The Effect of Cannabis Legalization on Driving Under the Influence of Cannabis (DUIC)

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Executive Summary

Nearly 100 published articles over the past 20 years have indicated a moderate relationship between acute cannabis intoxication and motor vehicle crashes. This growing phenomenon, termed "driving under the influence of cannabis" (DUIC), is problematic as science for prevention, detection, and enforcement is decades behind the efforts to control and diminish traditional DUI, or "driving under the influence of alcohol". Yet, at the end of 2022, approximately 72 percent of Americans lived in a state with a medicinal or recreational cannabis program.

Americans are clearly responding to the policy enactment of cannabis programs, with self-reported past-year cannabis use skyrocketing from 10.4 percent in 2002 to 19.3 percent in 2021. Simultaneously, cannabis potency has also grown exponentially, from the "Woodstock Weed" that contained THC levels of 1-3 percent to the modern commercial cannabis that averages THC levels of between 19.2 and 21.5 percent. Worse, the loosening of cannabis restrictions through state policy changes has introduced cultural changes in cannabis use perceptions, but little effort has been placed in reinforcing the potential risks DUIC places on traffic safety.

Recent analyses by the National Highway Traffic Safety Administration demonstrate a 48 percent growth (8.6 percent to 12.6 percent) in weekend nighttime DUIC between 2007 and 2014. A recent investigation of self-reported DUIC from the 2016-2018 NSDUH data by Salas Wright et al. (2021) indicated an overall DUIC prevalence rate of 4.47 percent (or more than 11 million annual self-reporting cannabis impaired drivers), but the DUIC rate for cannabis users was almost 30 percent. With detection science slowly responding to the DUIC phenomenon, authors such as Windle et al. (2021) have suggested a "no-driving window" after cannabis consumption of up to six hours.

This study explores a research gap in attributing more permissive state policies with increases in self-reported DUIC. It considers the research question: **Do less restrictive state policies regarding cannabis use encourage greater cannabis positivity amongst drivers and, therefore, higher prevalence**

of "driving under the influence of cannabis" (DUIC)? By hypothesizing that US states with policies permissive of medicinal and recreational cannabis programs have higher rates of DUIC, the connection between state policy and reported outcomes is quantitatively verified with both a t-tested difference in means and an OLS regression comparing the independent variable of high-THC state cannabis policies and dependent variable self-reported DUIC, using 2017 data from the annual NSDUH survey.

Statistically significant results showed a difference in means between the less permissive (n=32) and more permissive (n=18) states of 1.4265 percent, verifying that the prevalence of DUIC in more permissive states is 32 percent higher than the DUIC prevalence in less permissive states. Through OLS regression, the correlative influence of more permissive state policies indicated a statistically significant impact equaling 0.92 percent, demonstrating that nearly 1 percent of the mean difference is associated with more permissive state policies, controlling for additional variable such as monthly alcohol consumption, median age, and gender differences. Estimated with 2017 population data, this difference represents more than a million more cannabis-intoxicated drivers in the 18 more permissive states.

These results have a tremendous potential impact on future policy debates, especially as commercialization drives the adolescent belief that cannabis use is safe and normative, but enforcement compliance demonstrates between 11 and 23 percent of recreational sales end up in the hands of minors (Lipperman-Kreda & Grube, 2018). Meanwhile, cannabis consumption lounges (aka social consumption lounges) "are becoming the talk of the [cannabis] industry," (Serard, 2023) and are now legal in seven states (Nevada, New Jersey, New York, New Mexico, Illinois, Colorado, and California), bringing enormous pressure on the risk of cannabis intoxication and driving (Freedman, 2022, p. 30). As one legal researcher expressed the problem: "To the extent that the location of cannabis use affects the decision to drive, allowing public use could increase the prevalence of impaired driving" (Orenstein, 2021, p. 94).

Introduction

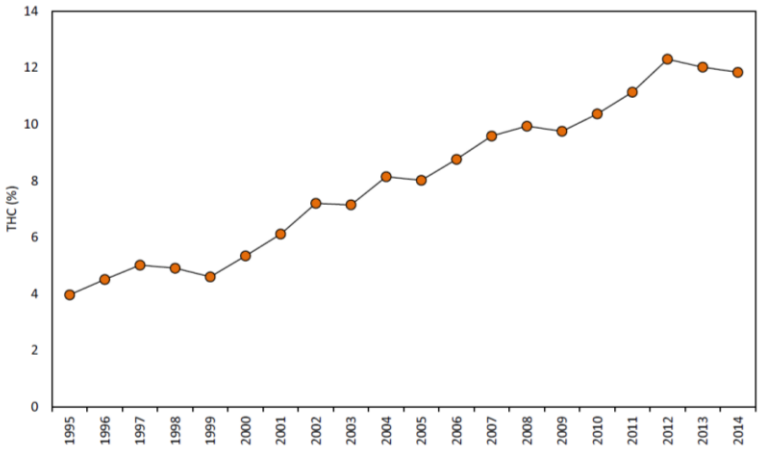
Research on "driving under the influence of cannabis" (DUIC) is an emerging topic in academic literature, with dozens of articles published just in the past two decades (Hostiuc et al., 2018; Windle et al., 2022). At least four meta-analyses of the effect of cannabis legalization (and decriminalization) on road safety have reviewed almost 100 articles collectively, with three studies indicating a relationship between acute cannabis intoxication and motor vehicle crash risk (Asbridge et al., 2012; Li et al., 2012; Rogeberg & Elvik, 2016; Windle et al., 2022).

