for all policies change and no longer remain statistically significant. Only the unemployment rate is statistically significant in this model which shows that it may be difficult to accurately assess the individual effects that the types of legalization have on traffic fatalities. This shows that adding the unemployment rate variable may be a potential confounder. To further see the effect, I included an interaction term between the unemployment rate and each type of legalization. None of them are significant though all are positive suggesting that for each one unit increase the unemployment rate the effect of the legalization on traffic fatalities increases by 0.001 for medical and decriminalization, and medical only, and by 0.0001 for decriminalization only and 0.0002 for illegal. In linear regressions without state fixed effects, the addition of the unemployment rate did not change the model drastically see table 2.

In the 3rd model, I included a binary variable for drunk driving as a control to address a possible confounding factor that may account for an unobserved factor that could affect both the legalization of cannabis and vehicle fatalities. The coefficient for drunk driving is rather small and statistically insignificant.

Originally, I had considered implementing another macroeconomic variable, income, that could affect cannabis legalization and/or traffic accidents however, I believe the unemployment rate is sufficient to see what might be happening across the US. Looking at the results from my data, I would rerun my regressions and include this variable to see if there were other potential confounders that might affect either side of the equation. The R2 for these regressions are much higher than expected. The R2 and adjusted R2 measure the percentage of the dependent variable and can be explained by the independent variables. Typically seeing an R2 of .2, or 20% to 40% is very good. Seeing something this high may indicate that there is significant overlap and could be due to adding the state fixed effects. Alternative explanations include the strong relationship between the independent variables with traffic fatalities. To truly be able to isolate and account for a causal relationship, I believe that an independent variable would need to be explored, though being able to make a causal claim would be challenging. I have yet to come across literature that tries to determine a causal claim between the legalization type and traffic fatalities.

Discussion

Literature on the implementation of medical cannabis laws often shows a decrease in traffic fatalities, though not always statistically significant. Conversely, the adoption of recreational cannabis laws has shown an increase in fatalities in several papers and many of them remain significant. However, aspects that have emerged throughout the studies are the need to further distinguish the mechanisms. The conclusions on the literature remain ambiguous as even among studies focusing on recreational cannabis, the presence of operational dispensaries had a significant impact on traffic fatalities yet was not adequately explored as some studies did not distinguish between the implementation of the law and access to cannabis. Little research has been done on the existing supply mechanisms, highlighting the need for further exploration on this topic.

Policy Recommendations

Unlike in the US, Canada's federal adoption of cannabis allow for clarity and standardization throughout its provinces. The situation remains complex for the United States as cooperation between states would most likely need to happen at the federal level yet, cannabis remains illegal federally. If the United States did take steps toward legalization, a lot could be learned from Canada. For instance, standardizing sobriety testing, establishing a limit for THC concentration in the bloodstream, creating penalties for impaired driving, and conducting surveys to capture behavioral trends of drivers (Government of Canada 2018a).

Additionally, as pointed out by Lensch (2020) that there needs to be more campaigns on the topic of driving under the influence of cannabis as people believe the risks to be less dangerous than drunk driving. With the study by Benedetti (2021) we find the attitudes and behaviors of adolescents in Europe can be affected by the cannabis policies applied yet, still little is known in the European context. This will be relevant if more member states seek to change the legal status of cannabis.

Lastly, discovering the type of supply mechanisms that are not associated with having higher impact on traffic fatalities is important for policymakers. It appears in Uruguay, according to Kilmer, that self-cultivators are associated with a statistically significant increase in traffic fatalities, but social clubs and pharmacies are not, with social clubs having the least impact of the three types.

