The Effects of Recreational Marijuana Dispensaries on Local Opioid Mortality

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Abstract

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This study examines how recreational marijuana dispensaries in Colorado affect opioid mortality at the county level. Using a difference-in-difference model with county and year fixed effects, I estimate the impact of recreational marijuana dispensary access on fatal opioid overdoses. Additionally, I employ distance from a major roadway and border as two instrumental variables to help limit the endogeneity associated with the location of dispensaries. Previous studies have shown that medical and recreational marijuana dispensary access decreases opioid mortality at the state level. Still, no study has explored the connection between recreational marijuana dispensaries and overdoses at the county level. Using data from the CDC, Colorado Department of Revenue, US Census, and other sources, I found that under some specifications, one additional dispensary is associated with a 0.0668 to 0.0747 unit decline in opioid mortality. However, this result was not robust under every specification. Given the worsening opioid crisis in the United States, research into alternate methods of reducing opioid mortality is critical.

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I. Introduction

In recent years, the United States has been dealing with a public health crisis.[1] Unintentional injuries, including drug overdoses, are the leading cause of death among Americans under forty-five years old.[2] Overdoses alone account for more deaths than any other single cause.[3] From April 2020 to April 2021, more than 100,000 Americans died from drug overdoses, a 28.5% increase from the prior year.[4] Efforts to curb the opioid crisis, including rehabilitation clinics, support groups, and methadone clinics, have not solved the problem. Over the last several years, the crisis has been exacerbated by the rising prevalence of heroin and synthetic opioids like fentanyl, which are less expensive and more potent. Because heroin and fentanyl are cheaper than prescription painkillers, the demand for opioids has increased. Policymakers, and suffering citizens, have looked to alternate methods of reducing the harm caused by opioids in both their prescription and synthetic forms. Although evidence is mixed, some previous studies have shown that medical marijuana can substitute for opioids and consequently reduce the number of opioid overdoses. However, far less work has been done linking recreational marijuana and opioid abuse. As the opioid crisis moves further away from prescription painkillers and progresses toward more dangerous synthetic opioids, such as heroin and fentanyl, the effect of recreational marijuana on opioid overdoses becomes an important policy question.

This study will examine the effect of recreational marijuana dispensaries on opioid overdoses at the county level in Colorado. This study uses a difference-in-difference specification with data from the CDC Multiple Cause of Deaths files, the US Census Bureau, the

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[1] No, not *that* public health crisis.
[2] Overdoses are not necessarily fatal. However, for simplicity, this paper will only use 'overdoses' to refer to 'fatal overdoses.'
[3] https://www.cdc.gov/injury/wisqars/animated-leading-causes.html
[4] https://www.washingtonpost.com/health/2021/11/17/overdose-deaths-pandemic-fentanyl/

Colorado Department of Revenue, and the Bureau of Labor Statistics. In the difference-in-difference specification, this study found that opening an additional dispensary is associated with a -0.0668 unit decrease in overdoses. This finding implies that opening an additional fifteen dispensaries would lower the number of overdoses in a county by one. This result was not robust to every specification. CDC data suppression standards lowered the number of observations from 704 to 97, substantially increasing the standard errors and biasing the coefficients toward higher values.

The OLS estimation may suffer from endogeneity, so we utilized an instrumental variable specification using distance from a major roadway and border as instruments. Endogeneity may be an issue because the location of recreational marijuana dispensaries is not random, and it is reasonable to assume that areas with a high demand for recreational marijuana may also have a high demand for opioids. In the instrumental variable regression, this study found that opening an additional dispensary is associated with a -0.0747 unit decrease in overdoses, implying that opening approximately thirteen additional dispensaries would lower the number of overdoses by one. Again, this result was not uniformly robust across specifications and suffered from a limited number of observations. We can observe that the difference-in-difference and instrumental variable regression results are similar, suggesting that endogeneity bias may not be as severe as feared. In any case, these similar results help affirm the veracity of this finding.

To my knowledge, this study is the first to consider the effects of recreational marijuana dispensaries on opioid mortality at the county level. Colorado was the first state to open recreational marijuana dispensaries in 2014, making them an ideal case study for this analysis. This study will focus on the time frame 2009-2019 to allow for a relatively even number of years before and after legalization while avoiding the endogenous effects of the COVID-19 pandemic on opioid overdoses. As many states weigh the benefits and consequences of legalization, relevant policy research into the effects of marijuana legalization on other aspects of society is crucial. Recreational marijuana is available to a larger segment of the population than medical marijuana, suggesting that it could interact with opioid use in unforeseen ways. Medical marijuana is a good substitute for prescription painkillers, but as the opioid crisis shifts toward synthetic drugs like heroin and fentanyl, we must consider whether recreational marijuana serves as a better substitute for these deadlier alternatives.