Evidence is clear that cannabis use among Americans has dramatically increased over the past two decades. In 2002, the National Survey on Drug Use and Health (NSDUH) estimated past year cannabis use at 10.4 percent of the adult population in the United States (Compton et al., 2016). In 2021, the estimate has almost doubled to 19.3 percent of the adult population (SAMHSA, 2023).

The potential danger from DUIC lies not only in the nearly two-fold increase in cannabis use, but also in the dramatic increase in cannabis potency. While the "Woodstock Weed" of the 1960s and early-1970s contained THC levels of 1 to 3 percent (Murray et al., 2016; Sabet, 2021), a recent potency study of modern cannabis products found advertised THC levels at between 19.2 and 21.5 percent (Cash et al., 2020). A more rigorous study of THC levels between 1995 and 2014 found nearly three-fold growth from approximately 4 percent to 12 percent (ElSohly et al., 2016).

Figure 1: Rise in average THC levels 1995-2014

(ElSohly et al., 2016)



Finally, the loosening of state policy on cannabis restrictions, exacerbated by the economic difficulties of the COVID-19 pandemic, has contributed to cultural changes in cannabis use perceptions

(Hasin & Walsh, 2021). Since the legalization of medicinal cannabis by California in 1996, a total of 37 states and the District of Columbia allow for medicinal use, including 22 jurisdictions allowing full recreational use (Carnevale Associates, 2022). Approximately 47.8 percent of the US adult population has legal access to recreational cannabis after the November 2022 elections – an amount that has grown by 43 percent in the past two years.

What is "Driving Under the Influence of Cannabis" (DUIC)?

The terminological use of "driving under the influence of cannabis" (DUIC) appears first in Walsh and Mann's 1999 study of the phenomenon in Ontario, Canada. The authors noted: "While cannabis is the most frequently found illegal drug in drivers killed or injured in motor vehicle collisions, little is known about driving under the influence of cannabis (DUIC) in the general population," including the "types of individuals" or the "impact of cannabis use on collision risk" (Walsh & Mann, 1999, p. 260). The authors scrutinized the 1996 and 1997 Ontario Drug Monitor surveys using logistic regression and determined that drivers who were younger, male, unmarried, and lesser educated were more likely to drive within an hour of smoking cannabis.

In the subsequent decade, Asbridge et al. (2012) identified nine research studies that investigated acute cannabis consumption (self-reported cannabis consumption within three hours with blood sample confirmation) and found a moderate association between cannabis use and motor vehicle collisions, with results indicating a nearly two-fold increase in collision risk for drivers with acute cannabis exposure. Li et al. (2012) performed a similar study of nine studies (only two were redundant of the Asbridge meta-analysis) linking cannabis consumption and motor vehicle crashes, finding drivers who tested or self-reported positive for cannabis consumption were more than twice as likely to be involved in a motor vehicle crash.

A subsequent set of studies by Rogeberg and Elvik (2016) sought to replicate the earlier finding of Asbridge et al. (2012) and Li et al. (2012). Highly critical of the earlier analyses, Rogeberg and Elvik (2016) removed sparse data biases and added adjustments for driver culpabilities from the earlier studies and added additional research to equal 74 risk estimates from 46 studies. While the authors suggested a lower estimate of increased risk from earlier studies, Rogeberg and Elvik (2016) found a statistically significant relationship increase in motor vehicle crashes by acutely intoxicated drivers.

More recently, Windle et al. (2022) reviewed 64 studies published between 2013 and 2021, including data regarding motor vehicle collisions in states with decriminalization, medicinal use, and recreational consumption, mostly focused on US examples. This meta-analysis concluded that all three policies were associated with increased cannabis intoxication in drivers, while drivers in medicinal use states had fewer motor vehicle collisions – possibly due to decreases in alcohol- and opioid-intoxications – while drivers in recreationally-legal states had increases in motor vehicle collisions.

Research Question

The distinctions between states that have decriminalized cannabis use, removed restrictions for medicinal use, or legalized cannabis for recreational use, are the basis for the primary research question for this study: **Do less restrictive state policies regarding cannabis use encourage greater cannabis positivity amongst drivers and, therefore, higher prevalence of "driving under the influence of cannabis" (DUIC)?**

This hypothesis is supported by all four of the above-cited previous meta-analyses (ie., Asbridge et al., 2012; Li et al., 2012; Rogeberg & Elvik, 2016; and, Windle et al., 2022). Brands, DiCiano and Mann (2021) outlined four significant questions for future DUIC research, including the assessment of increased collision risks, the identification of DUIC drivers, the DUIC behaviors that lead to collision risk, and the "big picture" role of DUIC in road safety (p. 2). Within the "big picture" of road safety, several

major studies have projected the role of DUIC in increased collisions risks. Wettlaufer et al. (2017) studied 2012 Canadian crash statistics and estimated the impact of DUIC at an annual toll of 75 deaths and nearly 4,500 injuries. More recently, Farmer, Monfort, and Woods (2022) estimated the DUIC impact in the United States, using injury and fatality crash data from 2009-2019. The authors estimated DUIC collisions from recreational cannabis consumption increased injuries by 6.5 percent and fatalities by 2.3 percent.