Conclusion

Literature on this topic would suggest a decrease in traffic fatalities for states that have adopted medical cannabis laws yet, an increase in states that implemented recreational cannabis laws. Though there have been studies that further investigate potential mechanisms, the results are inconclusive. The results of my study which investigated the five major types of cannabis legalization point to a decrease in recreational and medical and decriminalization

policies however, the addition of the unemployment rate would suggest a positive albeit insignificant association. This suggests that further exploration into the mechanisms is needed. One major area for concern arising throughout the literature, is a lack of standardization for cannabis testing by law enforcement both across the states and even within the same state (as seen with trauma centers) in the United States. This poses an issue with the validity of the results of the studies on this topic. It also prevents policymakers from obtaining exact information on how to decide a suitable threshold for the concentration of THC in the bloodstream when developing driving laws. As a growing number of states, member states, and countries introduce laws about cannabis, it is vital that governments are aware of the effects cannabis can bring to individuals. It is important to have a clear understanding of the negative externalities that it could impose particularly regarding motor vehicle safety. Especially given that the United States has a strong penchant for driving, as opposed to using public transportation, laws and regulations of road safety have a far-reaching audience. While the United States has much to learn about implementing laws that would help to reduce potential accidents caused by intoxicated driving, it can look to its neighbor, Canada as a prime example.

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Statename	Legalization Type
Alabama	Medical legalization only
Alaska	Recreational legalization
Arizona	Recreational legalization
Arkansas	Medical legalization only
California	Recreational legalization
Colorado	Recreational legalization
Connecticut	Recreational legalization
Delaware	Recreational legalization
District of Columbia	Decriminalization
Florida	Medical legalization only
Georgia	Illegal with no decriminalization
Hawaii	Medical legalization and decriminalization
Idaho	Illegal with no decriminalization
Illinois	Recreational legalization
Indiana	Illegal with no decriminalization
Iowa	Illegal with no decriminalization
Kansas	Illegal with no decriminalization
Kentucky	Illegal with no decriminalization
Louisiana	Medical legalization only
Maine	Recreational legalization
Maryland	Medical legalization and decriminalization
Massachusetts	Recreational legalization
Michigan	Recreational legalization
Minnesota	Medical legalization and decriminalization
Mississippi	Medical legalization and decriminalization
Missouri	Recreational legalization
Montana	Recreational legalization
Nebraska	Decriminalization
Nevada	Recreational legalization
New Hampshire	Medical legalization and decriminalization
New Jersey	Recreational legalization
New Mexico	Recreational legalization
New York	Recreational legalization
North Carolina	Decriminalization
North Dakota	Medical legalization and decriminalization
Ohio	Medical legalization and decriminalization
Oklahoma	Medical legalization only
Oregon	Recreational legalization
Pennsylvania	Medical legalization only
Rhode Island	Recreational legalization
South Carolina	Illegal with no decriminalization
South Dakota	Medical legalization only
Tennessee	Illegal with no decriminalization
Texas	Illegal with no decriminalization
Utah	Medical legalization only
Vermont	Recreational legalization
Virginia	Recreational legalization
Washington	Recreational legalization
West Virginia	Medical legalization only
Wisconsin	Illegal with no decriminalization
Wyoming	Illegal with no decriminalization