The paper will proceed as follows. Section II will discuss the background and literature review, building the theoretical framework for this analysis. Section III will discuss the data sources and manipulations used to generate the variables. Section IV will describe the model in detail, explaining the logic behind the difference-in-difference specification and the instrumental variable regression. Section V will feature the results and discuss their meaning in relation to the existing literature and implications for future policy. Finally, section VI will conclude the analysis with a summary of the findings and potential avenues for future research.

II. Background and Literature Review

The opioid crisis has received prominent attention in the media and has touched the lives of many families in the United States. The root causes of opioid addiction have a sinister history in the United States. Prescription painkillers such as OxyContin prescribed for unverifiable maladies like chronic pain made up the majority of overdoses until 2010 (Anderson, Rees 2021). That year, the makers of OxyContin reformulated the pill to make it harder to abuse. Over the following decade, the opioid crisis shifted toward heroin and fentanyl, helping cause the recent surge of overdoses (Evans et al., 2018). Economic conditions can also affect drug abuse. Ruhm (2018) describes this framework, defining “deaths of despair” as excess deaths caused by drug overdose, suicide, or alcohol-related injury. However, Ruhm found that medium-run economic conditions cause only one-tenth of these deaths of despair and that counties with more severe economic decline had relatively more deaths of despair.

Meanwhile, recreational and medical marijuana dispensaries have proliferated in recent years, with thirty-six states allowing medical marijuana and eighteen states allowing recreational marijuana.[5] In particular, recreational marijuana is a new phenomenon, with Washington and Colorado being the first to legalize it in 2012. Recreational marijuana legalization marks a dramatic change in US drug policy, affecting a significant portion of the nation's population. As a national debate over the costs and benefits of marijuana legalization continues, a natural question is, how will recreational marijuana legalization affect the opioid crisis? If a significant relationship exists between these two drugs, policy decisions concerning either should consider this connection. Particularly, if recreational marijuana and opioids are substitutes, the opening of new recreational marijuana dispensaries could significantly decrease local opioid mortality.

A History of Marijuana Legalization

We will start with a brief history of medical and recreational marijuana legalization. Although some states had banned the use of marijuana in the early twentieth century, the Federal government effectively banned its medical and recreational use nationally in 1937 with the Marijuana Tax Act. In 1970, the Controlled Substances Act classified marijuana as a Schedule I drug, indicating no known medical use and a high potential for abuse. The war on drugs developed in the following decades, increasing violent crime, property crime, and the prison population (Miron 2004). In 1996, California passed Proposition 215, allowing for the medicinal use of marijuana and legalizing the drug's possession, cultivation, and retail sale to qualified patients. In 2009, the Deputy Attorney General released the Ogden Memo, stating that the

[5] Washington D.C. has also legalized recreational and medical marijuana.

federal government would not actively prosecute medical marijuana users in compliance with their respective state laws. Over the following years, several states legalized medical marijuana in response, and today, thirty-six states and Washington D.C. have legalized medical marijuana.

Washington and Colorado passed the first recreational marijuana laws in 2012. The 2013 Cole Memorandum clarified the federal government's plan for enforcing state marijuana legislation and specified instances where they would intervene. Oregon and Alaska legalized recreational marijuana in 2014, while Colorado and Washington began commercial sales. Today, eighteen states and D.C. have legalized recreational marijuana, with eleven states operating retail dispensaries. The Cole Memorandum was repealed in 2018, and the House of Representatives recently passed the MORE Act in 2020, a substantive step toward federal legalization.

Social Consequences of Legalization

There is fear that marijuana legalization will come with unintended social consequences. This section will address a few leading areas of concern: legalization's impact on crime, teen consumption, alcohol consumption, and painkiller prescriptions. Anti-marijuana arguments hinge on the premise that marijuana is a complement for other drugs so that an increase in marijuana consumption would increase other drug use. However, the evidence suggests that marijuana may be a substitute for other drugs and that its effects on teen consumption are minimal. This finding suggests that the primary arguments against legalization are flawed, and indeed, legalization may present more social benefits than costs.

One of the primary arguments against legalized marijuana is the concern that drug usage leads to more non-drug crimes. If marijuana and opioids are complementary goods, we would expect recreational marijuana dispensary openings to increase crime. Brinkman and Mok-Lamme (2017) examined the effect of retail dispensary concentration on neighborhood crime in Denver and found that legalization led to a highly localized crime reduction, with few effects on surrounding neighborhoods. They utilized a difference-in-difference approach and instrumented the distance to a major roadway to observe changes in crime that resulted from changes in dispensary accessibility. Overall, they found that opening a new dispensary is associated with a reduction of 17 crimes per 10,000 residents. In a similar study, Burkhardt and Goemens (2019) used a difference-in-difference specification to examine the effects of dispensary openings on a wide range of crimes and found a reduction of crimes within a half-mile of new dispensaries, but only in above-median income neighborhoods. Further, they found a 13% reduction in hard drug and alcohol-related crimes but a 15% increase in car break-ins.