This study, however, seeks to evaluate the impact of state-level cannabis policy restrictions on DUIC. Similar studies evaluating the association between these two variables include Benedetti et al. (2020), Fink et al. (2020), Lensch et al. (2020), and Dutra et al. (2022). These four studies greatly vary in their methodology, data, and conclusions. Benedetti et al. (2020) uses a multiple logistic regression model, for example, while Fink et al. (2020) used a difference-in-difference model and Dutra et al. (2022) employed a generalized linear model regression. Benedetti et al. (2020) studied data from the Traffic Safety Culture Index, conducted by the AAA Foundation for Traffic Safety, while Fink et al. (2020) used three surveys (National Longitudinal Alcohol Epidemiological Survey, National Epidemiologic Survey on Alcohol and Related Conditions, and Alcohol Use Disorder and Associated Disabilities Interview Schedule). Lensch et al. (2020) surveyed more than 28,000 respondents through the International Cannabis Policy Study, while Dutra et al. (2022) utilized responses from their National Cannabis Climate Survey.

Results of the Benedetti et al. (2020) study were not significant regarding differences in state policy restrictions (illegal, medicinal, and recreational). Fink et al. (2020) reported an increase in DUIC in states that enacted medicinal cannabis programs. Lensch et al. (2020) indicated higher DUIC levels in states with recreational cannabis programs, although the study also demonstrated higher success rates of marketing programs to reduce DUIC in those same states. The results from Dutra et al. (2022) were opposite of earlier studies, with self-reported DUIC higher in states with policy restrictions against

cannabis consumption than states with medicinal and recreational cannabis programs, controlling for demographics, frequency of use, and geographic clustering.

With recent variations regarding the impact of state policy restrictions on DUIC, this study employs differing methodology and data in an effort to add evidence to scholarly literature on DUIC.

Research Context

A review of relevant literature on the topic of DUIC and state cannabis policies yields many articles on a variety of topics. A quick summary of this literature provides four major conclusions: prevalence of DUIC is increasing as overall cannabis usage by Americans in increasing, risk perceptions for driving under the influence of alcohol and cannabis are inherently different, effective methods to test for DUIC are still lacking in scientific innovation, and statistical analysis linking traffic crashes and/or fatalities to DUIC have shown moderate association. Similarly, academic literature can be classified into four differing themes, including definitional/perceptional, behavioral/predictive, outcome-based, and prevention/detection. The following literature review is separated into these four categories.

Definitional/Perceptional

The range of psychological effects from the consumption of cannabis range "include euphoria, dysphoria, sedation, and altered perception" (Hartman & Huestis, 2013, p. 478). As a 2017 federal study on DUIC concludes, previous research, strengthening of safety standards, and improvements in enforcement have helped to alleviate the effect of alcohol consumption on motor vehicle safety (Compton, 2017). Hartman and Huestis (2013) point out almost two-thirds of major motor vehicle crashes have drugs and alcohol as contributing factors and that, after alcohol, cannabis is the next most frequently cited contributor.

Karoly et al. (2020) tested groups in both Colorado and Washington for psychomotor impairment, concluding that subjects were immediately affected by cannabis consumption, with strong significance within the first hour of consumption. Two notable driving simulation studies have also tested the effects of cannabis impairment on driving performance. Dahlgren et al. (2020) found cannabis impairment was related to increased accidents, speed, and lateral driving movement, as well as reduced rule-following, especially among chronic users whose consumption began prior to the age of 16 years old. Meanwhile, Hartman et al. (2015) further emphasized the effect of cannabis impairment on lateral driving factors, finding increased instances of lane weave and lane departures similar to the effects of alcohol impairment. A clinical study of visual function had mirrored results to the driving simulation studies, with reduction in visual impairment caused by cannabis consumption influencing changes in lateral, as well as longitudinal, driving control (Ortiz-Peregrina et al., 2021). Ramaekers et al. (2009) found cannabis consumption also affected stop reaction times.

Systemic reviews on modeled DUIC have been both supportive and critical of research methods. Sevigny (2021) stressed the need to better categorization of neurobehavioral effects of cannabis consumption, as well as better linkages between observed deficits and driving performance. The author further advocated for additional scrutiny on the magnitude of driving impairment and the influence of cannabis tolerance development. Burt et al. (2021) stressed the need to consider increases in cannabis potency as an emerging research topic, as well as changes in cannabis intake.

Deviating from clinical considerations, Ramaekers (2018) questions the dichotomy of user psychology, stating: “Regular cannabis users often admit to driving under the influence of cannabis and wrongfully believe that cannabis does not affect their driving performance or that they can compensate for cannabis-associated impairment” (p. 1434). Several recent studies analyze a system of beliefs model of DUIC with qualitative and quantitative research indicating that control beliefs, norms, and attitudes can affect DUIC intentions. Scott et al. (2021) surveyed respondents on the social acceptability of DUIC,

finding that DUIC could be informed through a Protype Willingness Model. Borodvsky et al. (2020) similarly identified survey respondents' safety perceptions of cannabis impairment as a factor in DUIC. Lastly, Watson et al. (2019) described cannabis users reactions to DUIC as "just a habit," using qualitative interviews to classify DUIC as ordinary, convenient, and controllable (p. 531).

Behavioral/Predictive

Other studies have sought to quantify the DUIC phenomenon, to identify correlative factors contribution to DUIC, or to find predictive evidence in cultural or demographic data. Three recent studies have focused on DUIC prevalence within the United States, using data from the National Survey on Drug Use and Health (NSDUH) conducted by the Substance Abuse and Mental Health Services Administration (SAMHSA).

