ABSTRACT

Title of Thesis: THE EFFECTS OF MARIJUANA LEGALIZATION ON ADOLESCENT ALCOHOL CONSUMPTION

Ashley Montano, Master of Arts, 2019

Thesis directed by: Dr. Laura Dugan
Department of Criminology and Criminal Justice

Among researchers, there has been a long-standing debate on the issue of whether alcohol and marijuana are used as substitutes or complements of one another. In other words, does the increased usage of one decrease the usage of the other (substitution) or does usage of both substances simultaneously increase (complements)? The primary purpose of this study is to identify whether a suggested substitution or complementary effect exists among adolescent drinking patterns following the recent emergences of increased marijuana legalization. To explore these effects, data is used from 38 different states included in the Youth Risk Behavior Surveillance System between the years 1995 and 2017. The primary analysis finds limited support for a substitution effect and no evidence of a complementary effect among adolescents. This study also includes a supplementary analysis providing implications for the direction of future research on the apparent relationship between alcohol and marijuana usage patterns.

THE EFFECTS OF MARIJUANA LEGALIZATION ON ADOLESCENT ALCOHOL CONSUMPTION

By

Ashley Montano

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Advisory Committee:

Dr. Laura Dugan, Chair
Dr. James Lynch
Dr. Greg Midgett

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1. Introduction

1.1. Introduction

In recent years, the United States has seen a rapid emergence of marijuana legalization policies across a majority of states. *Currently,* ten states and the District of Columbia have adopted the most expansive laws legalizing marijuana for adult recreational use and retail sales. In these states, excluding the District of Columbia, marijuana is taxed and regulated similar to alcohol. Additionally, a total of twenty-three states have broadly legalized medical marijuana programs while an additional thirteen states have passed narrowly defined laws allowing the use of low delta-9-tetrahydrocannabinol (THC), high cannabidiol (CBD) products for limited medical reasons. This sudden emergence of marijuana legalization raises a number of public health and safety concerns – particularly for youth and adolescents.

Identifying and understanding the unintended consequences of these rapidly emerging policies is critical for a number of public health concerns. While the medicinal benefits of marijuana are becoming increasingly accepted, the controversy surrounding marijuana laws focuses primarily on the potential health risks associated with its use, particularly for adolescents. However, there is a substantial lack of evidence supporting these concerns. On the other hand, what is even less understood, is whether marijuana legalization influences usage rates of alcohol – a widely accepted, legal substance which is *known* to have detrimental effects on the physical, psychological, and social wellbeing of users. Among researchers, there has been a long-standing debate on the issue of whether alcohol and marijuana are used as substitutes or complements of one another. In other words, does the increased usage of one decrease the usage of the other

(substitution) or does usage of both substances simultaneously increase together (complements)? If alcohol and marijuana are substitutes for one another, then laws that legalize the use of marijuana could potentially decrease the use of alcohol, presenting a major public health benefit. If they are complements, these laws could exacerbate alcohol usage. However, little up-to-date research has been done to observe this substitution or complementary effect in light of these modern policy changes. The primary purpose of this research is to identify whether a suggested substitution or complementary effect exists following the recent changes in many state's laws.

When considering the advantages and disadvantages of drug policy, it is critical for researchers and policy makers to approach topics from an unbiased and evidence-based perspective. Thus, the structure of this thesis includes a comprehensive history of marijuana in the United States in order to establish a firm understanding of how American perceptions have evolved and contributed to the controversial political climate surrounding marijuana for generations. In addition, the health concerns associated with both marijuana and alcohol are included to allow the reader a full understanding of the known dangerousness associated with each substance. Once these contexts are established, I present the theoretical bases for the substitution and complement effects, pharmacological, and Rational Choice Theory.

To explore these effects, data is used from the Youth Risk Behavior Surveillance System (YRBSS) between the years 1995 and 2017. Among these data are measures of adolescent alcohol and drug use from 38 different states. A better understanding of the relationship between alcohol and marijuana use could contribute to further research

surrounding the unintended public health consequences or benefits from an increase or decrease of usage rates associated with each substance.

1.2 History of Marijuana in the United States

Hemp is an ancient plant that has been used and cultivated by humans for millennia. In the United States, hemp was encouraged by the federal government to be used in production for various products including rope, sails, and clothing throughout the 17th Century (Herndon, 1963). The crop was a staple in colonial America and proved to be incredibly versatile in its uses, mostly due to its strong and durable fibers. The Virginia Assembly passed legislation in 1619 requiring every farmer to grow hemp, those who refused could be jailed (Herndon, 1963). In addition, hemp was often used to barter or even as legal tender for farmers to pay taxes in many colonies from 1631 until the early 1900s (Herndon, 1963). During the late 19th century, cannabis had become an increasingly popular ingredient in medical products and was openly available in drug stores (Siff, 2014). There were a number of medicinal fads throughout the century, often referring to cannabis as "a pleasurable and harmless stimulant" or a source for "new inspiration and energy"; however, recreational use was not widely known or accepted at this time (Siff, 2014; Vanity Fair, 1862).

Following the Mexican Revolution of 1910, the United States experienced an influx of Mexican immigrants, who ultimately introduced to American culture the recreational use of cannabis, which was referred to as "marihuana" (Siff, 2014; McDonald, 2017). The new and authentic sounding label of "marihuana" became increasingly associated with Mexican immigrants and quickly tied in with prejudice attitudes held towards them at the time (McDonald, 2014). This growing tension led to

public and governmental concern about the usage of marijuana and sparked an uptick in anti-marijuana campaigns linking the substance to violence, crime, and other deviant behaviors which were primarily associated with the "racially inferior" (McDonald, 2017). The "war against marijuana" arguably began in 1930 with the establishment of the Federal Bureau of Narcotics and its first named director, Harry J. Anslinger. The agency of this time had numerous, racially charged claims intended to spread misinformation, referring to marijuana as "the most violence-causing drug in the history of mankind" and suggesting that "reefer makes darkies think they're as good as white men" (McDonald, 2017). While the fear mongering strategy seems outrageous, it worked as intended and newspapers were soon dubbing Mexican cannabis as the "Marijuana Menace" (Siff, 2014; McDonald, 2017).

By 1931, 29 states had outlawed marijuana and by 1937 Congress passed the Marijuana Tax Act, criminalizing marijuana and restricting possession of the drug only to those who paid an excise tax for medical and industrial uses (Marijuana Tax Act of 1937). Sentencing laws grew even more strict by the Boggs Act (1952) and Narcotics Control Act (1956) – setting mandatory sentences for drug related offenses, including marijuana (Boggs Act of 1952; Narcotics Control Act of 1956). Under these sentences, there was a minimum sentence of 2-10 years with a fine of up to $20,000 for a first-offense marijuana possession. Many of these mandatory penalties for drug-related offenses were eventually repealed by Congress in 1970 after the widespread acknowledgment that the mandatory minimum sentences did nothing to eliminate the popular drug culture of the 1960's (Drug Abuse Prevention and Control Act of 1970). This legislation also included the Controlled Substances Act, a statute establishing U.S.

drug policy and the regulation of substances. The statute contains five schedules (classifications) qualifying drugs based off three factors: potential for abuse, accepted medical use, and potential for addiction. Under this act, marijuana was classified as a Schedule I drug, the most restrictive and high-risk category.

In 1971 President Nixon declared the first "war on drugs" and further increased the size and presence of federal drug control agencies (Drug Policy Alliance, 2019). In addition, public concern over marijuana use continued to increase as a nationwide parents' movement against marijuana emerged in 1976 throughout the 1980's, lobbying for stricter regulations of marijuana and prevention of teenage drug use (Dufton, 2013; Drug Policy Alliance, 2019). Many of the groups became increasingly influential on public attitudes and also gained support from the Drug Enforcement Administration (DEA) and the National Institute on Drug Abuse (NIDA) (Dufton, 2013; Drug Policy Alliance, 2019). Among eleven states, there was a brief emergence of decriminalization proposals which were readily abandoned as progress continually shifted under an unprecedented expansion of the drug war by President Ronald Reagan. The late 1980s consisted of a dramatic increase of political hysteria regarding drug abuse: polls in 1985 reflected only around 2 to 6 percent of Americans who saw drug abuse as the nation's "number one problem", within four years these numbers reached 64 percent – this shift is known as one of the most intense fixations by the American public in polling history (Drug Policy Alliance, 2019).

In 1986, the Anti-Drug Abuse Act was signed by President Ronald Reagan, implementing mandatory sentences for drug related crimes (Anti-Drug Abuse Act of 1986). This was done in conjunction with the Comprehensive Crime Control Act of 1984

which raised federal penalties for marijuana possession and dealing (Comprehensive Crime Control Act of 1984). These penalties were calculated based off the amount of the drug involved, rather than the type of substance. Under these definitions, the possession of 100 marijuana plants received the same penalty as 100 grams of heroin. The Anti-Drug Abuse Act would later be amended to establish a "three strikes and you're out" policy, requiring life sentences for repeat drug offenders and allowing the death penalty for "drug kingpins" (Omnibus Anti Drug-Abuse Act of 1988). The war on drugs proceeded to expand throughout the 1990s under the presidency of Bill Clinton. While the public outcry surrounding drug use eventually waned, the draconian style policies enacted during the time of political hysteria remained – contributing to escalating levels of arrests and incarceration (Drug Policy Alliance, 2019).

Nearing almost 100 years since the very beginnings of a movement which criminalized marijuana in the early 20th Century, California was the first state to once again legalize the medicinal use of marijuana in 1996 with Proposition 215 (The Compassionate Use Act of 1996). This allowed the sale of marijuana to patients with AIDS, cancer, and other serious and painful diseases. Since then, 33 more states, the District of Columbia, Guam, and Puerto Rico have enacted similar laws for medical marijuana, decriminalization efforts, and even recreational use.

1.3. Current Federal Laws

Currently, marijuana still remains classified as a Schedule I drug by the federal government, making the distribution of marijuana a federal offense. According to the Controlled Substances Act, a Schedule I drug must have a "high potential for abuse" and

"no currently accepted medical use in treatment in the United States" (DEA, 2018; Anderson et. al, 2001).

In 2009, the Obama Administration encouraged federal prosecutors not to prosecute people who distribute marijuana for medical purposes in accordance with state laws. By 2013, the United States Department of Justice (USDOJ) updated their marijuana enforcement policy with the Cole Memorandum, stating that while marijuana remains illegal federally, the USDOJ expects states which pursue legalization to create "strong, state-based enforcement efforts.... and will defer the right to challenge their legalization laws at this time." However, the department does reserve the right to challenge states at any time if deemed necessary (Cole, 2013).

In more recent events, Attorney General Sessions issued a Marijuana Enforcement Memorandum which rescinded the Cole Memorandum, allowing federal prosecutors the discretion on how to prioritize enforcement of federal marijuana laws. The Sessions memorandum instructs U.S. Attorney's to "weigh all relevant considerations, including federal law enforcement priorities set by the Attorney General, the seriousness of the crime, the deterrent effect of criminal prosecution, and the cumulative impact of particular crimes on the community."

1.4. Current State Laws

With marijuana remaining a Schedule I drug under federal law the discrepancies between state laws which are pursuing legalization efforts are abundant. For instance, medical marijuana cannot legally be "prescribed" under its current definition as a Schedule I drug with "no currently accepted medical use in treatment" – rather these "prescriptions" are more often called "recommendations" or "referrals". Furthermore,

states with medical marijuana programs typically have some form of patient registry, which may provide individuals with some legal protection for possession up to a certain amount of marijuana.

While marijuana laws are rapidly changing and vary by state, they can be condensed into three *general* categories: legal, medical, and illegal. Currently, recreational marijuana is legal in ten states and the District of Columbia, which allow for recreational adult use *and* medical use programs (National Conference of State Legislatures, 2018; Marijuana Policy Project, 2018). In all of these states, excluding Vermont and the District of Columbia, marijuana is taxed and regulated similar to alcohol. A total of twenty-three states allow comprehensive medical marijuana/cannabis programs while an additional thirteen states allow use of "low THC, high CBD" products for limited medical reasons. While these states have some form of a medical program, the laws still vary significantly, and the general decriminalization of marijuana is still mixed amongst these states. For example, while some states may have legalized a medical marijuana program, the possession, use, and/or distribution of marijuana for individuals without a medical license is still illegal and may still be punishable by fines and/or imprisonment (Marijuana Policy Project, 2019). Lastly, Idaho, South Dakota, Nebraska, and Kansas are the final four states where *all* forms of marijuana use or programs are currently illegal, including access to "low THC, high CBD" products.