Finally, Dragone et al. (2018) used difference-in-difference and spatial discontinuity designs to examine the quasi-experimental changes in recreational marijuana laws along the Washington-Oregon border. Following legalization, Washington saw a 2.5% increase in marijuana consumption and a 0.5% decrease for other drugs. There was a statistically significant reduction in rapes and property crimes, with the authors concluding that legal marijuana does not increase crime and possibly reduces it. One benefit of dispensaries is that marijuana users can avoid utilizing the black market. Interactions with drug dealers provide access to harder drugs than dispensaries would, and black market interactions are more likely to result in drug tampering, violence, or robbery. Together, these findings support the notion that marijuana is a substitute for alcohol and harder drugs that are more likely to be associated with criminal behavior.

Aside from crime, a sizable literature exists discussing whether marijuana is a complement or substitute for other substances. The “gateway drug” hypothesis suggests that marijuana use leads to other alcohol and drug experimentation, ultimately increasing the likelihood of addiction and overdose. Early work focused on the connection between the legal drinking age and marijuana use. Yoruk and Yoruk (2011) found that marijuana use drastically increased at twenty-one years old (suggesting complementarity), whereas Crost and Guerrero (2012) found a sharp decrease in use (suggesting substitutability). In a reply to the Journal of Health Economics, Crost and Rees (2012) replicated Yoruk and Yoruk's results and found that they inadvertently conditioned on having used marijuana in the past month. After correcting this error, Crost and Rees confirmed that marijuana use decreases at twenty-one years old. Similarly, Anderson et al. (2013) showed an 8-11% decrease in traffic fatalities in the first year after medical marijuana legalization via a reduction in alcohol consumption. This result does not imply that driving under the influence of marijuana is safe but instead suggests that alcohol and marijuana are substitutes.

There is a valid concern that legalizing marijuana signals to teenagers that use is not risky and subsequently increases youth consumption. Using data from the Youth Risk Behavior Survey and exploiting geographic and temporal variation, Anderson et al. (2015) showed no causal relationship between legalization and teen use. They argue that the introduction of legal dispensaries crowds out drug dealers and decreases the supply of marijuana to teenagers. The paper found a 1.5% increase in teen use associated with legalization, but this change could be due to changing attitudes regarding the risks of marijuana use. There is no study connecting teen marijuana use and future opioid abuse, so the best evidence of their substitutability comes from the medical marijuana literature.

Understanding how medical marijuana affects opioid consumption is best seen in research regarding medical marijuana and prescription medication use. Both marijuana and opioids are used to treat chronic pain, so we expect medical marijuana dispensary openings to decrease opioid prescriptions. Bradford and Bradford (2018) examined the relationship between legalization and prescriptions that marijuana is known to also treat under Medicare Part D. Using a difference-in-difference specification on a near-census of Medicare Part D prescriptions from 2010-2015, they found that access to a medical marijuana dispensary results in 2343.9 fewer daily doses of prescription pain medication per year. This result suggests that marijuana and prescription painkillers are substitutes for chronic pain sufferers.

Directing chronic pain sufferers away from prescription painkillers and toward legal marijuana has high potential benefits. Many states have adopted prescription drug monitoring programs (PDMPs) to regulate the activities of "pill mills," chronic pain clinics that gained notoriety for overprescribing painkillers, often for personal monetary gain. Chronic pain poses issues because it is a debilitating condition to live with and difficult to verify that a given person is suffering from it. Marijuana can treat chronic pain without the negative consequences of opioid addiction, making legalization a viable alternative. There is reason to believe that recreational marijuana works similarly to medicinal marijuana, and a larger segment of the population who have not sought chronic pain relief or have been illegally self-medicating will have access to a legal alternative.

Medical Marijuana and Opioid Mortality

A notable literature exists connecting the introduction of medical marijuana laws and opioid mortality in the United States. One critical early study was Bachhuber et al. (2014) which found that states with medical marijuana laws saw a 24.8% relative decrease in non-suicide opioid deaths. Further analysis indicated that the relationship between medical marijuana and lowered overdoses strengthened over time. This result was widely reported in the media and is frequently cited by pro-marijuana advocates and politicians (Anderson, Rees 2021). Recently, an analysis by Shover et al. (2019) found that when replicating the result with data through 2017, the sign flipped significantly, indicating that medical marijuana states now experience greater than expected opioid overdoses. They argue that pro-marijuana advocates are using Bachhuber et al.'s finding as proof that marijuana and opioids are substitutes and that, in general, the negative association is not robust. These conflicting findings serve as part of the motivation for the current study, as the relationship between marijuana use and opioid overdoses has come into question.

Helping to confirm Bachhuber's original finding, Powell et al. (2018) found that heterogeneity in medical marijuana laws affected their relationship with prescription opioid abuse. Using data from Medicare Part D, they found that marijuana access lessened opioid abuse and that laws allowing for greater access to operational dispensaries saw the largest effect. They used a difference-in-difference approach with non-medical states as the control group and exploited differential timing of implementation. Building on the idea that access to operational dispensaries drives the effect of medical marijuana on overdoses, Smith (2020) examined dispensary openings at the local level using a difference-in-difference approach. He found an 11% decrease in opioid-related fatalities following a dispensary opening and a 17% reduction in counties after the first three years of operation. These results corroborate the previous findings and help argue that marijuana acts as a substitute for opioid abuse.