Specifically assessing 2018 survey data, Azofeifa et al. (2019) predicted the DUIC rate in the United States at 4.7 percent of legal drivers, or approximately 12 million drivers, skewing towards males aged 16-34. Two larger studies of the same survey data over larger time periods found similar results. For example, Salas-Wright et al. (2021) reported a DUIC prevalence estimate of 4.5 percent of legal drivers between 2016 and 2018 and Myers et al. (2023) estimated the annual DUIC prevalence rate between 4.2 and 4.9 percent. However, the prevalence of DUIC among actual cannabis users is much higher – estimated at about 29.5 percent, among frequent users – estimated at 57 percent, and among users with cannabis abuse disorder – estimated at 63.8 percent (Salas-Wright et al., 2021).

Multiple studies identify correlative trends within the population regarding DUIC. The NSDUH data suggests higher DUIC associations with adults aged 18-25, males, whites, and the unemployed (Salas-Wright et al., 2021). The higher associations among younger drivers (Sterzer et al., 2022) and male drivers (Lloyd, Lopez-Quintero, & Striley, 2020) have been substantiated in other data beyond the NSDUH surveys.

A systemic review of 219 articles on this topic identified sociodemographic, psychosocial and legal factors contributing to DUIC, which emphasizes results substantiated in the above literature (Hasan et al., 2022). However, the authors also isolated studies indicating other factors, such as marital status, education, lifestyle factors, urbanization levels, psychological factors, risk perceptions, and social influences. Several studies identified cultural factors within cannabis users, utilizing data from studies in Washington state, regarding shared attitudes, as well as behavioral, normative, and control beliefs (Otto et al., 2021; Ward et al., 2017). Finally, research indicates the role of risk perceptions influences the prevalence of DUIC. Two studies of Canadians found that "DUIC was perceived as less dangerous and more socially acceptable than driving under the influence of alcohol" (Pollard, Drakes, & Harris, 2022) and that medicinal cannabis was perceived as 45 percent safer for DUIC than non-medicinal cannabis (Wickens et al., 2023).

Outcome-Based

Much has already been presented above regarding outcome-based studies of the association between DUIC and motor vehicle crashes and/or fatalities. Without restating the results of the previously cited studies (see earlier mentions of Asbridge et al., 2012; Benedetti et al., 2020; Dutra et al., 2022; Fink et al., 2020; Lensch et al., 2020; Li et al., 2012; Rogeberg & Elvik, 2016; and, Windle et al., 2022), a few other recent studies deserve mention and summary.

Notably, a review by Hostiuc et al. (2018) of twenty-four studies, none of which have been individually cited within this report, countered the prevailing argument of correlation between DUIC and motor vehicle crashes and suggested a lack of statistical significance due to three issues (methodological flaws, poor methods identifying cannabis use, or lack of correlative effect). Another recent meta-analysis of ten studies (Preuss et al., 2021) demonstrated a slight, but statistically significant, increased

risk of motor vehicle crashes from DUIC, but no relationship after consumption of cannabis products with lower THC potencies.

Several recently published studies not included in the above systemic analyses have also supported the theory of correlation between DUIC and motor vehicle crashes. Two of these studies evaluated fatalities caused by DUIC per miles of travel. Adhikari, Maas, and Trujillo-Barrera (2023) used a difference-in-difference model to estimate the effect of recreational cannabis programs on traffic fatalities, finding an increase in 2.2 fatalities per billion miles traveled (or 1,400 additional annual US fatalities) in their analysis of 2007-2020 data from the Fatality Analysis Reporting System (FARS). In a similar study, Farmer, Monfort, and Woods (2022) projected recreational cannabis programs increasing DUIC injury crashes by 6.5 percent and DUIC fatal crashes by 2.3 percent. The estimate of overall DUIC involvement in total fatal crashes in the US rose dramatically between 2000 and 2018, rising from 9 percent of all fatal crashes to 21.5 percent (Lira et al., 2021).

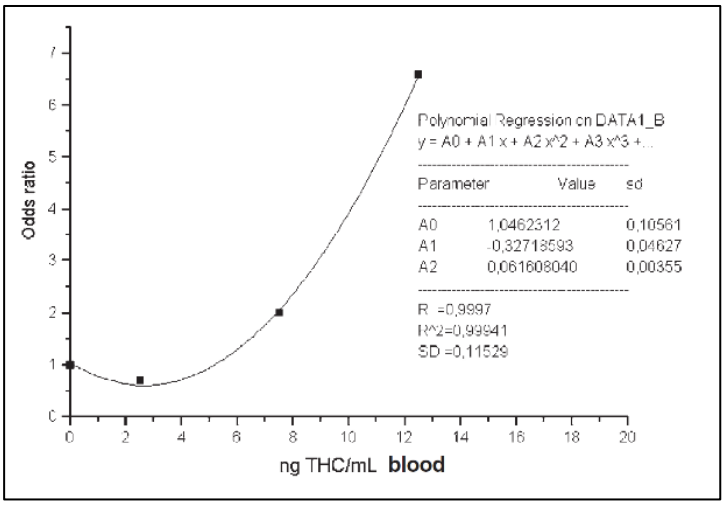
Prevention/Detection

A final grouping of literature is oriented towards prevention and deterrence of DUIC. This classification of literature can be further separated into science of detection of THC in drivers and prevention programs to change social and behavioral attitudes regarding DUIC. According to the 2017 NHTSA report on DUIC, "no evidence-based methods to detect [DUIC]" or "impairment standard for [DUIC]" currently existed (Compton, 2017, p. 13). The Blood Alcohol Concentration (BAC) test for alcohol impairment has dramatically improved the enforcement of DUI/DWI and science is currently behind policy regarding the reliability and accuracy of THC detection (Arkell et al., 2019; Berning, Compton, & Wochinger, 2015; NCSL, 2022).

