# The Effect of Medical Cannabis Dispensaries on Opioid and Heroin Overdose Mortality

Garin, Julio and Pohl, R. Vincent and Smith, Rhet A.

Claremont McKenna College, University of Georgia, University of Arkansas at Little Rock

20 October 2018

# The Effect of Medical Cannabis Dispensaries on Opioid and Heroin Overdose Mortality

Julio Garin*
Claremont McKenna College

R. Vincent Pohl†
University of Georgia

Rhet A. Smith‡
University of Arkansas at Little Rock

This Draft: October 2018

**Abstract**

Opioid overdose is the most common cause of accidental death in the United States and no policy response has been able to contain this epidemic to date. We examine whether local access to medical cannabis can reduce opioid-related mortality. Using a unique data set of medical cannabis dispensaries combined with county-level mortality data, we estimate the effect of dispensaries operating in a county on the number of overdose deaths. We find that counties with dispensaries experience 6% to 8% fewer opioid-related deaths among non-Hispanic white men. Mortality involving heroin declines by approximately 10% following the opening of a dispensary.

**Keywords:** Cannabis Dispensaries; Medical Cannabis Laws; Marijuana; Opioid Overdoses; Heroin Overdoses; Opioid Epidemic.

**JEL codes:** I12; I18; K32.

*Robert Day School of Economics and Finance, email: jgarin@cmc.edu.
†Department of Economics, Terry College of Business, email: pohl@uga.edu.
‡College of Business, email: rasmith5@ualr.edu.

# 1 Introduction

With over 42,000 deaths due to opioid overdoses in 2016, the ongoing opioid epidemic is arguably the most pressing public health crisis in the U.S. It has even contributed to a reversal in the long-term trend of declining mortality rates among middle-aged non-Hispanic whites (Case and Deaton, 2015). No policy has been successful in reducing opioid-related mortality overall, which is driven by an exponential increase in heroin and fentanyl (a synthetic opioid) overdoses in recent years. While not intended as a remedy for the opioid crisis, several studies have shown that the legalization of medical cannabis may alleviate this epidemic. These existing studies focus on the role of state laws that legalize the consumption of cannabis for medical purposes. In contrast, we depart from the state-level approach by allowing for within-state heterogeneity in availability of medical cannabis to quantify the extent to which local access to cannabis impacts opioid-related mortality rates. This more granular approach allows us to examine how this relationship depends on the presence medical cannabis dispensaries rather than on the legal status of medical cannabis on the state level.

Using a novel dataset that documents the locations and opening and closing dates of medical cannabis dispensaries, we capture changes in the effective costs of drug consumption that follow the implementation of medical cannabis laws (MCL). Specifically, we exploit the variation in the presence of dispensaries over time and within and across states to estimate the relationship between access to medical cannabis and opioid-related mortality. In addition to the legal consequences of drug acquisition, geographic proximity plays a crucial role. While state-level MCL reduce the legal costs associated with possessing and consuming cannabis, they do not, *per se*, affect the relative costs related to searching for or acquiring the drug. Under the assumption that there is a certain degree of substitutability between opioids and cannabis, the effect of an MCL on the effective price of cannabis (relative to opioids) should be strongest in areas directly exposed to dispensaries.[1]

Studies that rely on state-level variation in MCL cannot account for within-state heterogeneity in the cost of accessing cannabis. For instance, given that rural and urban areas differ in their access to dispensaries, there is no reason to believe that they should be equally affected by a state-level MCL. To the extent that dispensaries are not uniformly distributed within a state, it is difficult to infer the effects of cannabis legalization from policy variation on the state level. From a public policy perspective, those estimates may provide policy makers with conclusions about the convenience of MCL which are not grounded in the ef-

[1]By "effective price" we refer to the price inclusive of costs associated with legality, search, and transportation.

fects of cannabis *per se*. By capturing the effect of the presence of a dispensary on opioid mortality at the county level, our estimates come closer to capturing the "true" effect of cannabis on opioid-related mortality.

Departing from existing studies, our research design compares counties with and without dispensaries within the same state. Therefore, we are not only able to control for the legal status of medical cannabis but also for any unobserved factors that may drive differences in opioid use between states. In addition, we allow for persistent unobserved county-specific differences and state-specific trends in opioid mortality. Hence, our identification strategy relies on temporal variation in the access to medical cannabis within counties. This research design allows us to isolate the impact of a dispensary on opioid-related deaths more effectively than prior literature and brings our estimates closer to providing a causal interpretation. Furthermore, our work addresses the criticism that the state-level analyses used in existing studies do not provide conclusive evidence because unobserved differences between states could explain the estimated relationship between medical cannabis legalization and opioid mortality (Finney, Humphreys, and Harris, 2015; Hall et al., 2018).

Using time variation in dispensary opening and estimating Poisson regressions of county-level deaths due to opioid overdoses, we find a significant decline in mortality in counties where dispensaries are present. While medical cannabis dispensaries reduce opioid-related mortality overall, our results are strongest for heroin overdoses. Specifically, we find that mortality related to any opioids and prescription opioids declines by 6% to 8%. For heroin, the reduction in mortality amounts to 10%, although this effect is less precisely estimated. Importantly, these effects are limited to counties where dispensaries opened and do not apply to non-dispensary counties in states with that have legalized medical cannabis. In fact, with the exception of heroin-related overdoses, MCL themselves have a positive effect on opioid-related mortality. That is, while legalizing medical cannabis is not associated with lower levels of opioid overdose mortality, the presence of dispensaries has a large negative impact on the number of opioid-related deaths.