Motivation

Given the evidence of medical marijuana's substitutability for alcohol and prescription opioids, without a notable increase in teen use, it follows that recreational marijuana would have a similar effect. The key difference between medical and recreational marijuana is that a far broader group of people can use recreational marijuana. This study examines whether access to recreational marijuana, primarily through dispensaries, affects local opioid overdoses. Counties with more functioning dispensaries should see a relative decline in overdoses compared to counties in the same state with fewer dispensaries. If marijuana's substitution effect extends to more potent opioids like heroin and fentanyl, we expect to see a relative decrease in overdoses in states that have legalized recreational marijuana.

The recent shift toward synthetic opioids undermines the ability of medical marijuana to combat the opioid crisis. Shover et al.'s (2019) work shows that relying on medical marijuana research fails to account for recent changes in the opioid crisis. As the nature of the crisis changes, medical and recreational marijuana may prove less closely related, prompting a need to study recreational marijuana's effect alone. If medical marijuana is no longer effective, understanding the effects of recreational marijuana becomes increasingly important, as the two forms of legalization may have a different effect on opioid overdoses.

The most comparable work to this study comes from Chan et al. (2020). They used a difference-in-difference approach to estimate the effects of medical and recreational marijuana laws on opioid mortality rates, finding that these laws reduce overdoses by 20-35%. This paper was one of the first analyses of the effect of recreational marijuana laws on opioid overdoses. Notably, they found that recreational marijuana had a greater effect on synthetic opioids. Their findings are particularly important given the recent shift toward these more potent and lethal alternatives. This analysis occurs at the state level and includes data from the CDC National Vital Statistics System from 1999-2017, when eight states had an operational recreational marijuana dispensary for any amount of time. Their findings support the notion that recreational marijuana legalization has different effects depending on the nature of the opioid crisis.

The present study will consider a similar research question to Chan et al. (2020), with some key differences. First, this study will examine the effects of recreational marijuana dispensary openings at the county, rather than state, level to determine the impact of new dispensary openings on opioid mortality in the surrounding area. To my knowledge, no study examines this issue at the county level. These findings will help inform local policymakers in states where recreational marijuana dispensaries are legal to decide if opening a dispensary in their community is advisable. Further, we will benefit from a longer sample period than other studies. Most prior studies have used medical marijuana as a proxy for recreational marijuana, but given the changing nature of the opioid epidemic, observing recreational marijuana's effects directly is crucial. If recreational marijuana is a better substitute for heroin and fentanyl than medical marijuana, understanding this relationship could help end the opioid crisis.

III. Data

The data for this study derives from multiple sources. It covers an eleven-year span from 2009-2019. This time frame offers an equal number of years before and after legalization (in 2014) while avoiding the effects of Covid-19 on opioid overdoses. Colorado overdose mortality data comes from the CDC Multiple Cause of Death files (MCOD) 2009-2019. The MCOD dataset includes county-level mortality data for the United States, compiled from death certificates. Overdose deaths are coded following CDC standards, with X40-44, X60-64, X85, and Y10-14 indicating unintentional overdoses, suicides, homicide, and undetermined, respectively. These data represent virtually all opioid-related deaths in Colorado during the sample period. Unfortunately, confidentiality standards suppressed a significant portion of the overdose data in low-population counties. In total, we have only 97 county-year observations from eleven different counties. The '*opioid_ods*' variable provides the total number of opioid deaths during that county and year and serves as the dependent variable of interest. The natural log of '*opioid_ods*' will serve as an additional dependent variable, encoded as '*log_deaths*.'

Data on recreational marijuana dispensary locations in Colorado was constructed from the Colorado Department of Revenue (CDR).[6] The CDR's Marijuana Enforcement Division maintains archived records of licensed facilities, so I assigned opening year values to each dispensary. To calculate the total number of dispensaries in each year by county, I summed the number of dispensaries open in each year from 2014-2019. For each county-year observation from 2009-2013, the number of dispensaries is zero because Colorado's first recreational marijuana dispensaries opened on January 1, 2014. Finally, I collapsed dispensaries by county and reshaped the data into panel format to merge later. This process was used to create the '*disp*' variable, the key independent variable.

County-level demographic data was compiled from the United States Census Bureau from 2010-2019. These data include population information for median age, race, ethnicity, and sex. Values for 2009 were not available, so I generated predicted values by calculating and inverting the growth rate during 2010 and 2011. The '*tot_pop*' variable represents the county's total population in that year and will control for county size as a determinant of overdoses. The effect of age is controlled for by '*median_age*.' I generated the variable '*male_pct*,' which represents the percentage of the total population that is male, calculated as the total number of men in a county divided by its population. I generated '*minority_pct*' as the share of all Hispanic or Black men and women in a county divided by the total population. Poverty rate data comes from the US Census Small Area Income and Poverty Estimates (SAIPE) program. This data will help create an interaction term to determine differential effects of socioeconomic characteristics across counties. Unemployment rate data comes from the Bureau of Labor Statistics and

[6] Available at: https://sbg.colorado.gov/med/licensed-facilities

provides a county-level measure of economic conditions, helping control for the effect of medium-run economic downturns.[7] The data came as several Excel files that I combined and copied into Stata.