According to the National Conference of State Legislatures (2022), DUIC testing is currently "problematic due to the limitations of drug-detecting technology and the lack of an agreed-upon limit to

determine impairment." Earlier work on limitations includes a 2006 analysis of DUIC limitations that outlined both observational approaches, as well as zero tolerance and "per se" limitation approaches (Grotenhermen et al., 2006). This study concluded that a preliminary "per se" THC limit of 7-10 ng/ml correlated with a BAC level of 0.05. An odds ratio graph displaying the probability of a crash by THC blood levels (see Figure 2) of Australian drivers indicated the potential of a causal connection between DUIC and vehicle crashes that could impact potential policy limitations.

Figure 2: Australian crash odds ratio per THC levels
(Data from Drummer et al., 2004, presented by Grotenhermen et al., 2007)



Arkell et al. (2019) recently tested such limits through point-of-collection testing for THC in oral fluids at a 10 ng/ml cut-off for 24 subjects at differing time components (10 to 180 minutes) and found a 5 percent false positive and 16 percent false negative rate. A further analysis of 14 infrequent cannabis users in a driving study at two timepoints by Arkell et al. (2021, p. 102) concluded: "There appears to be a poor and inconsistent relationship between magnitude of impairment and THC concentrations in biological samples, meaning that 'per se' limits cannot reliably discriminate between impaired from unimpaired drivers. There is a pressing need to develop improved methods of detecting cannabis intoxication and impairment."

Yet, other observational techniques for detection of cannabis impairment have also been scrutinized within the literature. Pearlson, Stevens, and D'Souza (2021) questioned the efficacy of roadside tests for cannabis impairment, noting the similarities and differences with alcohol impairment (of which roadside observational tests were developed to detect) have not been rigorously explored. In

fact, the authors specifically question whether measurements including "postural sway, nystagmus, heel-to-toe walking and repeating a sentence correctly" are not, specifically, applicable to cannabis impairment, much less multi-drug intoxication (p. 9). The use of Drug Recognition Experts (DREs) in Canada (and, to a limited extent, the US) has shown some promise, yet the lack of evaluation of the efficacy of such programs, as well as the cost of police training, means that such advancements are questionable at best (Watson & Mann, 2016).

These challenges have led scholars such as Ward et al. (2018) to suggest priorities should be placed on changing behaviors to prevent DUIC as the science of detection slowly advances. Windle et al. (2021) have advanced the idea that health care professionals in both counselling and primary care functions could help persuade cannabis users of the risks of DUIC. In fact, the authors suggested patient advice to include a no-driving window of six hours after cannabis consumption. Ward et al. (2018) proposed a traffic safety culture model to predict DUIC that recommended prevention methods to stymie the willingness and intention behaviors within cannabis consumers for DUIC. Using grounded theory, the authors proposed changing attitudes, descriptive norms, and injunctive norms to reduce the idea that DUIC is acceptable as a societal norm.

Policy Perspectives: DUIC Enforcement and Cannabis Legalization

State public policy guidelines differ greatly on DUIC enforcement and the permissiveness of cannabis use within the United States. While previous research on DUIC indicates a moderate impact on motor vehicle collisions and modern testing for cannabis impairment is still evolving, cannabis use and DUIC have both grown substantially in the past two decades. With medicinal or recreational cannabis programs in US states representing more than 241 million in population (Carnevale Associates, 2022), similar DUIC time trend increases of nearly 50 percent from 8.6 percent in 2007 to 12.6 percent in 2013-2014 (Berning, Compton, & Wochinger, 2015) are inherently logical, if not predictable.

However, differing methodologies have produced inconsistent results regarding DUIC prevalence. For example, the study by Berning, Compton, and Wochinger (2015) included breath, oral fluid, and blood samples from 11,100 voluntary drivers from 60 sites in the contiguous United States between 2013-2014, with representation from more urban areas within four geographic regions and three levels of population density. The more recent study by Salas-Wright et al. (2021) utilized NSDUH data of self-reported DUIC from a sample of 128,205 adults from all 50 states and the District of Columbia between 2016-2018. The study of actual weekend nighttime drivers suggests one-in-eight (12.6 percent) of drivers have THC in their system, whereas the second study indicates almost one-in-twenty (4.47 percent) of the adult US population has self-reported DUIC within the past year, including almost three-in-ten (29.48 percent) of cannabis users.

The gap between 4.47 percent and 12.6 percent represents a "Bermuda Triangle" of unknown factors and inexact science regarding DUIC that has substantial policy, enforcement, and prevention implications. Not every driver within the 12.6 percent is likely DUIC impaired. The annual DUIC prevalence estimate of nearly 30 percent by cannabis users indicates a significant traffic safety issue. Yet, the literature indicates the science behind DUIC enforcement is still evolving and is potentially decades behind alcohol impairment. As well, significant sociodemographic differences in self-reported DUIC (Salas Wright et al., 2021) indicate higher prevalence by younger, male, non-Hispanic, and higher educated adults, with the largest gaps between genders (male prevalence 6.04 percent more than double the female prevalence of 2.99 percent) and age groups (drivers 18-25, 12.2 percent; drivers 26-34, 7.23 percent; drivers 35-49, 3.71 percent; drivers 50-64, 2.35 percent; and drivers 65 and above, 0.57 percent).