Table A 1

Figure 1

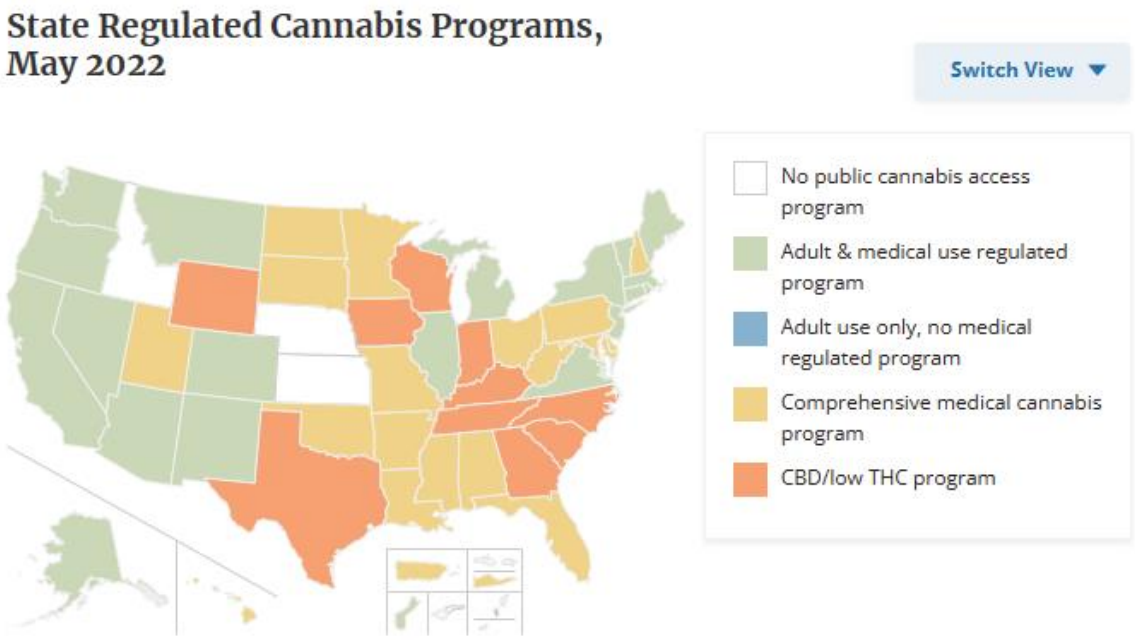