The instrumental variables are the distance from a major roadway (‘*road_dist*’), and the distance from a border (‘*border_dist*’) come from the US Census TIGER database and was provided courtesy of Jeffrey Brinkman at the Federal Reserve Bank of Philadelphia.[8] I averaged the distance to a major roadway by county and repeated this process for border distance. The ‘*road_dist*’ variable thus represents the average distance of a dispensary to a major roadway by county. Similarly, ‘*border_dist*’ represents the average distance of a dispensary to a border by county. These variables were then merged into the master dataset. The following section will discuss the validity of these instruments and their role in this analysis. See the following table for summary statistics of these variables.

Table 1: Summary Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
opioid_ods	97	27.94845	13.99358	10	81
disp	704	3.666193	14.8235	0	170
road_dist	704	170109.3	99150.64	1728.691	377139.2
border_dist	704	4036.982	3590.253	62.44915	22428.86
unemployment	704	5.476989	2.909329	1.5	18.5
tot_pop	704	83816.74	168584.9	689	727211
male_pct	704	.5188131	.0371982	.4791356	.7348622
minority_pct	704	0.2041936	0.1435578	0.0124761	0.6703632
median_age	704	41.89077	5.744856	31.2	57.2

[7] This data is easily accessible at https://www.bls.gov/lau/#tables
[8] See the paper: Brinkman, Jeffrey, and David Mok-Lamme. “Not in my backyard? Not so fast. The effect of marijuana legalization on neighborhood crime.” Regional Science and Urban Economics Vol. 78 (2019): 103460.

IV. Method

This study uses a difference-in-difference specification. This equation summarizes the underlying logic of a difference-in-difference model:

$$\text{Difference} = \Delta Y_T - \Delta Y_C \qquad (1)$$

ΔY_T represents the change in treated counties. In this study, the treatment is the presence of recreational marijuana dispensaries, with '*disp_dum*' representing the presence of any dispensaries and '*disp*' giving the discrete count of dispensaries. ΔY_C represents the change in counties without dispensaries or with relatively fewer dispensaries. The difference between the two terms in (1) represents a naive estimate of the policy's effect.

To control for other changes, I examine the causal effect of local dispensary openings on opioid mortality using the following equations:

$$\text{Deaths}_{it} = {}_0 + {}_1\text{Disp}_{it} + {}_2\text{Interaction}_{it} + {}_3\text{Unemployment}_{it} + {}_4X + \epsilon_{it} \qquad (2)$$

$$\text{Deaths}_{it} = {}_0 + {}_1\text{Disp\_dum}_{it} + {}_2\text{Interaction}_{it} + {}_3\text{Unemployment}_{it} + {}_4X + \epsilon_{it} \qquad (3)$$

Where Y_{it} is the dependent variable, indicating the difference in opioid overdoses. ${}_1$Disp represents the number of dispensaries in a county and ${}_1$Disp_dum represents if the county has any dispensaries. ${}_2\text{Demographics}_{it}$ represents the county-level demographics to control for differences in sex, race, ethnicity, and age. ${}_3\text{Unemployment}_t$ controls for the county-level unemployment rate, a proxy for general economic conditions. ${}_4$X represents a vector of control variables and ϵ_{it} is the error term, which encapsulates all unobserved variables that affect the dependent variable. The subscripts 'i' and 't' indicate county and year fixed effects.

Where dispensaries choose to open is not random and there is concern that this will introduce endogeneity into the OLS estimation. We expect the endogeneity to be positive because dispensaries are more likely to open in urban areas where there is high demand for recreational marijuana. We suspect that these attributes that partly determine dispensary location affect opioid mortality, so to combat the problem of endogeneity, I will utilize two instrumental variables following the standard two-stage least squares method. The instruments of choice are the distance between a recreational marijuana dispensary and a major roadway and border. I argue that this instrument satisfies both the inclusion and exclusion criteria. It follows that there will be increased demand for recreational marijuana in more accessible locations, making it a significant determinant of total dispensaries. This intuition can be tested empirically in a reduced form regression, as in Equation 4. This test occurs under Output 6 (see Appendix) in the next section.

The first-stage equation is:

$$\text{Disp} = \gamma_0 + \gamma_1\text{Roadway} + \gamma_2\text{Border} + \gamma_3\text{X} + \nu \qquad (4)$$

'*Disp*' is the independent variable of interest in our first-stage equation. γ_1Roadway and γ_2Border are the exogenous effects of our instrumental variables on the number of dispensaries in a county. γ_3X represents the other control variables, and ν is the error term. The first stage isolates the effect of '*Disp*' that does not arise from correlation to the error term.