Furthermore, while the research on the relationship between marijuana and alcohol use is still in its early stages, some current laws intend to limit the use of both substances. For example, it is currently illegal in all states to sell both marijuana and

alcohol at the same location[1] (Medical and Adult-Use Cannabis Regulation and Safety Act of 2017). Some laws also prohibit the consumption of cannabis in public places, including locations authorized to sell or serve alcohol. Further, the sale of cannabis infused (or mixed) alcoholic beverages is also prohibited (California Department of Public Health, 2017).

With the recent increases of decriminalization, medical marijuana licenses, and recreational marijuana laws across the United States a number of public health and policy questions are brought to the forefront. While there is growing support on the medical properties' marijuana may have to offer, the research underlying the potential health risks is limited. Furthermore, as marijuana becomes more accessible for recreational use, knowledge on other unintended consequences is mixed, including the impacts of usage rates on other more dangerous substances.

2. Marijuana and Alcohol

2.1. Marijuana

2.1.1. Gateway Drug

Marijuana has long been referred to as "the gateway drug" – implying that those who choose to use marijuana will eventually go on to use other, harder drugs. While this argument is supported by animal studies, which have shown that early exposure to addictive substances may change how the brain responds to drugs and enhance the experience for other addictive substances, statistics for humans consistently report that a majority of people who use marijuana never go on to use harder drugs (Drug Policy Alliance 2018; Panlilio, Zanettini, Barnes, Salinas, & Goldberg, 2013). A number of pharmacological studies have sought to answer the causal question of whether marijuana

is a gateway drug and findings are typically overstated and/or inconclusive (Caulkins, Kilmer, & Kleiman, 2016). Nonetheless, when taking into account a person's risk for drug use and addiction, researchers should consider more than just biological mechanisms, other factors should be taken into account such as a person's social environment, genetics, psychological and personality traits (Kreek, Nielsen, Butelman, & LaForge, 2005).

While there is not ample evidence to support marijuana as a gateway drug, other related factors should not be dismissed that could contribute to a "gateway effect". For example, using marijuana could increase an individual's desire to seek mind altering drugs or infer that drugs are less risky than previously supposed (Caulkins, Kilmer, & Kleiman, 2016). This could potentially influence an individual's decision to partake in harder drugs. In addition, the social interactions that come with marijuana use may increase contact with peers who favor drug use (Caulkins, Kilmer, & Kleiman, 2016). These interactions could also increase the opportunity to access other illegal drugs. However, legalizing marijuana could interfere with this relationship by removing marijuana from the supply chain in the underground market. In other words, decriminalizing marijuana would interfere with the criminal, social influences which might contribute to a gateway effect.

Overall, the question of increased drug dependency following marijuana use may indeed be possible but is yet to be proven. While evidence suggests that adolescents who use marijuana are more likely to go on to use other drugs than their abstinent peers, the use and access to alcohol, tobacco and marijuana are all more likely to come before the

use of other drugs in general (Secades-Villa, Garcia-Rodriguez, Jin, Wang, & Blanco, 2015; Levine, Huang, & Drisaldi, 2011).

2.1.2. Marijuana Medicinal Qualities

The marijuana plant contains more than 100 cannabinoids, which are the chemicals that include *delta-9-tetrahydrocannabinol* (THC), marijuana's primary psychoactive ingredient which is responsible for the "high" that users experience (National Institute of Drug Abuse, 2018). There are currently two main cannabinoids of medical interest from marijuana, THC and Cannabidiol (CBD). While THC does have a mind-altering effect, it has also been linked to decreasing pain, inflammation, muscle control problems, increased appetite and reduced nausea (NIDA, 2018). Unlike THC, CBD does not have an intoxicating effect on people and is thus not popular for recreational use but is still often used for various medical purposes including: reducing pain and inflammation, epileptic seizures, and possibly treating mental illness and addiction (NIDA, 2018).

After the passage of California's Proposition 215, the Institute of Medicine released a report exploring the therapeutic uses of marijuana. The report found that: "Scientific data indicate the potential therapeutic value of cannabinoid drugs, primarily THC, for pain relief, control of nausea and vomiting, and appetite stimulation; smoked marijuana, however, is a crude THC delivery system that also delivers harmful substances. The psychological effects of cannabinoids, such as anxiety reduction, sedation, and euphoria can influence their potential therapeutic value. Those effects are potentially undesirable for certain patients and situations and beneficial for others. In addition, psychological effects can complicate the interpretation of other aspects of the

drug's effect." (NCSL, 2018, p. 4). Since then, other studies have since found further evidence of the effectiveness of marijuana for medical uses. In early 2017, the National Academies of Sciences, Engineering, and Medicine released a report constructed of a review of over 10,000 scientific studies on marijuana health research. The final report obtains 100 conclusions related to health (Committee on the Health Effects of Marijuana, 2017). In summary, there is *substantial* evidence for cannabis to be used as effective treatment in relieving chronic pain, nausea and vomiting, and improving patient-reported multiple sclerosis spasticity symptoms. There is also *moderate* evidence for cannabis to be effective in improving short-term sleep outcomes for various causes of sleep disturbances. Lastly, there is *limited* evidence for the improvement of symptoms of Tourette syndrome, anxiety symptoms, posttraumatic stress disorder, and better outcomes following a traumatic brain injury or intracranial hemorrhage.

While the evidence of the therapeutic uses of marijuana is increasing, researchers have not yet conducted enough large-scale clinical trials to establish FDA approval that the benefits outweigh the risks in patients. For current medical marijuana patients, treatment recommendations are primarily up to the "budtenders" – or dispensary staff – to make product suggestions for patients. Since the therapeutic benefits of marijuana are still subjective, it is somewhat of an arbitrary process with no formal guidelines. However, the FDA does support current research of well-controlled clinical trials making efforts to develop safe and effective marijuana products to treat medical conditions (NCCIH, 2018). The FDA has currently approved three cannabinoids as drugs. Epidiolex, contains CBD derived from the marijuana plant for the treatment of seizures associated with two rare, severe forms of epilepsy (NCCIH, 2018). Two synthetic cannabinoids –

dronabinol and nabilone – have also been approved to treat nausea and vomiting from chemotherapy (NCCIH, 2018). Dronabinol has also been approved to treat loss of appetite and weight loss in people with AIDS (NCCIH, 2018). While research for medical uses of marijuana is increasingly gaining attention, there is still much that is largely unknown about the true medicinal qualities of the plant.

Nonetheless, the legalization of medical marijuana has provided other indirect pharmaceutical benefits. Since the late 1990's, opioid misuse and addiction has become a widespread issue in the United States. In 2017, opioid overdoses accounted for more than 47,600 deaths – averaging 130 deaths per day – and it is estimated that approximately 11.4 million people misused prescription opioids (U.S. Department of Health and Human Services, 2018). The U.S. Department of Health and Human Services has since declared the opioid crisis a public health emergency. Opioids are typically prescribed for the management of chronic pain; which is also a major indication for medical cannabis. Following medical marijuana legalization laws, research has begun to explore the impact of medical marijuana on opioid use and mortality rates. One study has found that states with medical marijuana laws are associated with significantly lower opioid overdose mortality rates and the relationship appears to strengthen overtime (Bachuber, Saloner, Cunningham, & Barry, 2014). More recently, other studies have further explored this relationship to identify the potential mechanism that facilitates the decrease in opioid overdose deaths and the reduction of daily doses filled (Powell, Pacula, & Jacobson, 2018). Findings suggest that broader access to medical marijuana facilities and more liberal allowance for dispensaries facilitate the substitution of marijuana for opioids (Powell et al., 2018). Conversely, stricter laws and regulations for medical marijuana

dispensaries remove this protective factor among states (Powell et al., 2018). Apart from overdose related deaths, the legalization of medical marijuana has also been associated with a decrease in traffic fatalities involving drivers testing positive for opioid use, between the ages of 21 to 40 years (Kim, Santaella-Tenorio, Mauro, Wrobel, Cerda, Keyes, Hasin, Martins, & Li, 2016). In summary, while the medical properties of marijuana are still being studied, there is limited support suggesting evidence of additional indirect benefits of medical marijuana legalization if it is indeed being used to substitute for suggestively much more harmful pharmaceuticals.

2.2. Health Concerns

2.2.1. Marijuana

The Substance Abuse Center for Behavioral Health Statistics and Quality reported from the 2016 National Survey on Drug Use and Health that marijuana is the most commonly used illicit substance in the United States, including young adults aged 18 to 25. However, there are no recorded instances of fatal overdoses from marijuana alone (NIDA, 2018).

Marijuana has a number of short-term effects on various parts of the brain, causing the reported “high” consumers seek. The effects generally include altered senses, altered sense of time, changes in mood, impaired body movement, difficulty thinking and problem-solving, and impaired memory (NIDA, 2018). If taken in high dosages, individuals could potentially experience hallucinations, delusions, or psychosis – particularly for those with an established psychotic disorder (Wilkinson, 2014; NIDA, 2018; Radhakrishnan, Wilkinson, & D’Souza, 2014). However, it should be noted that

the majority of individuals who consume cannabis do not experience any kind of psychosis (Radhakrishnan et al., 2014).

However, use of cannabis during adolescents has been linked to adult onset-psychosis. Caspi et al. (2005) found evidence that adolescent-onset cannabis use is associated with a functional polymorphism in the catechol-O-methyltransferase gene predicted the risk of psychosis in adulthood. However, this relationship was not found among individuals who began to use marijuana as adults. The authors also acknowledge the possibility that preexisting cognitive problems could lead psychosis-prone individuals to initiate cannabis use as teenagers. Nonetheless, these findings suggest that some adolescents could be neurobiologically vulnerable to cannabis, which should be taken into consideration when designing policy that affects adolescent access to marijuana (Caspi et al., 2005).

As for the physical effects of marijuana use, reported instances include increased heart rate for up to 3 hours after smoking, nausea, vomiting, and breathing problems for people who smoke marijuana frequently (NIDA, 2018; National Academies of Sciences, Engineering, and Medicine, 2017). While many of these symptoms are comparable to tobacco smokers, research has yet to find any higher risks for lung cancer in people who smoke marijuana than cigarettes (NIDA, 2018; NASEM, 2017). Studies on the mental effects of marijuana are mixed but have been linked to mental illnesses in some people, such as: temporary hallucinations, temporary paranoia, and worsening symptoms in patients with schizophrenia (NIDA, 2018). Marijuana has also been linked to depression, anxiety, and suicidal thoughts among teens, but with inconsistent findings (NIDA, 2018).

The addictiveness of marijuana is frequently debated as well. Within the United States, the THC-potency has continually increased between the years 2001 to 2013 and the prevalence of past-year adult marijuana use more than doubled, however the *risk* of marijuana use disorders has slightly declined (Hasin, Saha, & Kerridge, 2015). Overall, this research suggests that between 9 and 30 percent of marijuana users may develop some degree of marijuana use disorder (Hasin, Saha, & Kerridge, 2015). Those who use marijuana long term and try to quit have reported mild withdrawal symptoms such as: grouchiness, sleeplessness, decreased appetite, anxiety, and cravings (NIDA, 2018).

The long-term effects of marijuana are still often debated and are currently heavily researched. However, a number of studies have investigated the long-term effects of adolescent-onset marijuana use on impairments of thinking, memory, and learning functions (NIDA, 2018; Meier, Caspi, & Ambler, 2012; Jackson, Isen, Khoddam, Irons, Tuvblad, Iacono, McGue, Raine, & Baker, 2016). One example includes a study in New Zealand which tested the association between persistent cannabis use and neuropsychological decline in order to determine whether decline is concentrated among adolescent-onset cannabis use (Meier et al., 2012). Findings suggest that people who heavily used marijuana in their teenage years *and* had an ongoing marijuana use disorder lost an average of 8 IQ points between ages 13 and 38 – which did not later return for those who quit marijuana as adults. The neuropsychological decline persisted broadly across domains of functioning, even when controlling for years of education (Meier et al., 2012). Contrarily, consumers who started smoking marijuana as adults did not show any significant IQ declines (Meier et al., 2012). Another recent study exploring the long-term effects of marijuana on IQ failed to support the implication that marijuana exposure in

adolescence causes neurocognitive decline (Jackson et al., 2016). This study included twin sets of users and non-users, controlling for genetic propensity and shared environment to determine the direct feasibility of a direct mechanism underlying the IQ-marijuana use association. While the study found a significant decline in general knowledge and verbal ability (approximately 4 IQ points) for marijuana users between the preteen years and early adulthood, future users already had significantly lower scores than nonusers at the baseline assessments – demonstrating that marijuana use may not necessarily *precede* lower IQ (Jackson et al., 2016). When comparing any changes in IQ since the baseline assessment, no predictable effects consistently emerged to suggest that the marijuana using twin exhibited greater IQ deficits relative to their marijuana-abstinent twin (Jackson et al., 2016). These findings suggest that the suspected IQ deficit in early marijuana users could be attributable to confounding factors which may influence both substance use initiation and IQ (Jackson et al., 2016). Nonetheless, further research is necessary to understand the suggestive effects of cannabis on the adolescent brain and highlight the importance of effective marijuana policy efforts with respect to adolescents.