Within this context of DUIC prevalence exists a myriad of differing policy choices regarding cannabis use permissiveness and DUIC enforcement (as demonstrated by the map illustrations in Figures 3-5). Figure 3 represents the status of DUIC enforcement approaches by each of the 50 states as

(Map Insert Page HERE)

reported by the National Conference of State Legislatures (NCSL) as of November 2022. Figure 4 represents the status of state cannabis permissiveness as reported by Carnevale Associates (2022). Finally, Figure 5 represents the self-reported level of DUIC in 2017 as reported by Salas-Wright et al. (2021) from the 2017 NSDUH data.

According to NCSL (2022), current DUIC state enforcement policies can be categorized into four classifications: zero tolerance laws, "per se" laws, under-the-influence of drugs (DUID) laws, and permissible interference laws. Zero tolerance laws prohibit drivers from exhibiting any amounts of THC or corresponding metabolites, with twelve states adopting such policies (Arizona, Delaware, Georgia, Indiana, Iowa, Michigan, Rhode Island, South Dakota, Oklahoma, Pennsylvania, Utah, and Wisconsin). "Per se" laws provide for limits on detectable amounts of THC, which is the norm in five states (Illinois, Montana, Nevada, Ohio, and Washington). One state (Colorado) allows for permissible interference, which creates a legal assumption of impairment with a blood THC level of 5 ng/ml or higher, although the introduction of affirmative defenses to counter the presumption of impairment is allowed. The remaining 32 states employ a driving under the influence of drugs (DUID) standard that requires evidence of impairment under an umbrella of drugged driving laws.

According to information collected by Carnevale Associates (2022), twenty-one US states now allow recreational use of cannabis, with an additional 16 states allowing some form of medicinal use. Only 13 states still prohibit the use of cannabis, representing approximately 27 percent of the US population. The District of Columbia also allows for recreational cannabis use. Between November 2020 and November 2022, the overall share of US residents living in recreational cannabis states increased from 34 to 48 percent. Based upon "public opinion polling and recent elections," Carnevale Associates (2022) expects "ever-growing support for cannabis legalization," but cautions policymakers to "[equip] with the information and tools [needed] to ensure that states can optimize their approaches to protect public health and safety" (p. 1).

The visualized results from Salas-Wright et al. (2021) indicate geographic clusters within the US states that need "equipping," especially in the Northeast Atlantic and Northwest Pacific regions. According to the 2017 NSDUH data, self-reported DUIC is most prevalent in Oregon (8.4 percent), Vermont (8.2), Rhode Island (8.0), Maine (7.5), and Montana (7.3), and least prevalent in Texas (3.0). This analysis focuses specifically on the policy aspects visualized in Figures 4 and 5. Specifically, this study tests the research question: **Do less restrictive state policies regarding cannabis use encourage greater cannabis positivity amongst drivers and, therefore, higher prevalence of "driving under the influence of cannabis" (DUIC)?** This hypothesis is tested by considering whether states with policies permissive of medicinal and recreational cannabis have a higher rate of DUIC.

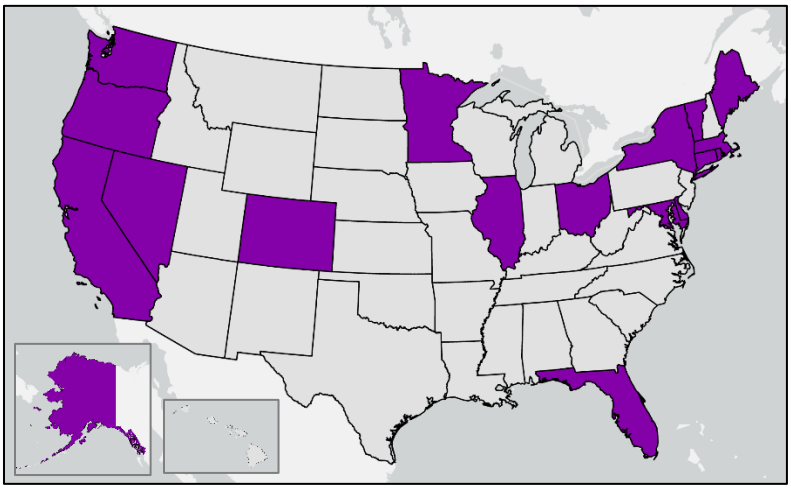
Data and Methodology

The literature indicates both clinical and observational studies demonstrate a moderate association between frequent cannabis use and driving with cannabis impairment. This study tests whether state cannabis policies influence self-reported DUIC, while controlling for other variables. The research hypothesis is that states with full medicinal and recreational programs will exhibit higher rates of self-reported DUIC. This hypothesis is tested by considering which states had more permissive policies regarding medicinal and recreational cannabis programs in 2017 and analyzing whether there is a statistically significant covariance with higher self-reported DUIC from the 2017 NSDUH data, controlling for other explanatory variables.