The second-stage equation takes the fitted-value $\widehat{Disp}$ as in independent variable, as below:

$$\text{Deaths} = {}_0 + {}_1\widehat{Disp} + {}_2\text{X} + \epsilon \qquad (5)$$

Y in equation (5) represents our outcome of interest, opioid overdoses. ${}_1\widehat{Disp}$ is the coefficient of our fitted-value, and ${}_2$X represents the vector of control variables described above. Because $\widehat{Disp}$ is a fitted-value, its inclusion will increase the standard error in (5). Testing the correlation between roadway and border distance and the number of dispensaries helps determine the instrument's strength.

Data suppression issues removed many of the observations that we would like for this analysis. In an attempt to glean some value from this missing data, we will demonstrate the effect of '*disp*' and '*disp_dum*' on the binary dependent variable '*suppressed*.' The regression takes the form:

$$\text{Suppressed} = \quad {}_0 + \quad {}_1\text{Disp} + \quad {}_2\text{X} + \epsilon \tag{6}$$

$$\text{Suppressed} = \quad {}_0 + \quad {}_1\text{Disp\_dum} + \quad {}_2\text{X} + \epsilon \tag{7}$$

Where '*Suppressed*' equals one if the data is suppressed (fewer than ten observations) and zero otherwise. As before, '*Disp*' and '*Disp_dum*' represent the number of dispensaries and if there are any, respectively. 'X' represents a vector of control variables and ϵ is the error term.

V. Results

First, we begin with a demonstration of the effect of a dispensary on data suppression. Mortality data are suppressed when there are fewer than ten observations in a county in a given year. It follows that if counties with more dispensaries are more likely to have suppressed data, then dispensaries reduce opioid mortality, even if we cannot directly observe the number of overdoses. As Output 1 shows, a basic regression with the binary dependent variable '*suppressed*' yields significant and positive results for both the '*disp_dum*'and '*disp*' variables.[9] '*Disp_dum*' has a coefficient of 0.154, meaning that having any dispensaries is associated with a 15.4% increase in the likelihood of data suppression. '*Disp*' has a coefficient of 0.00857, meaning that every additional dispensary is associated with a 0.857% increase in the likelihood of data suppression. Both of these results are statistically significant at the 1% level. This finding

[9] Remember that '*disp_dum*' represents if a county has any dispensaries, while '*disp*' is a discrete number of dispensaries.

implies that counties with more (or any) dispensaries are more likely to have less than ten opioid overdoses than counties with no dispensaries.

Next, we will use a difference-in-difference specification to estimate the impact of dispensaries on opioid overdoses using county and year fixed effects. Due to data suppression, we are limited to 97 observations in eleven different counties. The key independent variable is the number of dispensaries, and Output 2 shows the results. We can see that using the natural log of deaths as the dependent variable yields an insignificant result with a negative but small coefficient. However, using the total number of deaths as the dependent variable yielded significant results at the 5% level. The coefficient is -0.0668, implying that the opening of approximately fifteen dispensaries is associated with a one-unit decrease in deaths. For an area like Denver county, which has 170 dispensaries, this equates to a reduction of approximately eleven deaths. Further, CDC suppression rules bias our coefficient toward a higher value because counties with fewer fatalities are not included in our sample size. Thus, the actual effect has the potential to be much larger.

Output 3 shows the results for a difference-in-difference specification using '*disp_dum*' as the key independent variable, which signifies whether a county has any dispensaries. Column (1) is insignificant and provides no insight into the effect of having any dispensaries on opioid mortality. Similarly, column (2) shows that dispensaries insignificantly affect deaths. Because both of these results are insignificant, we cannot conclude that having any dispensaries affects opioid mortality. As before, these results are biased toward a greater coefficient due to suppression standards removing the smallest values. We should also consider that dispensaries tend to open in counties with higher populations (due to increased demand) and that high population counties tend to have higher opioid mortality rates regardless of dispensaries.

Dispensaries may have varying impacts on counties with different socioeconomic characteristics. To examine this, I augment Outputs 2 and 3 by adding interaction terms for the poverty rate and percentage of the population that is either Black or Hispanic. Output 4 shows the results with '*disp*' as the key independent variable. Columns (1) and (2) show that neither the 'disp' term nor either interaction term are significant under this specification. No conclusions can be drawn from these regressions, given the low significance level. In both columns, the minority percentage of the population is significant at the 5% level. However, the minority share of the population interaction term is not significant. Output 5 shows the results with '*disp_dum*' as the key independent variable, including interaction terms. As in Output 4, neither column (1) nor column (2) shows a statistically significant effect. Since these results are insignificant, we cannot draw any conclusions from this finding. As in Output 4, the interaction terms are all insignificant, and only the minority share of the population is positive and statistically significant.