In summary, while the health consequences of marijuana are still being heavily studied and the conclusions are generally mixed, the health concerns associated with alcohol use have long been understood by researchers.

2.2.2. Alcohol

The National Institute of Alcohol Abuse and Alcoholism reports estimate that of 88,000 people die from alcohol-related causes annually, making alcohol the third leading cause of preventable death in the United States (NIAAA, 2018). Of these deaths, 2,200

are from alcohol poisoning alone – an average of 6 deaths each day (Center for Disease Control and Prevention, 2018).

Drinking too much (binge drinking) has been heavily researched and shown to cause a number of serious health consequences. While the definition of *binge drinking* varies, for this particular data set, *binge drinking* is defined as consuming five or more alcoholic drinks, in a row, within approximately two hours (for males) or four or more alcoholic drinks in a row, within two hours (for females) (CDC, 2018). Alcohol consumption at this level typically result in acute impairment and contributes to a substantial proportion of all alcohol related deaths (Naimi, 2003). Other adverse health effects associated with binge drinking include: unintentional injuries (e.g., motor vehicle crashes, falls, drowning, hypothermia, and burns), suicide, sudden infant death syndrome, alcohol poisoning, hypertension, acute myocardial infarction, gastritis, pancreatitis, sexually transmitted diseases, meningitis, and poor control of diabetes (Naimi, 2004; NIAAA, 2018). Binge drinking can also lead to a number of social and economic consequences including interpersonal violence (e.g., homicide, assault, domestic violence, rape, and child abuse), fetal alcohol syndrome, unintended pregnancy, child neglect, and lost productivity (NIAAA, 2018; Naimi, 2003). The United States Department of Health and Human Services noted that reducing binge drinking among adults is one of the leading health indicators in *Healthy People* 2010 (USDHHS, 2010). Furthermore, a number of previous studies have consistently found binge drinking rates to be highest among young adults aged 21 to 25 years and underage drinkers aged 18 to 20 years (Kanny, Kaimi, Liou Lu, & Brewer, 2015; Naimi, 2003; Greenfiel, Midanik, & Rogers, 2000; SAMHSA, 1999).

The long-term effects of heavy alcohol use have been shown to weaken the immune system and cause permanent damage to the heart including problems such as: cardiomyopathy, arrhythmias, stroke, and high blood pressure (NIAAA, 2018). The liver also commonly experiences problems with long term drinking such as: steatosis, alcoholic hepatitis, fibrosis, and cirrhosis (NIAAA, 2018). Alcohol has also been shown to cause the pancreas to produce toxic substances that may eventually lead to pancreatitis. (NIAAA, 2018). There is also a strong scientific consensus based on extensive reviews of research studies of clear patterns between alcohol consumption and the development of several types of cancer including: head and neck cancer, esophageal cancer, liver cancer, breast cancer, and colorectal cancer (National Cancer Institute, 2018).

Alcoholism is currently considered a dire public health concern, and one of the most common addictions affecting Americans with reports of more than 15 million people struggling with alcohol use disorder – with less than 8% of these receiving treatment (NIAAA, 2018). Addictions are usually formed once an individual's brain adapts to the psychological effects of alcohol and thus the brain needs more alcohol to experience the same effect (Delphi Behavioral Health Group, 2018). This process creates an ongoing cycle of increasing one's tolerance, contributing to greater alcohol consumption in order to achieve the desired effects. Eventually, this cycle is likely to lead to alcohol dependence and addiction. Withdrawal symptoms upon quitting can begin to occur as early as two hours after a last drink and may include: insomnia, agitation, headaches, anxiety, nausea, rapid heartbeat, changes in blood pressure, sweating, fever, tremors, hallucinations, and seizures or convulsions (Delphi Behavioral Health Group, 2018). Some people may experience very few symptoms while others may suffer from

the more serious of these effects. These immediate symptoms often progress over a 48-hour timeline and can be experienced again within the first couple weeks after quitting. Others may experience more prolonged side effects that can last anywhere from a few weeks to a year with symptoms including: irritability or emotional outbursts, anxiety, low energy, trouble sleeping, memory problems, dizziness, increased accident proneness, and delayed reflexes (Delphi Behavioral Health Group, 2018).

2.3. Relationship Between Alcohol and Marijuana

Alcohol and marijuana are two of the most commonly used substances in the world and have comparable psychological effects upon consumption (SAMHSA, 2012; Wen et al., 2015). One can acknowledge that each substance poses their own set of health risks; however, even with the limited research on marijuana, it is clear that the risks associated with alcohol can be extremely detrimental. With the legalization of marijuana, the substance is becoming more accessible to the public and thus more likely to be obtained by adolescents. While many may be quick to assume that a potential rise in marijuana usage rates could be inherently harmful for adolescents and public health, previous research suggests that there is potential for this to lead to a decrease in alcohol consumption, if the substances are indeed substitutes of each other. When taking into account the public health crisis that has resulted from alcohol abuse and alcoholism, a substitution effect with marijuana could arguably present a major public health benefit. Alcohol use has undeniably been associated with multiple, permanent health problems and remains as one of the most common addictions, accompanied by aggressive withdrawal symptoms. While a substitution effect may have an impact on overall alcohol usage, there is also potential to decrease the rates of binge drinking, and thus impacting a

major proportion of all alcohol related deaths. Underage adolescents and young adults reportedly have the highest rates of binge drinking across all age groups; thus, it is critical to public health for policy makers to understand how the legalization of marijuana impacts adolescent drinking habits. Researchers across various disciplines have already investigated if such an effect exists between alcohol and cannabis; however, results have remained mixed and a consensus has yet to be synthesized. A number of studies have found support suggesting that these substances are indeed substitutes for one another (Anderson, Hansen, & Rees, 2001; DiNardo & Lemieux, 2001; Crost & Guerrero, 2012; Chaloupka & Laixuthai, 1997). However, several studies have also found that alcohol use complements marijuana use, which, if true, would enhance the damages associated with increased alcohol and marijuana use (Pacula, 1998; Yörük and Yörük, 2011; Williams, Pacula, Chaloupka, & Wechsler, 2004). Overall, there is still much ambiguity across findings of this phenomenon.

2.4. Substitutes and Complements

2.4.1. Pharmacological Theory

Among researchers, there has been a long-standing debate on the issue of whether alcohol and marijuana are used as substitutes or complements of one another (Anderson, Hansen, & Rees, 2001). In general, a "substitute" is something that takes the place of something else, whereas a "complement" is something that completes or enhances something else. These definitions can be applied to the categorization of drugs based on their interactions: "substitutes" can pharmacological replace one another, "complements"

enhance the effects of one drug with another, and "independent" if the effects of one drug are unaltered by the other (Subbaraman, 2016).

Marijuana and alcohol both target some of the same neural pathways in the human brain, which may result in similar psychological effects when using each substance (SAMHSA, 2012; Wen et al., 2015). More specifically, marijuana use produces similar rewarding and sedative effects, which are comparable to the effects of alcohol, particularly low-dose alcohol consumption (Wen et al., 2015). It is also worth mentioning that *only* extreme use of marijuana is shown to produce mild hangover effects, whereas mild-to-moderate alcohol consumption can produce debilitating hangover effects (Jones & Jones, 2019). Given these comparable effects in conjunction with the lower costs of marijuana following legalization, an individual may choose to substitute marijuana for alcohol to achieve a similar experience with less immediate consequences.

Contrarily, evidence also suggests that the overall intoxication experience may be enhanced by simultaneously using marijuana and alcohol together– suggesting that the substances are complements. Previous studies have found that ethanol, especially when consumed in high doses can facilitate an increased absorption of THC, resulting in an increase of the positive subjective mood effects of marijuana (Boys, Marsden, & Strang, 2001; Lukas and Orozco (2001). Furthermore, Lukas and Orozco (2001) conducted a randomized control experiment, which found that those participants which consumed marijuana simultaneously with high doses of ethanol reported more episodes and longer durations of euphoria than those that consumed placebo ethanol. This enhanced euphoria

following simultaneous consumption with high doses of alcohol could produce an urge for the consumer to drink even more (Wen et al., 2015). Such a scenario of complementary substances presents a direct competing hypothesis for a substitution effect. Thus, it is possible that the increased legalization and accessibly to marijuana may result in an increase of usage of both substances.

When considering the pharmacological effects on researching whether alcohol and marijuana are substitutes or complements, it is important to keep in mind that individual motives may also influence substance use patterns. For example, individuals seeking more mild effects of euphoria or relaxation may choose to partake in the consumption of one substance over the other. Whereas those seeking more intense euphoric or intoxicating effects would consume the substances together, potentially in higher doses. In addition, when substances become accessible and more normalized under liberalized policies, the perceived costs associated with usage tends to decrease, thus potentially influencing the likelihood of usage. While the substances have comparable psychological effects, it is sensible to assume that there is still a decision-making process that takes place when an individual is given the option of two accessible substances.

2.4.2. Rational Choice Theory

The rational choice model of deviant behavior and drug use explains an individual's drug use as a result of the decision-making process through a cost-benefit analysis (Black & Joseph, 2013). According to this theory, drug use will occur when the perceived benefits of engaging in the activity are greater than the risks associated with it. Furthermore, the rational choice model argues that individuals' behaviors are also

affected by incentives and constraints – both of which are taken into consideration in the individual's subjective yet rational calculation of reward, risk, and punishment (Black & Joseph, 2013). Laws criminalizing drug use are in part a strategy of deterrence intended to maximize the costs of engaging in the behavior, thus reducing the prevalence of drug use. However, one could argue that criminalization laws have been shown to be rather ineffective at eliminating marijuana consumption (Bostwick, 2012). Even with the current expansion of more liberalized policies, marijuana is still criminalized in many states yet remains as the most popular illicit substance (NIDA, 2018).

In the case of substance use, rewards of the activity may be inherit to the pleasures associated with the experience of consumption. On the other hand, the risks of substance use may be more subjective based on the perception of the number of risky factors associated with use, such as the likelihood of getting caught and the level of negative sanctions. Both formal and informal sanctions can be taken into account with this theory. Formal sanctions include actions that are typically defined by policy, enforced, and official in nature such as arrest, citations, or job loss (Black & Joseph, 2013). Informal sanctions are not laws, in a legal sense, but occur regularly in society such as shaming, ridicule, or disapproval by peers (Bottorff et al. 2013). These informal sanctions may be of particular importance when trying to understand an adolescent's rationale to partake in substance use, as disapproval from peers could deter drug use (risk) but also promote it through the possibility of peer pressure one may experience if trying to "fit in" (reward). While these calculations are entirely subjective to the individual and/or the given circumstances, in summary, the lower perceived risks

associated with the drug-use behavior, the greater chance that person will engage in consumption (Bostwick, 2012; Black & Joseph, 2013).

When the law changes in a certain way, it creates the opportunity of a chain of events to occur and influence one's decision to partake in substance use. Some of these may take place immediately and some may occur over a more extended amount of time. For adolescents living in states with more liberalized marijuana laws, the perceived risks associated with access, usage, and getting caught are likely to decrease almost immediately. For example, for states which marijuana is still illegal, access to the substance requires a connection to a dealer. The process of distributing and maintaining *illegal* substances carries an additional standard of risk than obtaining alcohol. In recreational states, marijuana use is essentially placed on the same level of risk as alcohol, with criminality only reaching the extents of a "minor-in-possession" status offense to those under 21 years of age (State of Colorado, 2019). Furthermore, legalization efforts may contribute to a community with an increase in accepting attitudes and normalization of marijuana, thus the social costs associated with usage will begin to drop. In other words, the negative stigma and consequences that are normally associated with using illicit drugs are becoming less applicable to marijuana following policy changes.

Some studies have already begun to suggest the beginning of this process by measuring changes in attitudes following marijuana policy changes amongst states. One study, analyzed attitudes towards marijuana of 8th, 10th, and 12th graders in California following decriminalization in 2010 (Miech, Johnston, O'Malley, Bachman,

Schulenberg, & Patrick, 2015). The study found an increase in permissive attitudes toward marijuana among 12th graders (Miech et al., 2015). These attitudes were measured using survey response questions regarding: using marijuana in the last 30 days, perceptions of regular marijuana use as a great health risk, disapproval of regular marijuana use, and expectations to use marijuana five years in the future. Another study, using the National Survey on Drug Use and Health (2003-2011) also tested for temporal changes of attitudes following the commercialization of marijuana in Colorado (Schuermeyer, Salomonsen-Sautel, Price, Balan, Thurstone, Min, & Sakai, 2014). The results showed that marijuana legalization and commercialization was associated with a lower risk perception reported among all age groups.