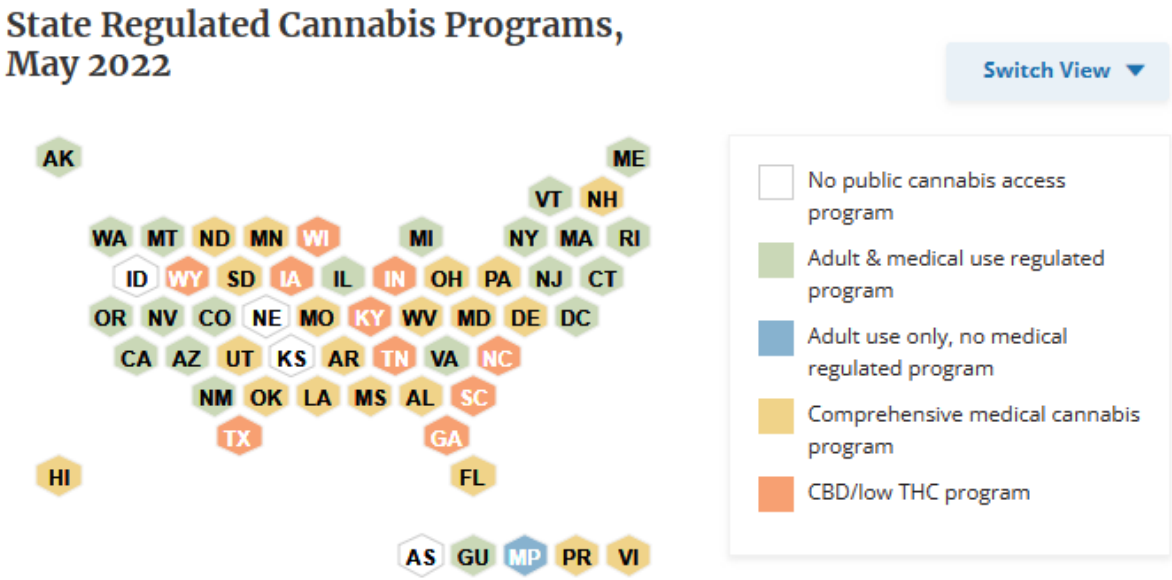
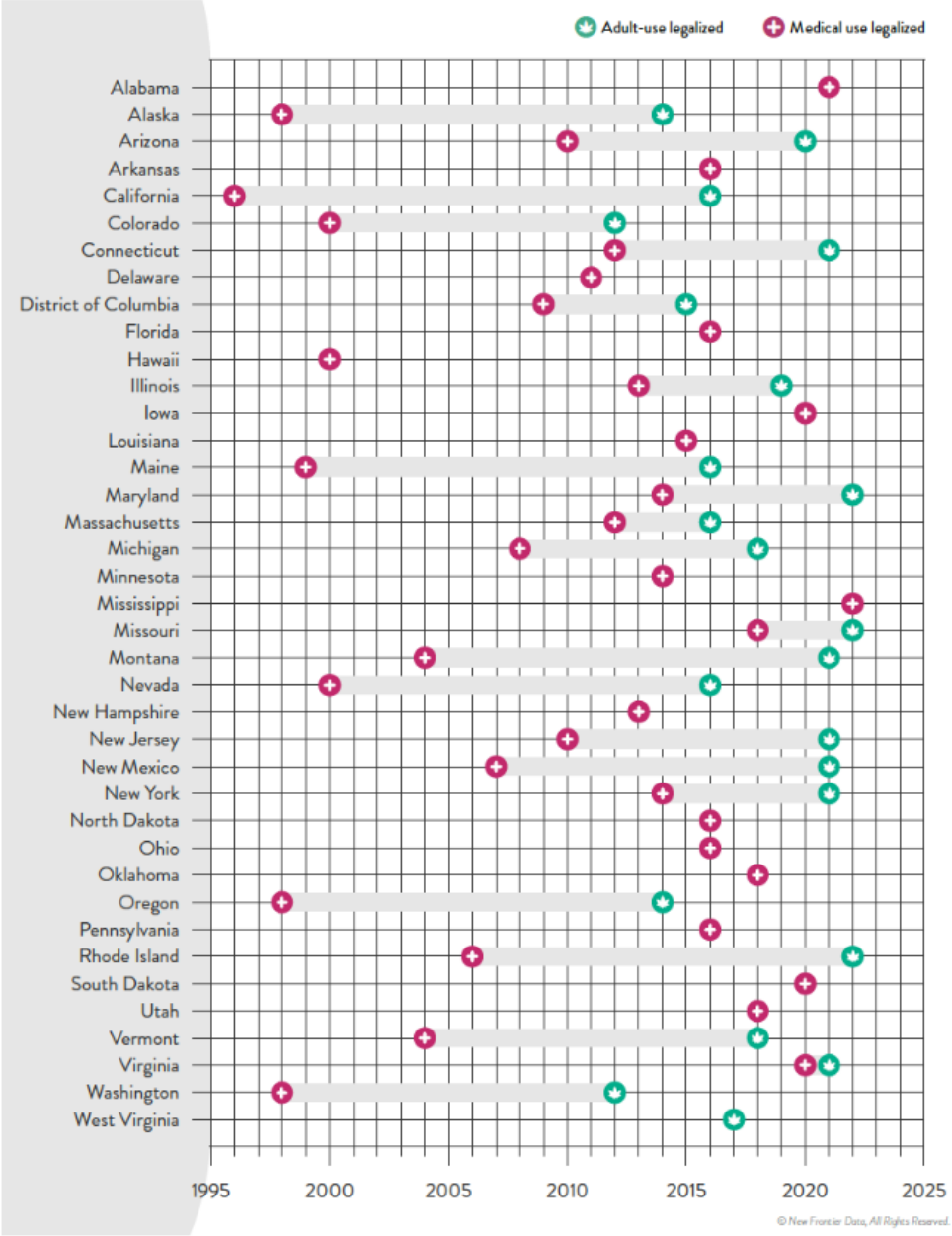