Instrumental Variable Regression

Next, we will examine the results for our second-stage instrumental variable regression. The OLS results in this study may be biased because the key independent variable, dispensaries, are not randomly assigned to counties. Instead, counties choose where to open dispensaries for several reasons, including demand, ease of access, and local laws. It is plausible that determining where dispensaries are located correlates with the number of opioid overdoses in that area. Thus, we employ two instrumental variables to mitigate the potential problem of endogeneity, distance from a major roadway and distance from a border. This choice of instruments aligns with Brinkman and Mok-Lamme (2017), who provided border and roadway data for the present analysis. These instruments make sense because dispensaries are likely to open in areas easily accessible to customers, and being near a major roadway ensures that. Customers who do not live in Colorado but want to consume recreational marijuana can access it by crossing the border, implying that opening dispensaries near a border would increase demand. Instrumental validity is conditional on satisfying the exclusion and inclusion criteria. The exclusion criteria cannot be tested empirically, so we justify these instruments by considering that opioid overdoses should have no intrinsic connection to the location of borders or roadways. The ubiquity of opioids means that it is generally unnecessary for a typical user to purchase these drugs out of their local area.

We will empirically test the inclusion criteria by regressing '*road_dist*' and '*border_dist*' on '*disp.*' Output 6 shows the result. Both have negative coefficients and are significant at the 1% level. Output 7 shows the results for '*disp_dum*' as the key independent variable instrumenting on distance from a major roadway and distance from a border. When either '*log_deaths*' or '*opioid_ods'* are the dependent variable, we see a statistically insignificant effect, though they would be significant at the 10% level. Both coefficients are large and negative, but since they are not statistically significant, we cannot conclude anything from them. Output 8 shows the results when '*disp*' is the key independent variable. Column (1) shows the results for the natural log of deaths and again is not statistically significant. Column (2) suggests that opening an additional dispensary is associated with a -0.0747 unit decrease in the number of opioid fatalities. This result is significant at the 5% level. This finding implies that the addition of approximately thirteen dispensaries would result in one fewer opioid overdose. This model also produces an R-squared of 0.792, the highest of any specification in this study.

This concludes the explanation of the results, and this section will now discuss the meaning of these findings. First, we should note that these results are not significant across all specifications, and thus we cannot affirm their robustness. Nevertheless, some specifications are particularly interesting as they suggest that recreational marijuana dispensaries have a non-negligible impact on opioid mortality. In particular, Output 1 shows that having dispensaries (and higher numbers of dispensaries) increases the likelihood of data suppression. Since data are only suppressed when there are fewer than ten fatalities, this finding implies that dispensaries decrease the number of deaths. Data suppression reduced the number of observations from 704 to 97. This reduction greatly increased the standard error in the regressions, lessening their ability to produce statistically significant results. It is encouraging that some specifications still produced significant results despite this small sample size.

The preferred specifications are Output 2 column (2) and Output 8 column (2). These are the number of dispensaries on the number of deaths and an instrumental variable regression which calculates a fitted value for the '*disp*' variable. The preferred specifications are both statistically significant at the 5% level. In finding that specifications using the number of dispensaries ('*disp*') as the explanatory variable, we can infer that the intensity of treatment is more important than having the treatment at all. In other words, simply opening a dispensary is not enough to create substantive change; there must be a sufficient number of dispensaries for positive effects. If we focus on the preferred specifications, Output 2 allows us to conclude that opening an additional dispensary is associated with a -0.0668 reduction in opioid fatalities, while Output 8 suggests a -0.0747 reduction. Despite different estimation techniques, these estimates are relatively similar, suggesting that they may be close to the true relationship. A back-of-the-envelope calculation suggests that the opening of approximately 13-15 additional dispensaries would save one life.

VI. Conclusion

This study examines the effects of recreational marijuana dispensaries on opioid overdoses in Colorado. Using county-level mortality data from the CDC, demographic data from the US Census, roadway and border data from the TIGER database, and unemployment data from the Bureau of Labor Statistics, I find that, under some specifications, increases in the number of dispensaries are associated with a decrease in opioid mortality by about -0.0668 to -0.0747 per dispensary. This result is not robust to every specification, but given the limited amount of data available, it points to a meaningful relationship between access to marijuana and reduced opioid mortality. Unexpected data suppression reduced the total number of observations from 704 to 97 while also biasing the results toward higher values, implying that there could be a large and negative relationship between recreational marijuana dispensaries and opioid overdoses.

Previous studies have linked recreational marijuana availability to reduced opioid mortality at the state level, but to my knowledge, this is the first study to consider the effects at the county level. Future research could improve this study in a few regards. First, gaining access to the restricted use data would free up several hundred observations and massively reduce the standard error in these regressions while eliminating the bias of results toward higher values. Further, one original goal of this study was to isolate the effect of recreational marijuana on synthetic opioids in particular, in line with the state-level findings of Chan et al. (2020). However, the data suppression made this impossible, as removing any more observations would make finding significant results infeasible. I believe that recreational marijuana may have a particular effect on synthetic opioid use because users of medical marijuana tend to get prescriptions for ailments that prescription opioids are also used to treat, such as chronic pain.