This reduction of social costs presents an opportunity for the individual to more equally weigh the costs and benefits associated with *each* substance, thus allowing for a potential substitution effect. For example, if an individual is choosing to partake in marijuana use or alcohol consumption, the costs may focus on other more immediate consequences related with each drug (e.g. intoxication effects, health concerns/medical benefits, hangovers, availability, price values) instead of having to consider the legality of one substance over the other. Overall, the consequences, normalization, and stigma associated with marijuana usage are all affected by changes in marijuana policy. The decrease in these informal sanctions, as well as, more acceptable attitudes among friends, parents, or the general community will likely all exert some sort of influence on the choices a youth might make.

Another factor for adolescents to take into consideration may be the prices of both alcohol and marijuana; which can vary drastically across states. In an attempt to reduce underage drinking, a number of alcohol policies have been implemented in the United States, making alcohol availability more difficult and expensive. Some states have attempted to control access to alcohol by decreasing the hours of sale, not allowing the sale of alcohol in corner stores, implementing an excise tax, or even containing "dry counties" - which forbid the sale of any kind of alcoholic beverage (Greenfield & Gresibecht, 2008; Frendreis and Tatalovich, 2010). Prior research shows that stronger state alcohol policies and higher beer excise taxes are associated with lower risk of escalating alcohol consumption among underage youth (Fairman, Simons-Morton, Haynie. Liu, Goldstein, Hingson, & Gilman, 2019).

Similarly, the prices of marijuana also vary drastically by state and the amount of time since legalization. Washington and Colorado both saw a sharp increase in marijuana prices immediately following the market's opening (Smart, Caulkins, Kilmer, Davenport, & Midgette, 2018; Orens, Light, Lewandowski, Rowberry, & Saloga; 2018). However, prices soon decreased to reflect the more current, nationwide trends of decreasing prices as the marijuana industry expands (Cannabis Benchmarks, 2018). Since the availability and prices of both alcohol and marijuana will vary from state to state, these factors will likely be an important part in the youth's decision-making process, which is entirely dependent on where they live.

Apart from this state variation, actual price comparisons between alcohol and marijuana is somewhat controversial. Primarily due to the fact that there is no "standard

dose" of marijuana or THC as there is for alcohol – a standard drink in the United States contains 14 grams of pure alcohol (NIAAA, 2018). This makes directly comparing costs by price indexes of each substance difficult; however, several informal sources, consisting of interviews and online prices reported by the public, generally conclude marijuana to be cheaper (Paul, 2018; Price of Weed, 2019). Furthermore, calculating dosages of the psychological active component of marijuana will also vary by the individual user, method of consumption, and strain of marijuana (Barrus, Capogrossi, Cates, Gourdet, Peiper, Novak, Lefever, & Wiley, 2017). Similar to alcohol types, different strains of marijuana contain different THC percentages. A recent study reporting THC levels in commercial marijuana samples across several U.S, cities found ranges of averages from 19% THC in Seattle, WA, to around 15% in Denver, CO, Sacramento, CA, and Oakland, CA. (Vergara, et al., 2017).

In an attempt to standardize portions of marijuana, more current estimates have adjusted the mean weight of marijuana in a typical joint of approximately 0.32 grams (Ridgeway & Kilmer, 2016). Using these standards, we can make rough price comparisons. For example, we could compare the average price of a mid-quality joint to the *average* 6-pack of beer, both of which might be shared amongst individuals whom are not considered heavy users with high tolerances. Assuming *most* adolescents are not considered heavy users, it is reasonable to assume that these measures should be generalizable to the population of interest. Since marijuana prices generally tend to decrease in recreational or medically legal states, a joint may cost anywhere from $2.21 in Oregon up to $3.90 in North Dakota – the District of Columbia has substantially higher marijuana prices than most legal and illegal states, averaging about $6.02 per joint (Price

of Weed, 2019). These prices were calculated from the average price of an ounce in each medical and recreational state. On the other hand, the national average for a 6-pack of beer, ale, and other malt beverages in 2018 was around $9.03 (United States Department of Labor, 2019). These estimates are intended to serve as an average, middle ground reference for a direct price comparison of servings, which show marijuana to be substantially cheaper than alcohol, even in the most expensive locations. Since many adolescents do not have a consistent flow of income, these cost savings could pose a significant influence on one's decision to substitute substances.

There are multitudes of individual and/or societal factors that could influence one's substance use patterns, these influences can range across income levels, social classes, social networks, drug cultures and policies (Subbaraman, 2016). These theoretical approaches will be important to consider when researching the complex epidemiology of substance use behaviors. As for the previous literature surrounding the extent of these behaviors on a substitution or complementary effect, it is generally inconclusive. In addition, there have been no previous studies, to my knowledge, which have explored this relationship since the introduction of recreational marijuana laws in the United States. The increased acceptability and accessibility that comes with recreational laws may allow researchers to more accurately understand the true relationship regarding usage of both substances. Nonetheless, while the previous literature is limited, many studies have attempted to uncover whether a substitution or complementary effect does indeed exist between alcohol and marijuana.

2.5. Empirical Research on the Relationship Between Marijuana and Alcohol Use

Two longitudinal studies have addressed this question by studying adolescents and young adults. Pacula (1998) examined the effects of state-level beer taxes on alcohol and cannabis use frequency in the past 30 days using the National Longitudinal Survey of Youth (NLSY) 1979 cohort (N=8,008). This study found support for alcohol and marijuana to be complementary: doubling the beer tax reduced the probability of drinking by 3.2% but also decreased the probability of cannabis use by 11.4%. Pacula (1998) also found further complementary support by assessing the effects of marijuana decriminalization, which appear to significantly predict increase alcohol usage. This support was found while controlling for other factors such as alcohol and cannabis prices and the ratio of crimes to officers in each state. Another longitudinal study of youth examined the effects of medical marijuana laws and found that time-varying state-level medical marijuana laws were not significantly related to past 30-day alcohol use (Anderson, Hansen, & Rees, 2011). This study is of particular interest to this thesis due to its ability to potentially capture the effects of increased accessibility to marijuana following the passage of medicinal laws.

Apart from these two longitudinal studies, the majority of studies on youth and the substitution effect rely on cross-sectional surveys. This could serve as a limitation when studying substitution because researchers are unable to establish a temporal ordering for changes in consumption. One of the first studies published to observe the substitution effect took place in response to Operation Intercept, an anti-drug measure implemented by President Nixon in 1969. This process closed the Mexican/American border which in turn limited the marijuana supply in the United States (McGlothlin,

Jamison, & Rosenblatt, 1970). The study consisted of a sample of university students and free clinic patients from Los Angeles, California. Of those who had used cannabis more than 10 times, reported a 44-51% decrease in usage frequency as a result of cannabis unavailability. The vast majority of these respondents (76-84%) reported an increase in alcohol use and other drugs in response to the cannabis shortage (McGlothlin et al., 1970).

Andersen, Hansen, and Rees (2013) also examined this relationship using the Behavioral Risk Factor Surveillance System to explore the impacts following the legalization of medical marijuana. Findings support evidence for a substitution effect by showing legalization to be associated with reductions in heavy drinking – primarily among those aged years 18 through 29. In addition, they found legalization to be associated with a 5% decrease in beer sales.

Several studies have attempted to capture the temporal ordering for changes in consumption using various cross-sectional designs. For example, a study using pooled cross-sectional data obtained from the Harvard SPH College Alcohol Study survey for the years 1993, 1997, and 1999 showed that higher beer taxes were related to lower alcohol and cannabis use and that the price of cannabis was negatively related to alcohol and cannabis use (Williams, Pacula, Chaloupka, & Wechsler, 2004). The decreased usage of both substances suggests that the substances were potentially being used as complements – as the price of one substance increased, the usage rates of both substances dropped correspondingly, rather than just the immediate impacted substance. This study also found decriminalization to have no significant effect on either substance usage.

Contrarily, a study conducted by DiNardo and Lemieux (2001) observed a substitution effect by analyzing the impacts on usage rates after the rise of the minimum legal drinking age from 18 to 21 in the 1980's. A sample of U.S. high schoolers was used from the 1982-1989 Monitoring the Future survey which measured past 30-day cannabis and alcohol consumption. Results indicated that increasing the drinking age did decrease alcohol use by 4.5% but increased cannabis use by 2.4% (DiNardo & Lemieux, 2001). A more recent analysis of the minimum legal drinking age using the 2002-2007 National Survey on Drug Use and Health showed that as young adults reached the minimum legal drinking age of 21, a sharp decrease in marijuana usage can be observed and accompanied by a significant increase in alcohol usage in the past 30 days, suggesting a possible substitution effect among young adults (Crost & Guerro, 2012). These findings did contradict an earlier, similar study using the NLSY97 which found turning 21 to be associated with an increase in marijuana and alcohol use (Yörük and Yörük, 2011). However, the sample of this study was restricted only to respondents who had used cannabis *at least* once since last interviewed. A re-analysis of this study was later conducted by Crost and Rees (2013) who then found no significant changes of cannabis use at 21 and thus no evidence of complementary support. This re-analysis poses an interesting suggestion, that current or more frequent marijuana users may complement more than the general population as a whole.

Based on their findings, DiNardo and Lemieux (2001), Crost and Guerrero (2012), and Anderson, Hansen, and Rees (2013) have all suggested that as marijuana becomes more accessible among states, that young adults are likely to respond by drinking less, not more. However, these studies face limitations in measuring the true

effects of these laws as they only consisted of states with medical marijuana laws. In these states, marijuana can only be purchased by individuals who obtain a medical marijuana card – for those who qualify, cards are issued by the state, following the recommendation of a physician. These individuals may be less likely abuse their medical card by illegally distributing marijuana to adolescents. However, with the passage of recreational laws, marijuana becomes regulated similarly to alcohol, thus significantly increasing the opportunity of accessibility for adolescents. This thesis assesses whether the suggested substitution or complementary effects exist for adolescents under more liberalized policies which include recreational marijuana laws.

3. The Proposed Study

The purpose of this research is to identify whether a suggested substitution or complementary effect exists under more current policies which include recreational use marijuana. This relationship is tested using the following four hypotheses. H1: States with greater accessibility to marijuana through legalization will experience an increase in marijuana use among adolescents. Support for this hypothesis could be explained by the increased acceptability and accessibility that comes with marijuana legalization. These factors may provide more opportunities for individuals to use and/or justify marijuana usage, thus it is probable to observe an increase in usage. The direct alternative to these circumstances would be observed in the second hypothesis, H2: States with greater accessibility to marijuana through legalization will experience a decrease in marijuana use among adolescents. While this relationship may seem unintuitive, it is possible that when legal marijuana markets are established, illegal markets are disrupted, making it

more difficult for teenagers to obtain cannabis. Of course, this assumes that adolescents would not have access to the legal market, which may be unreasonable in some states.

Upon observing an increase in marijuana use in *Hypothesis 1*, the combination of support with the third hypothesis is used to test for a substitution effect. H3: States with greater accessibility to marijuana through legalization will experience a decrease in alcohol consumption among adolescents. In other words, these hypotheses propose that as marijuana usage is normalized and increases, alcohol use will correspondingly decrease. This decrease in alcohol consumption could be attributed to a substitution effect with marijuana usage since legalization now provides more equally available options of another substance that some may favor over alcohol. Conversely, we could observe a complementary effect with usage rates of both substances increasing together, allowing for a direct alternative hypothesis. H4: States with greater accessibility to marijuana through legalization will experience an increase in alcohol consumption among adolescents. If a complementary effect is taking place, a significant increase in alcohol use can be expected. This complementary effect would be further confirmed with the support from both *Hypothesis 1* and *Hypothesis 4*. Overall, the combination of these four hypotheses represent a two-tailed hypothesis test of the effects of marijuana legalization on adolescent alcohol consumption.

For this study, marijuana and alcohol use are measured primarily by the frequency of usage in the last 30 days. Understanding marijuana legalization's impacts on substance use patterns should be of particular interest for public health and safety concerns. Furthermore, while the harms of marijuana are still frequently debated, legalization's

indirect effects on changes in use of other more harmful substances could potentially outweigh the concerns of marijuana related outcomes.