Figure 2



National Conference of State Legislatures 2023

Figure 3



New Frontier Data 2023

*According to NORML, Minnesota will implement recreational cannabis August 1, 2023 ("Minnesota Becomes the 23rd Legal Cannabis State - NORML" n.d.)

Figure 4

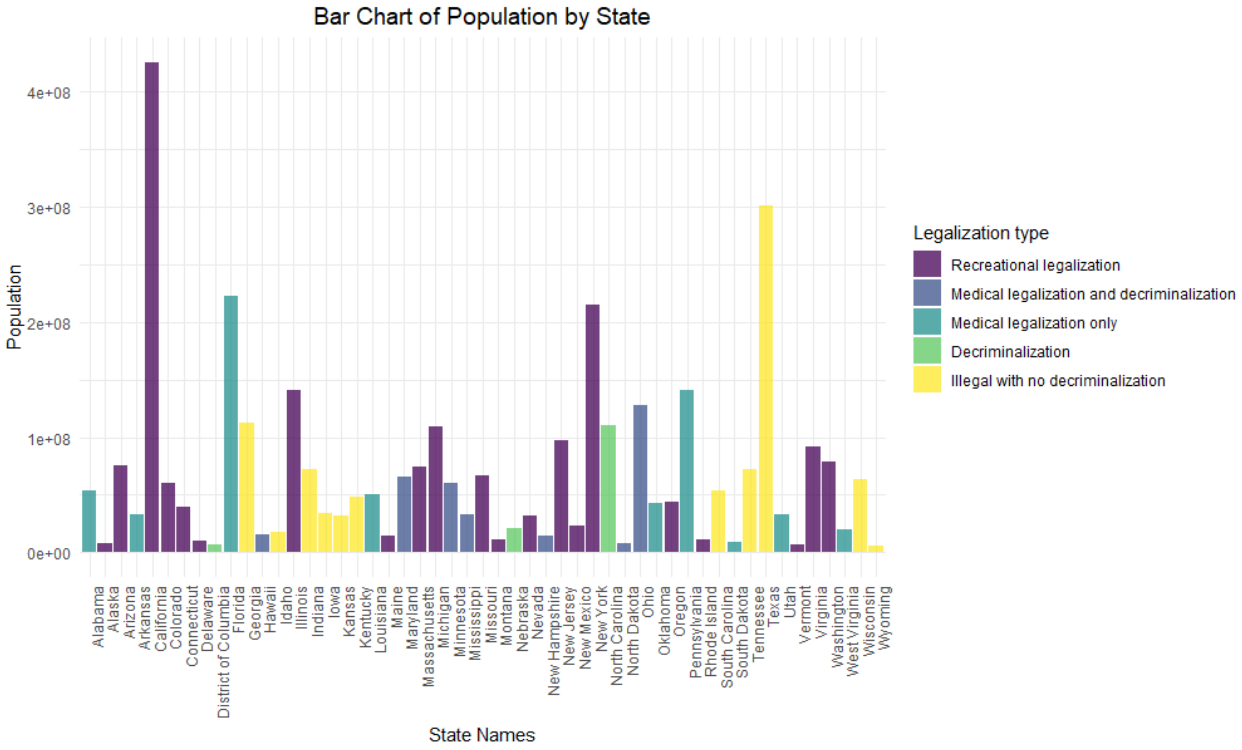


Figure 5

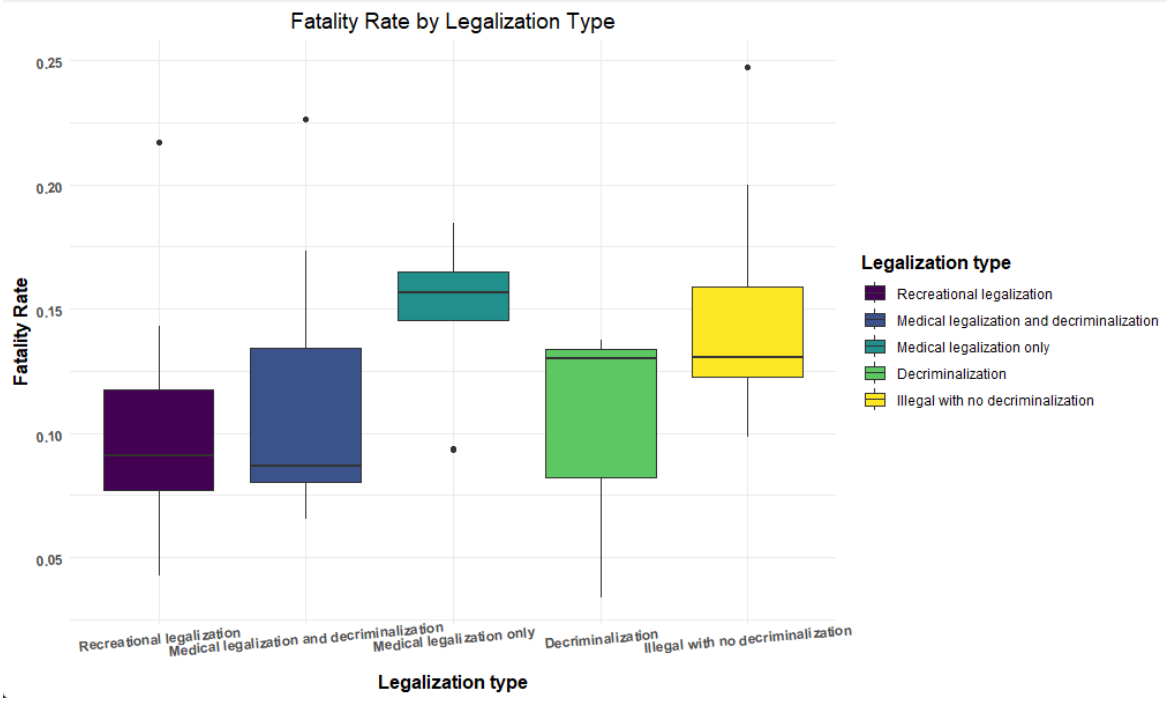


Figure 6

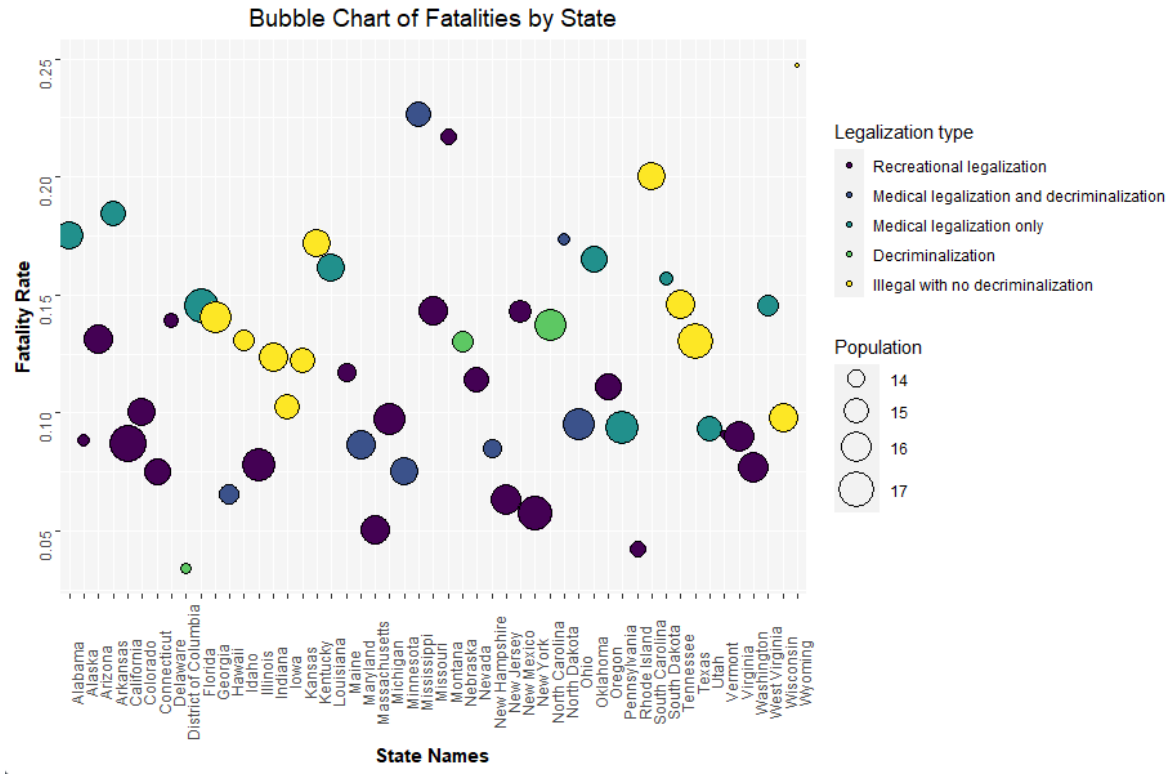


Figure 7