First, states were considered for their policies regarding cannabis permissiveness through the same methodology employed in Drug Free America's 2022 analysis of the impact of cannabis on mental health outcomes (Adomite, 2022). In this study, an ordinal scale was used to isolate the permissiveness level through a six-level ordinal scale from fully illegal to fully legal. Distinctions included state decriminalization policies, low THC medicinal programs, full medicinal programs, and recreational

programs (fully legal). In this analysis, the 50 states were divided into two groups, representing: (1) less permissive states that have only acted on decriminalizing cannabis use or implemented low-THC medicinal programs, and (2) states with higher THC medicinal programs and full recreational cannabis programs (see Figure 6). In 2017, eight states had adopted full recreational cannabis programs (Alaska, California, Colorado, Maine, Massachusetts, Nevada, Oregon, and Washington) and ten states had enacted higher-THC medicinal programs (Connecticut, Delaware, Florida, Illinois, Maryland, Minnesota, New York, Ohio, Rhode Island, and Vermont). Incidentally, seven of these states have since adopted full recreational programs. This binary data is tested for differences in means (group 0 = 32 states, group 1 = 18 states) and then regressed against DUIC data while controlling for additional variables suggested through the review of literature.

Figure 6: Groups by Permissiveness Policies (2017)
Illegal & Low-THC Policy Group 1: 32 States (Gray)
High-THC Policy Group 2: 18 States (Purple)



The 2017 NSDUH data was extracted from the visual representations depicted by Salas-Wright (2021). As indicated in their study, state estimates were tabulated through the Restricted Use Data Analysis System (RDAS), since state-level data is not provided through the public NSDUH portal (p. 252). According to the authors, respondents were asked, “During the past 12 months, have you driven a vehicle while you were under the influence of marijuana?”, with a binary response of yes/no.

Additional explanatory variables were considered from the review of literature, including variables representing age, gender, marriage status, ethnicity, education, and alcohol consumption. Explanatory variables tested with statistical significance include monthly alcohol consumption, median

age, and gender. The variable for alcohol consumption was estimated from 2017 NSDUH data and represents the percentage of adults aged 18 and over that consumed alcohol within the past month. While this data does not capture drivers between the ages of 16 to 18 years, this choice was considered better than an estimate of 12 years of age and older. The additional variables for median age and gender were estimated from 2017 five-year population estimates from the US Census Bureau's American Community Survey.

Analysis and Findings

First, descriptive data from each group of states was generated through the statistical program Gretl. As displayed in Figure 7, the mean DUIC for the more permissive states (n=18) in Group 1 was 5.89 percent, whereas the mean DUIC for the less permissive states (n=32) in Group 2 was 4.46 percent. A null hypothesis of no difference in the means was tested with a two-tailed p-value of less than 0.1, indicating that there is statistical significance to the difference in means. While this test does not indicate correlation between the state policies and DUIC, it does indicate a difference-in-means of 1.4265 percent that is statistically significant, or a prevalence of cannabis-impaired driving that is almost 1.5 percent higher in the more permissive states. The mean

Figure 7: Descriptive Statistics and T-Test Results for More/Less Permissive State Groups for DUIC

(Source: 2017 NSDUH Data; per Salas-Wright et al., 2021)

	Group 1 More Permissive	Group 2 Less Permissive
Number of States	n=18	n=32
Mean	5.8889	4.4625
Median	5.45	4.20
Minimum	3.70	3.00
Maximum	8.40	7.30
Standard deviation	1.4978	0.9999
C.V.	0.2543	0.2241
Skewness	0.3367	1.1423
Ex. kurtosis	- 1.2486	1.0464
Interquartile range	2.5500	1.2750

Null hypothesis: Difference of means = 0
Two-tailed p-value = 0.0001957 ***

difference indicates that **the prevalence of DUIC in more permissive states is 32 percent higher than the DUIC prevalence in less permissive states**.

However, even a statistically significant difference-in-means is not conclusive evidence of a correlation between the more permissive state policies and the higher prevalence of DUIC in the 2017 NSDUH data. The association between the data can be improved by performing an OLS regression with an independent variable of interest as the enactment of a more permissive policy (with a control group of less permissive policy states) and a dependent variable of the percentage of cannabis-impaired driving. Additional control variables can improve the explanatory power of this linear regression by improving the R-squared total.

For this study, the OLS regression returned statistically significant results for the variable of interest (state policy permissiveness), as well as three control variables describing monthly alcohol consumption, median age, and gender. In this case, the enactment of more permissive state cannabis policies, the greater monthly consumption of alcohol, an increase in median age, and a higher percentage of males all positively influenced the increase in DUIC within the US states. Results are displayed in Figure 8.

Figure 8: OLS Regression

Ordinary Least Squares (OLS) Regression, 50 observations
Dependent variable: DUIC

	Coefficient	Standard Error	t-ratio	p-value
constant	- 29.5885	12.0966	- 2.446	0.0184 **
Permissive Policy	0.9200	0.3227	2.851	0.0066 ***
Alcohol Consumption	0.0442	2.1746	2.034	0.0478 **
Median Age	0.2619	0.0776	3.377	0.0015 ***
Gender	0.4391	21.4829	2.044	0.0468 **

Mean depend var	4.9760	**S.D. dependent var**	1.3745
Sum squared resid	44.1697	**S.E. of regression**	0.9907
R-squared	0.5229	**Adjusted R-squared**	0.4805
F (4, 45)	12.3279	**P-value (F)**	0.0000
Log-likelihood	- 67.8473	**Akaike criterion**	145.6946
Schwarz criterion	155.2547	**Hannan-Quinn**	149.3351

White's test for heteroscedasticity:
Null hypothesis: heteroscedasticity not present
Test statistic: LM = 12.3172
with p-value = P(Chi-square(13) > 12.3172) = 0.501821

Specifically, the **enactment of more permissive state policies was correlated with a statistically significant increase in the mean percentage of cannabis impaired driving (DUIC) of 0.92 percent**, indicating that enactment of such policies is associated with an increase in DUIC by almost 1 percent. A one percent increase in monthly alcohol consumption is attributed to a 0.05 percent increase in DUIC. A one year rise in median age relates to a 0.26 percent increase in DUIC, which is counterintuitive to the previous studies reviewed. However, consistent with review literature, a one percent increase in male gender is associated with a 0.44 percent increase in DUIC. Finally, with an adjusted R-squared of 0.4805, the OLS regression has approximately 48 percent explanatory power with the four included independent variables. The data is homoscedastic. Therefore, in answer to the research question, more permissive state policies regarding cannabis directly correlate with a higher cannabis positivity amongst drivers and, thus, a higher rate of DUIC.