3. 1. Data

To test these hypotheses, I use responses to survey questions of the Youth Risk Behavior Surveillance System (YRBSS). These data include responses from 894,287 adolescents across 38 states over the years 1995 to 2017. In addition, information on the variations of state laws passed and implemented on the legalization status of marijuana are used to test these hypotheses

The data from the YRBSS is a collected cross-sectionally from a school-based, national survey of youth in grades 9 through 12. The survey monitors six different categories of health risk behaviors that contribute to the leading causes of death and disability among young adults – including measures of alcohol and drug use. These data are collected biennially since 1991, using a national school-based survey conducted by the CDC which includes state, territorial, tribal, and large urban school districts. The ongoing surveys are conducted beginning in July of the preceding even-numbered year (e.g., in 2010 for the 2011 cycle) when the questionnaire for the upcoming year is released and continues until the data are published in June of the following even-numbered year (e.g., in 2012 for the 2011 cycle). For this particular study, I will be only be using the years 1995 through 2017 as a sufficient window to capture the variation in state marijuana laws. To test my hypotheses, the unit of analysis will be the individual.

The dependent variables used to test my hypotheses are continuous and include responses to survey questions based on a scale. Due to the ordinal nature of these

variables, all responsive ordinal variables will be recoded to a count variable by taking the midpoint of each range within the scale.

To capture 30-day alcohol and marijuana use, responses are recorded on similar scales in response to the questions: *During the past 30 days, on how many days did you have at least one drink of alcohol? During the past 30 days, how many times did you use marijuana?* The original measurement for the alcohol use scale was distributed accordingly: 1) 0 days, 2) 1 to 2 days, 3) 3 to 5 days, 4) 6 to 9 days, 5) 10 to 19 days, 6) 20 to 29 days, 7) all 30 days. The recoded count variable (*alcohol)* is measured as: zero, one, four, seven, fifteen, twenty-five, and thirty days. Marijuana use was measured similarly, capturing the number of times consumed in 30 days using a 6-point scale: 1) 0 times, 2) 1 to 2 times, 3) 3 to 9 times, 4) 10 to 19 times, 5) 20 to 39 times, and 6) 40 or more times. The recoded count variable is coded as: zero, one, six, fifteen, thirty, and forty times.

In addition to these data, each individual observation includes the state from which the response was collected. It is also important to note that these data do not include the District of Columbia, which is therefore be excluded from this analysis. For the independent variable, the state of each respondent is coded nominally according to the legal status of marijuana for the respective year (Table 2). Due to the complexity of each state's laws, marijuana legality is separated into three general categories: (3) legalized adult recreational use, (2) legalized for medicinal use, or (1) no legal adult marijuana program (Table 2). This final and most restrictive category includes both the four states with no public access marijuana programs *and* the fifteen states with narrowly defined laws allowing only low THC products.

For my analysis, these legalization categories are operationalized with a dummy variable for each year, depending on whether they are legalized recreationally or medicinally – with 0 signifying illegality in both cases. All recreational states are coded as (1) for both the medical and recreational variables, since there are no recreational states without a medical marijuana program. Additionally, *recreational* and *medical* will be defined by two separate variables – one signifying the actual passage of the law and the other representing its actual implementation and opening of each market. This is an important distinction to make when considering the theoretical approach of Rational Choice Theory; as legalization alone should lead to a softening of norms surrounding marijuana and thus decreases the informal costs associated with usage. Additionally, adolescents will always need some form of a "dealer" to provide them with marijuana whether or not dispensaries are up and running. However, the actual availability and opportunity to obtain marijuana may potentially increase once the legal marijuana market opens up - thus it is important to differentiate and understand the impacts following both of these scenarios.

A dummy variable is also included to control for decriminalization within fourteen states to help capture some of the variation across state laws. While this is one variation of medical marijuana laws that I am able to capture in these data, other variations between medical states can be extensive and will be more difficult to measure. For example, some medical states are much more restrictive on their criteria regarding who is qualified for a medical marijuana license, fewer physicians are licensed with the state's medical marijuana program, and there are a limited number of dispensaries throughout the state (Marijuana Policy Project, 2019). Whereas more liberalized medical

marijuana states have a much broader criteria for qualifying conditions, more enthusiasm among physicians participating in the program, and dispensaries are much more abundant (Marijuana Policy Project, 2019). While capturing the exhaustive variations of laws between medical marijuana states is beyond the scope of this thesis, it is a limitation which should be acknowledged when interpreting any results.

Furthermore, a dummy variable has been added to account for a spillover effect in non-recreational states who share a border with recreational states. Previous studies have found that after Oregon opened recreational stores in 2015, following Washington's store openings in 2014, Washington retailers along the Oregon border experienced a 41% decline in sales immediately following Oregon's market opening (Hansen, Miller, & Weber, 2017). Another study observed that recreational marijuana legalization in the states of Colorado and Washington has been associated with a significant positive impact on marijuana possession arrests in neighboring states with a shared border – particularly in counties that shared a border (Hao, Cowan, 2017).

While it is plausible that there may be increased enforcement and vigilance for marijuana trafficking within the neighboring counties, results nonetheless suggest that recreational marijuana is indeed being transported into neighboring states. In addition, it is worth noting that this study only found marijuana possession arrests to be entirely concentrated among adults, with no significant findings for juvenile possession. However, with the limited research surrounding these more modern laws, it is crucial to build upon previous findings and so this study also controls for a spillover effect in shared border states of recreational marijuana. For this particular data set, there are a total of twelve spillover states.

Additional control variables used in this study account for other substance use patterns and individual demographic characteristics. First, I include the 30-day alcohol or marijuana use as a control in the models that use the other substance as the dependent variable. When considering the complex epidemiology of one's decision to substitute or complement substances, we can assume that more than just marijuana legality will influence this decision. Additionally, other individual characteristics include age for all years between 12 through 18 years old, sex (*male* or *female*), and race which is divided into four primary categories: *white, black, Hispanic,* and *all other races.* Table 1 includes the names and descriptions of the provided survey responses used for this study, as well as their operationalizations.

The data used in this analysis consist of several strengths that are beneficial for the current study. Primarily, it is a relatively large sample (N=894,287) over an extended amount of time (twenty-two years) that includes the variation of state laws over time, including up to 5 years of recreational legality – a measure previous research has significantly lacked. In addition, while this is not a complete national sample of all 50 states, these data include an impressive majority of (38) states which are distributed across the country (Table 2). This aspect is important because the conclusions of this study will remain fairly generalizable to the rest of the country, since the data are not condensed to a specific state or region. However, this generalizability should be taken lightly as the states were not randomly selected.

Furthermore, states with some form of legalization and accessibility, may capture more accurate marijuana usage rates as the substance becomes more normalized. Conversely, these data may also risk the underreporting of usage rates from adolescents

in non-legal states, as they may be less willing to indicate illegal substance use. This is likely to be more prevalent in states with stricter marijuana laws or during time periods before legalization efforts, thus portraying a possible underrepresentation of true usage rates. An even bigger consequence of this, is that it could exaggerate the differences between usage in legal versus illegal states, leading to a Type I error.

This analysis does face other limitations, as well. Because the data are pooled cross-sectional, individuals are only surveyed once, which limits my ability to establish a definite, causal relationship. Additionally, only a subset of the YRBSS surveys are used in this dataset. State YRBSS datasets are owned and controlled by the health and education agencies that conducted the surveys. A number of these agencies have not given the CDC permission to include their data in the combined dataset, which was used for this analysis. Furthermore, some state surveys and/or previous years exclude some of the questions used in the 2017 YRBSS survey. As a result, missing variables preclude my ability to measure other patterns of substance use, including binge drinking, in these analyses. Binge drinking is one of the most detrimental and popular alcohol consumption methods among young adults and adolescents and is an even more relevant public health concern than frequency of alcohol consumption.

While these data are among the first to include recreational states, the timeline since the passage of most state's legislation is still relatively short. This raises concern when observing trends over time, considering that the *first* states to legalize recreational marijuana – Colorado and Washington – did so only in 2012. As a result, the analysis of recreational laws is limited to observing changes within approximately a five-year time frame. This aspect is further limited due to some missing data, particularly from two

states with some of the oldest recreational laws, Washington and Oregon. Following Colorado's legalization (2012), Alaska is the next state with the oldest recreational laws (2014) in this particular data set. While this is not detrimental to the analysis, the relatively short time frame may be important to consider upon establishing conclusions.

Table 1. Operational Definitions of Key Variables

VARIABLE	OPERATIONAL DEINITON	INDICATOR	COUNT VARIABLE (RECODE)
Alcohol	Past 30 days alcohol use	1. 0 days 2. 1 to 2 days 3. 3 to 5 days 4. 6 to 9 days 5. 10 to 19 days 6. 20 to 29 days 7. all 30 days	0. days 1. day 4. days 7. days 15. days 25. days 30. days
Marijuana	Past 30 days marijuana use	1. 0 times 2. 1 to 2 times 3. 3 to 9 times 4. 10 to 19 times 5. 20 to 39 times 6. 40 or more times	0. times 1. times 6. times 15.times 30. times 40. times
Sex	Sex of Respondent	0. Male 1. Female	
Race	Race of Respondent	1. "White" 2. "Black of African American" 3. " Hispanic/Latino " 4. "All other races"	
Age	Age of Respondent	12. 12 years or younger 13. 13 years old 14. 14 years old 15. 15 years old 16. 16 years old 17. 17 years old 18. 18 years or older	

Table 2. States and Years with Corresponding Legalization Code

STATE	1995	1997	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017
AK	1				2		2	2	2	2	3	3
AL	1	1	1	1	1	1		1	1	1	1	
AR	1	1	1	1		1	1	1	1	1	1	2
AZ					1	1	1	1	2	1	2	2
CA											2	3
CO						2		2	2			3
DE			1	1	1	1	1	1	2	2	2	2
FL				1	1	1	1	1	1	1	1	2
HI	1	1	1			2	2	2	2	1	2	2
IA		1				1	1		1			1
ID				1	1	1	1	1	1	1	1	1
IL	1						1	1	1	2	2	2
KS						1	1	1	1	1		1
KY		1			1	1	1	1	1	1	1	1
LA		1					1	1	1	1		1
ME	1	1		2	2	2	2	2	2	2	2	3
MI		1	1	1	1	1	1	2	2	2	2	2
MO	1	1	1	1	1	1	1	1		1	2	2
MS	1	1	1	1	1		1	1	1	1	1	
MT	1	1	1	1	1	2	2	2	2	2	2	2
NC	1			1	1	1	1	1	1	1	1	1
ND	1		1	1	1	1	1	1	1	1	1	2
NE					1	1			1	1	1	1
NH	1				1	1	1	1	1	2	2	2
NJ				1		1		1	2	2		
NV	1	1	2	2	2	2	2	2		2	2	3
NY		1	1		1	1	1	1	1	1	2	2
OK					1	1	1	1	1	1	1	1
PA								1			1	2
RI		1		1	1	1	2	2	2	2	2	2
SC	1	1	1			1	1	1	1	1	1	1
SD	1	1	1	1	1	1	1	1	1	1	1	
TN					1	1	1	1	1	1	1	1
UT	1	1	1	1	1	1	1	1	1	1		2
VA									1	1	1	1
WI		1	1	1	1	1	1	1	1	1		1
WV	1	1	1		1	1	1	1	1	1	1	2
WY	1	1	1	1	1	1	1	1	1	1	1	

3.2. Methods

In this thesis, given that my dependent variable is a count variable, with a possibly over dispersed variance, I use a negative binomial model in order to test my hypotheses.

$$Y_{\text{ijt}} = \beta_{\text{o}} + \beta_1 \text{recreational}_{jt} + \beta_2 \text{medical}_{jt} + \beta_3 \text{spillover}_{jt} + \beta_4 \text{decriminalization}_{jt} \quad (1)$$
$$+ \beta_5 localtrend_{jt} + \beta_6 controls_{ijt} + \beta_i + \beta_j + \mu$$

This model uses subscripts: *i* for the individual, *j* for the state, and *t* for the year. Additionally, my models are also clustered by state, as the error terms within states will be more correlated than across states. In order to absorb some of the variation within states such as: price differences, price changes, the presence of dispensaries, and state alcohol policies, I include fixed effects for the state, which is depicted by β_j in equation 1. Year fixed effects (β_t) are included to account for systematic effects that are unique to each year for all states. By controlling for these fixed effects, the estimates are invulnerable to unmeasured state to state or year to year changes in the data.

The *recreational* and *medical* variables represent the dummy variables for either the initial passage of laws or the actual implementation of laws, respectively. By running these two separate models, I am be able to conduct a sensitivity analysis in order to observe the impact of mere legalization versus increased accessibility.