Recreational marijuana is available to the general public and could be a better substitute for synthetic opioids than medical marijuana.

Most studies to date have failed to support the 'gateway drug' hypothesis, which posits that marijuana use leads to experimentation with 'harder' drugs. This study further weakens this argument. In reality, both empirical studies and simple observations have shown that there are not serious consequences to medical or recreational marijuana legalization. Marijuana is not harmful when used responsibly and in moderation, and demand will be present regardless of prohibition. Thus, legalization is the better policy, in no small part because removing marijuana sales from the black market makes it difficult for sellers to offer dangerous alternatives, such as opioids. The notable precedent of alcohol prohibition should make the issue of recreational marijuana legalization common sense. In a similar vein, policy should consider broader alternatives to prohibition to combat the worsening opioid crisis. Harm-reducing drug policies can potentially shift the national response away from treating opioid addiction as a criminal matter and instead address the public health issue that it is. Local recreational marijuana legalization could act as another harm reducing measure that both refocuses policing efforts from marijuana enforcement and decreases the number of opioid overdoses.

This study's hypothesis that recreational marijuana dispensaries decrease county-level opioid mortality is demonstrated in the preferred specifications, but this finding is not robust to all specifications. No regressions using the natural log of deaths as the dependent variable yield significant results under any specification. This is surprising given that the histogram of opioid overdoses (see Appendix) appears to support logging this variable. Colorado was the first state to open recreational marijuana dispensaries, but several states have followed suit in recent years. Early results do not indicate major adverse effects associated with this shift in policy. As more data becomes available, better econometric analyses of the effects of legalization will help cement the relationship between marijuana and opioids, crime, labor, and a host of other outcomes.

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Appendix

Output 1

VARIABLES	(1) suppress	(2) suppress
disp_dum	0.154***	
	(0.0276)	
disp		0.00857***
		(0.000817)
Constant	0.0903***	0.106***
	(0.0153)	(0.0125)
Observations	704	704
R-squared	0.043	0.136

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Output 2

VARIABLES	(1) log deaths	(2) deaths
disp	-0.00177	-0.0668**
	(0.00108)	(0.0334)
Year Fixed Effects	-0.289**	-9.800**
County Fixed Effects	0.0788	-0.215
Constant	3.187***	29.06***
	(0.0834)	(2.567)
Observations	97	97
R-squared	0.243	0.217
Number of fips	10	10

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Output 3

VARIABLES	(1) log deaths	(2) deaths
disp_dum	0.0347	2.375
	(0.280)	(8.684)
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Constant	3.190***	29.15***
	(0.0849)	(2.635)
Observations	97	97
R-squared	0.217	0.176
Number of fips	10	10

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Output 4

VARIABLES	(1) log_deaths	(2) deaths
disp	-0.00378	0.0952
	(0.00799)	(0.241)
poverty_rate	-0.0103	-0.154
	(0.0135)	(0.406)
poverty_inter	1.98e-05	-0.00158
	(0.000154)	(0.00465)
minority_pct	14.55**	651.5***
	(7.276)	(219.1)
minority_inter	0.0139	0.0637
	(0.0174)	(0.525)
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Constant	-0.528	-137.2**
	(1.858)	(55.96)
Observations	97	97
R-squared	0.311	0.317
Number of fips	10	10

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Output 5

VARIABLES	(1) log_deaths	(2) deaths
disp_dum	0.101	-1.259
	(0.202)	(6.120)
poverty_rate	0.000550	-1.324
	(0.0797)	(2.409)
poverty_int	-0.00875	1.234
	(0.0793)	(2.398)
minority_pct	9.620**	379.9***
	(3.779)	(114.2)
minority_int	0.145	-0.260
	(0.457)	(13.82)
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Constant	0.730	-68.01**
	(0.972)	(29.39)
Observations	97	97
R-squared	0.291	0.293
Number of fips	10	10

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Output 6

VARIABLES	(1) roadway	(2) border
road_dist	-3.30e-05***	
	(5.50e-06)	
border_dist		-0.000473***
		(0.000155)
Constant	9.278***	5.575***
	(1.083)	(0.836)
Observations	704	704
R-squared	0.049	0.013

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Output 7

VARIABLES	(1) instrument_log_deaths	(2) instrument_deaths
disp_dum	-3.511*	-108.6*
	(1.931)	(60.27)
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Constant	3.628***	40.32***
	(0.175)	(5.464)
Observations	97	97
R-squared	0.406	0.311

Output 8

VARIABLES	(1) instrument_log_deaths	(2) instrument_deaths
disp	-0.00159	-0.0747**
	(0.00109)	(0.0336)
Year Fixed Effects	Yes	Yes
County Fixed Effects	Yes	Yes
Constant	3.528***	37.05***
	(0.0941)	(2.896)
Observations	97	97
R-squared	0.815	0.792

Histogram of Opioid Fatalities