Contributions, Limitations, and Policy Recommendations

The ramifications of the differences in permissiveness between states with high-THC programs and low-THC or no cannabis programs can be quantified into a correlative impact of cannabis-intoxicated drivers. **In fact, using 2017 population statistics, the correlative effect of permissive cannabis policies can be forecasted to an increase of 1,062,913 more cannabis-intoxicated drivers in the 18 more permissive states.** Moreso, with the addition of seven more states with recreational cannabis programs in the past five years, the estimated correlative impact of more permissive cannabis policies equals 1,368,198 additional cannabis-intoxicated drivers. While the direct impact of the increase in DUIC cannot be directly translated into an increase in motor vehicle accidents or fatalities, the findings explored in previous literature suggest that more permissive state cannabis policies can lead to roads that are less safe.

This study represents a first-of-its-kind comparison of state cannabis policies with DUIC data. Connecting state policies with self-reported DUIC data is a significant contribution to the literature. However, despite the correlative results mentioned above, the analysis is limited to a correlative impact that does not directly correspond to a causal impact. A major limitation of the state policy dataset is the translation of high-THC programs with the alternative programs, which is explained in greater detail in Adomite (2022). As such, state policies are coded in the dataset as permissive (1) or non-permissive (0), providing a low level of deviation. Data with greater deviation, such as an average THC level in marketed cannabis products (similar to regional data collected by Cash et al., 2020) would greatly enhance this analysis. Additionally, additional years of DUIC data that could be incorporated into a panel data study would allow for greater causal study.

. The policy implications from this research are clear: more permissive cannabis policies present a potential road safety hazard in states with recreational and high-THC cannabis programs. First, the literature suggests the commercialization of the cannabis itself leads users to believe cannabis intoxication is safe and normative within the context of driving. State legislators should strongly consider this trend in context of teenage driving, especially when research suggests between 11 and 23 percent of recreational cannabis sales end up in the hands of minors (Lipperman-Kreda & Grube, 2018).

Furthermore, cannabis commercialization is far outpacing innovation in DUIC enforcement. Recreational consumption away from private residences is now legal in seven states (Nevada, New Jersey, New York, New Mexico, Illinois, Colorado, and California), meaning the culture of driving to an onsite consumption lounge (aka social consumption lounge) and returning home is becoming a trend in the cannabis industry (Serard, 2023). While the commercialized cannabis industry touts such social lounges as “safe spaces for consumption,” citing the availability of professional cannabis bartenders and need to bring the industry “off the streets” (O’Brien, n.d.), these arguments need to be counterbalanced with what Orenstein (2021) relates: “To the extent that the location of cannabis use affects the decision

to drive, allowing public use could increase the prevalence of impaired driving" (p. 94). In fact, these concerns were highlighted by the Nevada Cannabis Advisory Commission's recommendations (2021) regarding consumption lounges, where the mitigation of impaired driving was specifically cited (p. 9). Door-to-door safety should be a strong consideration for the expansion of any state cannabis program.

Finally, the prevalence of DUIC and road safety should also be a strong consideration for state legislators considering expansion of "drive-thru" lanes at recreational cannabis dispensaries, which was recently debated in the Spring 2023 Illinois General Assembly session (McCoppin, 2023). If motor vehicle safety is already at risk from DUIC under general recreational cannabis policies, greater scrutiny is warranted of any programs that involve increasing cannabis intoxication prior to operating a motor vehicle or changing the cannabis product sales to delivery directly to a motor vehicle operator. Worse, these policy proposals trend in concert with changes to state legal standards that disallow traffic stops based upon probable cause for cannabis possession.

Conclusion

This study marks the first quantitative analysis of the effect of permissive state cannabis policies on the prevalence of "driving under the influence of cannabis" (DUIC). While not causative, a correlative relationship is established between more permissive state cannabis policies and an increase in self-reported DUIC. In fact, the presence of a high-THC cannabis policy is associated with a higher 0.92 percent increase in self-reported DUIC, while controlling for alcohol consumption, age, and gender.

The research question of whether more permissive state cannabis policies correlate with an increase in self-reported DUIC is affirmed, with the association consistent in both a difference-in-means and OLS regression analysis between 18 more permissive states and 32 less permissive states in 2017.

After a review of existing DUIC literature, policy makers should take note of the multiple meta-analyses summarizing research on the association between cannabis intoxication and increased motor

vehicle accidents. The results of this study suggest more permissive state policies result in an estimated one million more cannabis-intoxicated drivers in 2017. As of November 2022, approximately 72 percent of Americans now live in a state with a medicinal or recreational cannabis program. State legislator and local government policy makers should consider the risk of DUIC as they consider expansions to legal cannabis programs that involve cannabis consumption and driving, such as social consumption lounges and drive-thru cannabis deliveries.

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