In addition, after further observation of the usage rate variables, there appears to be a consistent downward trend in alcohol use since the year 1995 (Appendix C). Marijuana use also follows a similar trend but to a lesser extent. While some of this may be accounted for on a national level by fixed effects, it is likely that each state may also have its own variation of usage trends. It is important to account for both trends because changes in local trends can distort the estimates of state laws. To control for this factor, I

include the estimated trend of alcohol and marijuana use for each state generated from negative binomial models (See Equation 2). In the primary analyses, each substance's usage trend is controlled for when the respective substance is used as the dependent variable.

$$\hat{y} = \beta_0 + \beta_1 \text{year} \quad (2)$$

In this study, the final model is used a total of four times, twice with each substance (alcohol or marijuana) as the dependent variable. Significant results (p<0.05) are interpreted and applied to each hypothesis. The support of *Hypothesis 1* would be given by significant, positive coefficients for my primary independent variables measuring legality when using 30-day marijuana use is used as the dependent variable. *Hypothesis 2* would be supported by a significant, negative coefficient with my primary independent variables when 30-day marijuana use is used as the dependent variable. Using 30-day alcohol use as the dependent variable, a significant, negative coefficient of my primary independent variables would propose support for *Hypothesis 3.* Lastly, *Hypothesis 4* would be supported by a significant, positive coefficient of my primary independent variables when using 30-day alcohol consumption as the dependent variable. A suggestive substitution effect would be provided by support from *Hypothesis 1* and *Hypothesis 3.* Whereas a complementary would be suggested by support from *Hypothesis 1* and *Hypothesis 4*.

3.3. Results

In this section I first present the descriptive statistics to summarize the primary dependent and independent variables. I then present the results of the negative binomial models and sensitivity analyses used to test the hypotheses. The results are first presented by changes in marijuana use followed by changes in alcohol use in response to law

passages and/or actual implementation. These results are then interpreted and applied to the four hypotheses. Finally, this section ends with a supplementary analysis for the purpose of further observation and future research suggestions.

3.3.1. Descriptive Statistics

Table 3 provides descriptive statistics which consists of the means, standard deviations, 95% confidence intervals, and the minimum and maximum measures for the independent and dependent variables of interest. The 30-day alcohol use variable consists of 819,935 responses with a mean of 1.94 and a standard deviation of 4.77 – these numbers suggest that the *average* US high school student drinks roughly 1 to 2 days a month. The 30-day marijuana use variable consists of 863,592 responses with a mean of 2.85 and a standard deviation of 8.79. These descriptive statistics suggest the *average* US high school student uses marijuana around 2 to 3 times a month. While at first glance, this may appear to suggest higher usage rates than alcohol, it is important to clarify the distinction that alcohol is measured in *days* and marijuana use is measured in number of *times* – as an individual can use marijuana multiple times per day. Additionally, the measurement scale for marijuana contains a much larger range for each measurement point and has a higher maximum value than alcohol. The combination of these factors may partly explain the large standard deviation – overall this variable is much more spread in its measurements and responses.

Table 3 also includes the primary usage measures separated by state laws. The table confirms that majority of responses are indeed from illegal states, followed by medical, and then recreational. Table 3 displays that the means and standard deviations for alcohol use both decrease as marijuana legalization increases. This table suggests an

increase in the mean marijuana use states legalize medicinally; however, both measures again drop below the original *illegal* statistics for recreational states.

To further understand usage in these data, Table 4 provides the joint probability distribution showing the proportions of whether or not individuals used alcohol and/or marijuana in the past 30 days. The majority of students appear to abstain from both alcohol and marijuana use whereas only 15.5% had consumed both. Unsurprisingly, there was more consumption of only alcohol and no marijuana 21.1%, compared to only marijuana and no alcohol 3.8%.

Table 3. Descriptive Statistics of Primary Variables

VARIABLE	N	Mean	SD	Min.	Max.	95% CI
30 Day Alcohol Use	819,935	1.94	4.77	0	30	[1.93, 1.95]
30 Day Marijuana Use	863,592	2.85	8.79	0	30	[2.83, 2.87]
ILLEGAL						
30 Day Alcohol Use	570,954	2.14	4.99	0	30	[2.13, 2.15]
30 Day Marijuana Use	599,230	2.81	8.73	0	40	[2.78, 2.82]
MEDICAL						
30 Day Alcohol Use	233,540	1.51	4.25	0	30	[1.49, 1.52]
30 Day Marijuana Use	247,838	2.98	8.99	0	40	[2.95, 3.02]
RECREATIONAL						
30 Day Alcohol Use	15,441	0.95	3.37	0	30	[0.90, 1.00]
30 Day Marijuana Use	16,524	2.57	8.37	0	40	[2.44, 2.69]
State Legal Status	894,287	1.32	0.51	1	3	

Table 4. Probability Distribution of Alcohol and/or Marijuana Use

	MARIJUANA	
ALCOHOL	**NO**	**YES**
NO	.595	.038
YES	.211	.155

3.3.2. Model Results

The following results include an overview of the two separate regression models for each substance, observing the impacts of initial legalization efforts versus the actual openings of medical and recreational markets. Significant results are interpreted using the incidence rate ratio, which calculates the ratio of two incidence rates. This is done by dividing the incidence rate among the exposed portion of the population by the incidence rate in the unexposed portion of the population to give a relative measure of the effect of a given exposure and thus approximates the relative risk of the occurrence. These models are used to conduct a sensitivity analysis between law passage and implementation and results from both are be applied to my hypotheses.

Marijuana

To test *Hypothesis 1* and *2,* I examine the impacts that marijuana laws and dispensaries have had on either the increase or decrease of marijuana usage rates. I have provided the results of each respective negative binomial regression for Model 1 and Model 2 (Table 5). Model 1 examines the effect directly after the passage of either medical or recreational laws. Model 2 was run similarly but exploring the effect only

after medical or recreational dispensaries had officially opened. The significant results of these models are interpreted using the incidence rate ratio and later applied to test the hypotheses.

Model 1, which observes 30-day marijuana use after law passages, suggests a negative relationship between recreational and medical marijuana laws with 30-day marijuana use: however, these variables are insignificant. Thus, these results suggest that there is no significant increase in marijuana use among adolescents following the passage of medical or recreational marijuana laws. However, decriminalization appears to have a slight significant increase in marijuana use, by a rate of 1.052 ($p<0.05$).

The additional substance use pattern in the model is significant and suggests a positive relationship with 30-day marijuana use. This positive relationship with alcohol may suggest the possibility that individuals who are *already* using alcohol may be complementing with marijuana. However, this relationship could also be spurious.

Model 2, which measures 30-day marijuana use after the opening of medical and recreational markets is insignificant for all primary variables of interest. In comparison to Model 1, decriminalization has also lost its significance. This model further confirms that there is no significant increase (or decrease) in marijuana use among adolescents following the opening of medical or recreational markets. Additionally, the remainder of the substance use patterns are almost directly comparable relationships to Model 1.

Table 5. Results of Negative Binomial Regression

30-day Marijuana use	Model 1 (laws passed) β (SE)	Model 2 (laws implemented) β (SE)
Recreational	-0.0256	0.0087
	(0.0417)	(0.0680)
Medical	-0.0516	-0.0122
	(0.0300)	(0.0355)
Spillover States	0.0057	0.0125
	(0.0379)	(0.0375)
Decriminalization	0.0504*	0.0492
	(0.0256)	(0.0333)
30-day Alcohol use	0.2292***	0.2292***
	(0.0072)	(0.0072)
Local Trend	0.1595***	0.1647***
	(0.0351)	(0.0337)
Black	0.3385***	0.3392***
	(0.0556)	(0.0556)
Hispanic	0.1915***	0.1914***
	(0.0545)	(0.0545)
All other races	0.2248**	0.225151
	(0.1193)	(01191)
Sex	-0.4328***	-0.4327***
	(0.0198)	(0.0199)
Age	0.2514***	0.2515***
	(0.0105)	(0.0105)

**indicates p-value*<0.05, **indicates p-value <0.01, ***indicates p-value <0.001

Alcohol

To test *Hypotheses 3* and *4*, I examine the impacts marijuana laws and dispensaries have had on either an increase or decrease in alcohol usage rates. I have provided the results of the separate negative binomial regressions from Model 3 and Model 4 below (Table 6). Model 3 examines the effect directly after the passage of either medical or recreational laws. Model 4 was run similarly but observes the effect only after medical or recreational dispensaries have officially opened.

After observation of Model 3, there is a significant negative relationship of 30-day alcohol use and the passage of recreational marijuana laws by a factor of 0.891 ($p<0.01$). While the directions of the other variables of interest are also negative, none of these are significant.

Apart from the primary variables of interest, there again appears to be a trend among substance use. For individuals who have used marijuana in the last 30 days, there is a significant expected increase of alcohol use by a rate of 1.074 ($p<0.001$). This relationship once again suggests that individuals who are *already* using marijuana may be complementing with alcohol.

When conducting a sensitivity analysis with Model 4, which observes 30-day alcohol use in response to the openings of recreational and medical marijuana dispensaries, there is still a suggestive decrease in alcohol use associated with the opening of both dispensary types; however, none of these are significant (Table 6: Model 4). Additionally, the directions and significance of all other control variables are comparable to Model 3 (Table 6).

Table 6. Results of Negative Binomial Regression

30-day Alcohol use	Model 3 (laws passed) β (SE)	Model 4 (laws implemented) β (SE)
Recreational	-0.1159** (0.0444)	-0.1113 (0.0938)
Medical	-0.0294 (0.0286)	-0.0489 (0.0526)
Spillover States	-0.0606 (0.0443)	-0.0468 (0.0468)
Decriminalization	-0.0336 (0.0553)	-0.0075 (0.0648)
30-day Marijuana use	0.0713*** (0.0018)	0.0713*** (0.0018)
Local Trend	0.2838*** (0.0429)	0.2872*** (0.04348)
Black	-0.5694*** (0.0371)	-0.5693*** (0.0370)
Hispanic	0.0285 (0.0448)	0.0287 (0.0447)
All Other Races	-0.2197** (0.0638)	-0.2197** (0.0638)
Sex	-0.0635** (0.0220)	-0.0636** (0.0220)
Age	0.1951*** (0.0073)	0.1952*** (0.0074)

**indicates p-values*<0.05, **indicates p-value <0.01, ***indicates p-values <0.001

Hypothesis 1

The first hypothesis in this thesis proposes that states with greater accessibility to marijuana through legalization will experience an increase in marijuana use among adolescents. The increase in accessibility was defined as the passage of recreational and medical marijuana laws, as well as the official openings of recreational and medical markets. To assess my hypothesis, a negative binomial regression was conducted to explore the impacts of marijuana policies on 30-day marijuana consumption and a

sensitivity analysis was conducted for law passage and implementation. The results indicated that none of my independent variables of interest were significant to support this hypothesis. However, there may be some limited support provided by a significant increase of marijuana use following decriminalization in Model 1 (Table 5).

Hypothesis 2

As for the alternative hypothesis, the was no support suggesting that states with greater accessibility through legalization will experience a decrease in marijuana use among adolescents. None of the models indicated a significant decrease in 30-day marijuana use following the passage or implementation of any legislation.

Hypothesis 3

The third hypothesis in this study proposes that states with greater accessibility to marijuana through legalization will experience a decrease in alcohol consumption among adolescents. This hypothesis was only explicitly supported by Model 4 (Table 6), showing a significant decrease in 30-day alcohol use at a rate of 0.891 after the initial passage of recreational laws ($p<0.01$).

Hypothesis 4

The fourth hypothesis proposes a direct alternative to *Hypothesis 3*, which suggested that states with greater accessibility to marijuana through legalization will experience an increase in alcohol consumption among adolescents. The results of the negative binomial regression showed no significant support for this hypothesis across Model 3 and Model 4 (Table 6). In other words, there was no significant increase for alcohol use related to the passage of marijuana laws or the opening of medical or recreational dispensaries.

3.3.3. Substitution Effect

The hypotheses thus far have provided limited support for a possible substitution effect following marijuana legalization. While Model 4 (Table 6) shows support for *Hypothesis 3,* suggesting a significant decrease in alcohol use following the passage of recreational laws, there is no suggested increase in marijuana rates for recreational laws. However, *decriminalization* does suggest a significant increase in 30-day marijuana use in Model 1 (Table 5). When comparing different types of legislation within these models, these are the only significant results across all four models that may indicate the possibility of a substation effect. In addition, both of these results are in the models observing changes after the initial passage of marijuana laws.

While the significant responses are observed for separate laws, this may pose some evidence that substitution patterns could be taking place.

3.3.4. Complementary Effect

A complementary effect would have been suggested by support for *Hypothesis 1* and *Hypothesis 4;* however, both these hypotheses were unsupported by the primary variables of interest. While there was an increase in marijuana use for decriminalization in Model 1, there were no models which showed a significant increase in alcohol use following any sort of marijuana legalization policies.

However, other variables among usage patterns may suggest a potential complementary effect among individuals who are already using both substances. Table 6 displays a significant increase in alcohol use with an increase in 30-day marijuana use and Table 5 respectively showed an increase in marijuana use with 30-day alcohol use.

However, there is no support for an increase of additional individuals experiencing a complementary effect as a result of law changes.

3.3.5. Supplementary Analysis

Apart from the impacts of law changes, demographics appear to be an important predictor in substance use. In reference to the *white* race variable, all race categories suggest a significant increase in 30-day marijuana use, except for *all other races* (Table 5; Table 6). For Model 1, marijuana use is increased for *black, Hispanic,* and all other races – with *black* obtaining the greatest magnitude at an increased rate of 1.40 ($p<0.001$). This model also suggests that being female is associated with a significant decrease in marijuana use compared to males at a rate of 0.65 ($p<0.001$). For these demographics, Model 2 has almost directly comparable results.

Furthermore, *age* has a significant, positive correlation with marijuana use, which is expected. In other words, adolescents increase 30-day marijuana use by a factor of with each additional year of age. However, after further observation of 30-day marijuana use by *age*, there appears to be a dramatic increase in the mean of marijuana use for 12-year old's (see Appendix B1). In total, 35% of 12-year old's report using marijuana 30 or more times each month. When removing this age group from the model, the positive *age* coefficient remains, at a slightly lesser magnitude, but the significance remains (See Appendix B2). All other coefficients also remain comparable to previous models. While it is possible that these observations may have been recorded in error, the original *age* variable was kept in the final models as to not induce further bias.

For alcohol use, all race categories appear to be significant, except for *hispanic*, in reference to the *white* race variable. Findings suggest that *black* adolescents appear to

consume less alcohol than *whites* to the greatest magnitude when compared to other races – with an expected decrease by a factor of 0.567 ($p<0.001$). To a lesser extent, all other races appear to consume alcohol less frequently than whites, with an expected decrease by a rate of 0.802 ($p<0.05$).

The age variables once again present an interesting trend with a dramatic increase in the mean of alcohol use for 12-year old's (see Appendix B3). After removing 12-year old's and rerunning the models, *age* remains positively significant to a lesser magnitude and all other variables remain fairly comparable (See Appendix B4).

Furthermore, while other control variables measuring substance use have been excluded from my primary models due to missing observations, exploring the impacts of these variables in a separate negative binomial regression model suggest some interesting relationships that may be of interest for future research. However, it is worth noting that this model only includes 29,265 observations from the year 2017 of the total variables in this dataset (n=894,287).

The removed variables include the largest number of drinking consumed in the last 30 days (*most alcohol),* number of days of alcohol consumption in lifetime (*lifetime alcohol),* and binge drinking (*binge)*. When including these variables following initial law passages, results show a significant decrease in alcohol use by a factor of 0.857 ($p<0.001$) in recreational states and a decrease by 0.913 ($p<0.05$) in medical states (See Appendix D1). There is also a significant decrease in spillover states by 0.424 ($p<0.001$); however, decriminalized states suggest an increase in alcohol use by a rate of 1.11 ($p<0.01$) (See Appendix D1).

Furthermore, the relationships of 30-day marijuana use suggests a significant increase in marijuana use at a rate of 1.957 ($p<0.001$) for recreational laws, an increase of 1.209 ($p<0.01$) for medical laws, and an increase of 8.31 ($p<0.001$) for spillover states (See Appendix D2). However, decriminalization shows a significant decrease of marijuana use at a rate of 0.523 ($p<0.001$).

These models present further support for a substitution effect with a significant increase in marijuana use but a significant decrease in alcohol use for recreational, medical, and spillover states. Interestingly, decriminalization also supports a substitution effect but in the other direction, suggesting a significant increase in alcohol use and a significant decrease in marijuana use.

An additional factor of these missing data is that binge drinking was only included on the state-level YRBSS surveys during the year of 2017 (n=69,332). However, when exploring the possibility of a substitution or complementary effect, binge drinking is an important factor to consider, since it is one of the most dangerous alcohol consumption patterns and most popular among teenagers and young adults. Due to the missing data, this will not be considered in testing my hypotheses; however, the impacts of marijuana laws on binge drinking will still be explored to suggest potential directions for future research.

The binge drinking variable measures the frequency of binge drinking occurrences in the last 30 days. Binge drinking is defined by 4 or more drinks for females and 5 or more drinks for males in approximately 2 hours. When *binge drinking* is included in the model as the dependent variable, there is evidence of a significant increase in binge drinking following recreational laws by a rate of 1.73 ($p<0.001$) as well

as for spillover states with an increase of 1.31 ($p<0.001$) (See Appendix D3). However, a significant decrease in binge drinking is found following medical marijuana laws by a rate of 0.952 ($p<0.001$), decriminalization also significantly decrease binge drinking rates by 0.914 ($p<0.001$).

While these models are limited, they suggest some interesting patterns that should be taken into consideration by future research. The YRBSS survey does offer extensive data on various substance use patterns; however, many of these responses from various states and previous years are unfortunately missing. Past studies have also confronted the limitation of lacking detailed data on substance use patterns over time. While it is still a common issue, future researchers should take inspiration of these limited observations to further study the impacts of marijuana laws on substance use and binge drinking rates with more complete data.

4. Discussion

The models have thus far suggested limited support for marijuana laws impacting a substitution effect, particularly with the passage of recreational laws, suggesting a significant decrease in alcohol use. While the other variables of interest were not significant, the directions followed suite with a negative direction. However, there were no significant increases in marijuana use other than following decriminalization. While an increase in marijuana use is technically required to satisfy the definition of a substitution effect, it cannot be ruled out that this positive increase in marijuana use may also be related to complementing substances. However, there is no significant increase of alcohol use within this particular analysis. Beyond this speculation, there is no significant support suggesting a complementary effect within any of the models. However, there

may be cases of complementing for individuals who already use both substances. Table 5 displays a significant increase in marijuana use with an increase in 30-day alcohol and Table 6 reciprocates this relationship by an increase in alcohol use with an increase in 30-day marijuana use. However, for those that may be complementing, there appears to be a usage of alcohol at a lesser rate than marijuana.

In addition, race appears to be an important factor of substance use patterns, in reference to the *white* respondents. *Black* respondents appear to consume both alcohol and marijuana at higher rates than *white* respondents and thus may be more likely to complement substances. Whereas *all other race* respondents consume only marijuana at a significantly higher rate than *white* respondents and *Hispanic* respondents consume more marijuana. In summary it appears that certain substance use trends may be more prevalent among minorities.

Last, while the supplementary analysis is incredibly limited, it certainly gives incentive to further explore the relationships of substance use and marijuana laws with more sufficient data. These models provided significant support for a substitution effect, suggesting a significant decrease in alcohol use and increase in marijuana use in recreational, medical, and spillover states. However, this substitution relationship was in the reverse direction for decriminalization.

Impacts on binge drinking were mixed but still significant. Recreational and spillover states suggested a significant increase in binge drinking whereas medical and decriminalized states suggested a significant decrease. However, the individual substance use patterns suggested a significant increase in binge drinking to be associated with an increase in both 30-day alcohol and marijuana use. Thus, individuals who are more

involved in substance use or the "party culture" may be at even greater risk of binge drinking. Given this relationship is true, increased access to alcohol or marijuana could pose serious consequences for these individuals. Further understanding the dynamics of this relationship is critical in order to properly address it. With this knowledge, schools and communities can more effectively disseminate information and provide education on the dangers associated with complementing these substances at such high usage rates. Nonetheless, even with the limited data, these mixed but significant findings give sufficient reason to pursue a better understanding on how marijuana policies impact binge drinking rates. When considering the detrimental effects of binge drinking and its popularity among adolescents, this is an important substance use pattern that should not be overlooked and taken into serious consideration for policy implementation.

4.1. Conclusion

With the rapid changes in marijuana laws spanning across the country, it is critical to understand the underlying consequences of these policies. Previously, researchers have been unable to fully measure a substitution or complementary effect as marijuana has remained illegal in all 50 states, thus restricting access and usage. However, with legalization spreading across the country, alcohol and marijuana are finally becoming equally accessible in many states. Taking inspiration from the previous literature on a potential substitution or complementary effect, the recent legalization movements present a distinct opportunity to research these effects in a thorough and more precise manner. This thesis is among the first to analyze this relationship as marijuana is becoming more accessible to many American's.

While the findings are limited, there is marginal support for a potential substitution effect. Furthermore, there is ample evidence that the changes in marijuana policy and availability do not contribute to a complementary effect. While, there are mixed patterns suggesting that current users of both marijuana and alcohol may be substituting and/or complementing substances, there is no evidence of an increase in marijuana users contributing to either trend except possibly with decriminalization. In addition, for those that may be complementing, there appears to be a usage of alcohol at a lesser rate than marijuana. However, there is also no evidence of an increase in alcohol users that may be attributing to this.

In summary, the provided decreases in alcohol use presented by these findings could contribute to a major public health benefit, especially with little to no evidence supporting an increase of marijuana and/or alcohol use for adolescents following legalization. With respect to decriminalization, these findings present an even greater public health benefit than a substitution effect, since *no* substance usages are increasing. As for decriminalization, this increase in marijuana use could be due to the combination of more relaxed norms but also no disruption to the underground market. Thus, if marijuana is to become decriminalized, opening some sort of legal market may actually contribute to a reduction in adolescent accessibility to marijuana. If this is the case, it is something future researchers and policy makers should seriously consider upon future legislation changes.

This study, among many others, have found an apparent relationship between alcohol and marijuana that should be taken into consideration upon future research and policy implementation. While limited, this analysis should shed light on the dynamic

between these two substances. The relationships found in this analysis and supplementary analysis certainly highlight directions that future research should consider as more thorough data becomes available.

Additionally, suggestions for a stronger analysis would be able to capture more of the variation among marijuana laws. More specifically, while this analysis did attempt to control for decriminalization and spillover states, future model suggestions might include running separate analyses by each spillover state. While this particular analysis is beyond the scope of this thesis, it may be more effective in capturing the effect of the spillover phenomenon.

Furthermore, it is important to highlight the difficultly in accurately measuring a shift in norms. While this thesis theoretically implied that law changes may influence norms, this is likely a reciprocal relationship. In other words, laws may also be changing due to a shift in norms. Taking this dynamic into consideration is an important aspect to consider for future researchers when trying to explain changes in trends and the normalization of marijuana.

Nonetheless, while this analysis is limited, this thesis highlights potential future directions of marijuana policy research and brings a unique contribution of further understanding the substitution/complementary dynamic of alcohol and marijuana under more current legislation. This analysis further supports previous findings suggesting that there is indeed an apparent relationship between alcohol and marijuana use. While the causal mechanisms are still unclear, this is a relationship that should be taken into strong consideration upon the implementation of future marijuana policy.

Appendices

Appendix A. Cross Sectional State Identifiers

Table 1. State and Year for 30-Day Alcohol Use and Marijuana Law Changes

state id	β	Robust S.E.	p-value
2	0.2704484	0.0575044	0
3	0.1843937	0.0620503	0.003
4	0.0670788	0.0708791	0.344
5	0.1422002	0.0222776	0
6	0.1229852	0.022692	0
7	0.0645406	0.0525673	0.22
8	0.0711151	0.0636493	0.264
9	0.1579233	0.0650691	0.015
10	0.1544536	0.0636262	0.015
11	0.0781952	0.0629664	0.214
12	0.1195483	0.0499491	0.017
13	0.1251085	0.064529	0.053
14	0.0990498	0.0658482	0.133
15	0.3851179	0.0630337	0
16	-0.1863905	0.0196255	0
17	0.0379186	0.0587124	0.518
18	0.1376139	0.0582004	0.018
19	0.3626392	0.0342534	0
20	0.2040072	0.072316	0.005
21	0.1305626	0.0332652	0
22	0.1902067	0.0732499	0.009
23	0.1394176	0.0637373	0.029
24	-0.0253499	0.0525482	0.63
25	0.2078132	0.0652108	0.001
26	0.1598022	0.0243745	0
27	0.1780049	0.0230793	0
28	0.1600758	0.0620872	0.01
29	0.0477923	0.0672014	0.477
30	-0.1108677	0.0445265	0.013
31	0.2098866	0.0554939	0
32	0.1548434	0.0653508	0.018
33	0.0591711	0.0647103	0.361
34	-0.4181674	0.0677727	0
35	0.0774408	0.0664689	0.244
36	0.1163389	0.0647497	0.072
37	0.0526696	0.0676668	0.436
38	0.1484155	0.071516	0.038
year			
1997	-0.0177337	0.0264671	0.503
1999	-0.0060451	0.0342239	0.86
2001	-0.0233265	0.0460448	0.612
2003	-0.0343292	0.0483829	0.478
2005	-0.0154732	0.0601644	0.797
2007	0.0402848	0.0647086	0.534
2009	-0.0707478	0.077519	0.361
2011	-0.2018215	0.0807731	0.012
2013	-0.2786989	0.0877962	0.002
2015	-0.326628	0.0939754	0.001
2017	-0.3635175	0.0982923	0
cons	-3.383005	0.214546	0
lnalpha	1.367893	0.0262775	
alpha	3.927067	0.1031934	

Table 2. State and Year for 30-day Marijuana Use and Marijuana Law Changes

state id	β	Robust S.E.	p-value
2	-0.419864	0.0596665	0
3	-0.2084643	0.0500463	0
4	-0.035996	0.0655618	0.583
5	-0.2802209	0.0277552	0
6	-0.0447733	0.0303893	0.141
7	-0.0541333	0.050834	0.287
8	-0.2215737	0.0494344	0
9	-0.1944935	0.051429	0
10	-0.4218309	0.0609265	0
11	-0.4069307	0.0583704	0
12	-0.1422586	0.0451305	0.002
13	-0.3315969	0.05895	0
14	-0.1965802	0.053473	0
15	-0.3106385	0.0549505	0
16	-0.0244491	0.0390494	0.531
17	-0.1265364	0.0427971	0.003
18	-0.1710239	0.0494326	0.001
19	-0.4807796	0.0513475	0
20	-0.1373244	0.0384261	0
21	-0.1938337	0.0415568	0
22	-0.4671672	0.0503206	0
23	-0.5420992	0.0641411	0
24	-0.0017177	0.0590549	0.977
25	-0.3917087	0.0464782	0
26	-0.1751995	0.0223063	0
27	-0.3335725	0.0426521	0
28	-0.3143068	0.0492159	0
29	-0.2017447	0.0523023	0
30	0.0492647	0.0437195	0.26
31	-0.2675471	0.0564965	0
32	-0.2949802	0.0406526	0
33	-0.1478551	0.0517786	0.004
34	-0.7039538	0.0767141	0
35	-0.3399924	0.0553362	0
36	-0.2559133	0.0531934	0
37	-0.1602009	0.055706	0.004
38	-0.3139113	0.0499122	0
year			
1997	0.2400772	0.0713347	0.001
1999	0.3070386	0.0703584	0
2001	0.3237555	0.0811714	0
2003	0.3368053	0.0763871	0
2005	0.1344671	0.07347	0.067
2007	0.1048893	0.0746822	0.16
2009	0.2474028	0.0645214	0
2011	0.4672678	0.0647753	0
2013	0.4923765	0.0729427	0
2015	0.5102059	0.065647	0
2017	0.4896874	0.0689998	0
cons	-4.426035	0.2006202	0
lnalpha	2.66789	0.0266961	
alpha	14.40954	0.384678	
2	-0.419864	0.0596665	0

Appendix B. Age Trends

Table 1. Average 30-day Marijuana Use by Age

Age	Mean	Standard Deviation
12	**16.06113**	**0.4008955**
13	2.055909	0.1358481
14	1.318954	0.0183172
15	2.054155	0.0154426
16	2.891121	0.0182942
17	2.301504	0.011517
18	4.34223	0.0341513

Table 2. Results of Negative Binomial Regression of 30-day Marijuana Use by Legalization Excluding Age 12 Years Old

marijuana	β	Robust SE
Recreational	-0.0191	0.0401
Medical	-0.0509	0.0304
Spillover	0.0065	0.0384
Decriminalization	0.0482	0.0256
Alcohol	0.2315***	0.0074
Local Trend	0.1630***	0.0355
Black	0.3368***	0.0562
Hispanic	0.1892**	0.0552
All other races	0.2232	0.1199
sex	-0.4335***	0.0200
age	0.2561***	0.0112

**indicates p-values*<0.05, **indicates p-value <0.01, ***indicates p-values <0.001

Table 3. Average 30-day Alcohol Use by Age

Age	Mean	Standard Deviation
12	**13.61049**	**0.3155662**
13	1.665292	0.1024473
14	1.063982	0.0113946
15	1.458097	0.0088513
16	1.903563	0.0099441
17	2.301504	0.011517
18	3.014152	0.0190647

Table 4. Results of Negative Binomial Regression of 30-day Alcohol Use by Legalization Excluding Age 12 Years Old

alcohol	β	Robust SE
Recreational	-0.1280**	0.0442
Medical	-0.0283	0.0282
Spillover	-0.0579	0.0437
Decriminalization	-0.0329	0.0534
Marijuana	0.06979***	0.0017
Local Trend	0.2812***	0.0419
Black	-0.5774***	0.0358
Hispanic	0.0098	0.0396
All other races	-0.2333***	0.0634
sex	-0.0595**	0.0219
age	0.2143***	0.0080

**indicates p-values*<0.05, **indicates p-value <0.01, ***indicates p-values <0.001

Appendix C. Trends in Alcohol Use Over Time

Table 1. Means of 30-day Alcohol and Marijuana Use by Year

	Mean	
Year	**Alcohol**	**Marijuana**
1995	2.878308	2.67734
1997	2.951167	3.406641
1999	2.878396	3.326383
2001	2.668148	3.325142
2003	2.435913	3.320846
2005	2.177602	2.526274
2007	2.184289	2.525268
2009	1.911219	2.753577
2011	1.666615	3.017072
2013	1.470822	2.8153
2015	1.331197	2.811382
2017	1.171105	2.543501

Figure 2. 30-day Alcohol Use Over Time

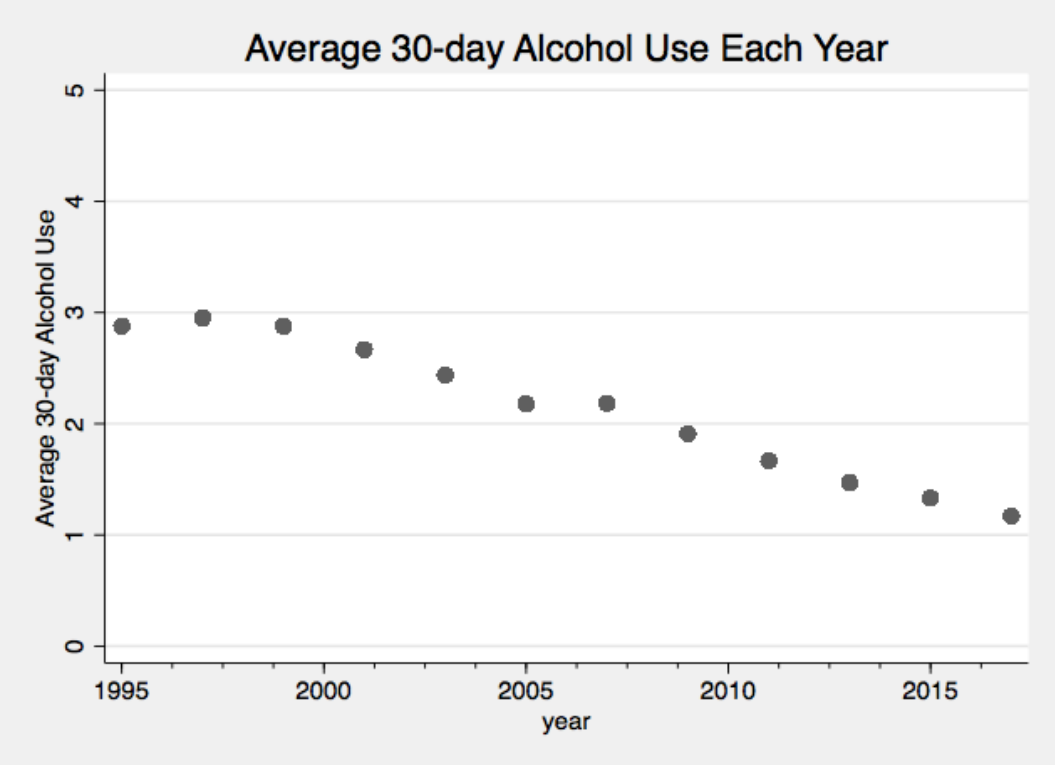
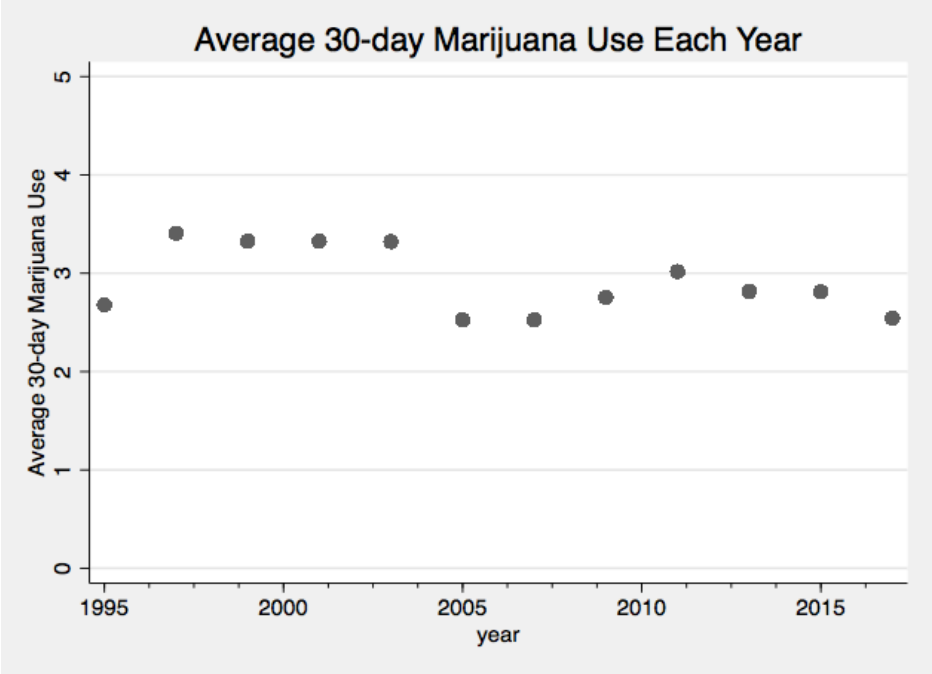


Figure 3. 30-day Marijuana Use Over Time



Appendix D. Exploration of Additional Variables

Table 1. Results of Negative Binomial Regression of 30-day Alcohol Use and Legalization

alcohol	β	Robust SE
Recreational	-0.1546***	0.0146
Medical	-0.0908*	0.0357
Spillover	-0.8588***	0.1385
Decriminalization	0.1042***	0.0185
Marijuana	0.0121***	0.0021
Most Alcohol	0.3732***	0.0168
Lifetime Alcohol	0.0196***	0.0005
Binge	0.0026***	0.0078
Black	-0.0796	0.0422
Hispanic	0.0623	0.0430
All other races	-0.1010	0.0584
Sex	0.3747***	0.0342
age	0.0603***	0.0146
Local Trend	-0.5549***	0.1491

**indicates p-values*<0.05, **indicates p-value <0.01, ***indicates p-values <0.001

Table 2. Results of Negative Binomial Regression of 30-day Marijuana Use and Legalization

marijuana	β	Robust SE
Recreational	0.6714***	0.1533
Medical	0.1901**	0.0626
Spillover	2.1175***	0.2557
Decriminalization	-0.6486***	0.1427
Alcohol	0.08359***	0.0175
Most Alcohol	0.2551***	0.0161
Lifetime Alcohol	0.0262***	0.0014
Binge	-0.1653***	0.0284
Black	1.1129***	0.2003
Hispanic	0.5438***	0.0905
All other races	0.4775**	0.1461
Sex	-0.1566*	0.0683
age	0.2309***	0.0300
Local Trend	1.8686***	0.1767

**indicates p-values*<0.05, **indicates p-value <0.01, ***indicates p-values <0.001

Table 3. Results of Negative Binomial Regression of Binge Drinking and Legalization

binge	β	Robust SE
Binge	0.5482***	0.0254
Recreational	-0.0492***	0.0037
Medical	0.2681***	0.0148
Spillover	-0.0903***	0.0070
Decriminalization	0.4041***	0.0167
alcohol	0.0303***	0.0015
marijuana	-0.8737***	0.0592
Black	-0.1197***	0.0439
Hispanic	-0.3737**	0.0563
All other races	0.2293***	0.0339
Sex	0.2009***	0.0174
Age	0.8662***	0.0169
Local Trend	0.5482***	0.0254

**indicates p-values*<0.05, **indicates p-value <0.01, ***indicates p-values <0.001

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