These estimates imply that 10 per 100,000 (8.5%) fewer opioid-related deaths would have occurred between 1999 and 2015 if states that legalized medical cannabis during this period had had dispensaries in all counties as soon as the MCL came into effect. Our results have direct policy implications since we find that MCL lead to a reduction in opioid-related deaths that is limited to counties where access to medical cannabis is facilitated through the presence of dispensaries.

As of October 2018, 31 states and the District of Columbia have legalized the use of cannabis for medical purposes.[2] However, legal markets were relatively small until 2009 when the federal government issued the Ogden Memorandum stating that federal resources would no longer be used to prosecute individuals in compliance with state medical cannabis laws (Ogden, 2009). In the wake of the Ogden Memorandum, medical cannabis dispensaries began opening up across multiple states that had legalized medical cannabis.[3] The existing literature use state-level variation in MCL to assess the effect of medical cannabis legalization on opioid-related outcomes. For example, Bradford and Bradford (2016), Bradford and Bradford (2017), Bradford et al. (2018), and Wen and Hockenberry (2018) show that MCL lower prescriptions of opioid analgesics. Again using state-level policy variation, Bachhuber et al. (2014) and Powell, Pacula, and Jacobson (2018) find that MCL reduce opioid-related mortality. Powell, Pacula, and Jacobson (2018) also estimate that the effect of MCL on opioid overdoses is mostly driven by whether dispensaries are active and legal on the state level but do not account for sub-state-level variation in access to cannabis. In contrast to these two studies, Pohl (2018) shows that the effect of MCL are sensitive to the inclusion of state-specific time trends. In an important departure from the common state-level analysis, Smith (2017) estimates that counties with medical cannabis dispensaries experience fewer opioid-related admissions to drug treatment facilities conditional on MCL.

As a possible challenge to the substitutability from opioids to cannabis, the "gateway hypothesis" postulates that cannabis consumption eventually leads to use of harder drugs (Kandel, 1975). While this hypothesis is widely accepted to be true, the evidence in its favor is mixed (Fergusson, Boden, and Horwood, 2006; Van Gundy and Rebellon, 2010). Instead, the observed correlation between cannabis and hard drug use within individuals can be explained by pre-existing traits that increase an individual's propensity to use drugs in general (Morral, McCaffrey, and Paddock, 2002; Hall and Lynskey, 2005). Moreover, Robins et al. (2010) finds that former heroin users may substitute towards cannabis. Preliminary evidence suggests that cannabidiol, a non-psychoactive cannabis compound, can reduce craving among heroin users and may therefore serve a role in mitigating the opioid epidemic (Hurd et al., 2015; Hurd, 2017). It is therefore possible that facilitating access to medical cannabis through dispensaries lowers opioid consumption and thus associated mortality. Our findings directly support this hypothesis.

Until recently, the majority of overdoses were caused by prescription opioid analgesics such as OxyContin. However, it is common for heavy users of prescription opioids to switch to heroin (Compton, Jones, and Baldwin, 2016). As a result, heroin has become the most

[2] In addition, nine states and the District of Columbia have legalized cannabis for recreational use.

[3] See Smith (2017) for a detailed account of medical cannabis legalization and especially the emergence of dispensaries.

common drug involved in overdose deaths in recent years, at least among non-Hispanic white men. Most recently, abuse of synthetic opioids such as fentanyl have increased dramatically and exacerbated the impact of the opioid epidemic. The involvement of multiple drugs may require more complex policy responses. Whereas prescription drug monitoring programs (PDMP) have had some success in reducing consumption of and mortality related to prescription opioids (Paulozzi, Kilbourne, and Desai, 2011; Patrick et al., 2016; Buchmueller and Carey, 2018; Dave, Grecu, and Saffer, 2017), these programs cannot prevent utilization of illicit opioids such as heroin or synthetic opioids sold on the black market. Policies that are aimed at reducing the adverse effects of opioids in general—such as naloxone access laws and Good Samaritan laws—have led to mixed results (Rees et al., 2017) or may even be counterproductive (Doleac and Mukherjee, 2018). In particular, there is no policy to date that is successful in lowering utilization and mortality related to heroin, one of the main drivers of the opioid epidemic in recent years. Chu (2015) provides evidence that MCL enactments are associated with fewer treatment admissions for heroin addiction. However, his sample period ends in 2011 and does not observe the recent increase in heroin abuse. Our results imply that facilitating local access to medical cannabis may constitute a policy that is successful at lowering heroin-related mortality.

# 2 Data

We use restricted-use individual mortality data with county identifiers from the Centers for Disease Control and Prevention's National Vitality Statistics System. The data contain information on multiple causes of death, demographics, and county of residence for the universe of deaths in the United States from 1999 to 2015. Using these data, we calculate annual county-level opioid overdose mortality levels and rates among non-Hispanic white men aged 15 to 54 as follows. First, we select records for which the underlying cause of death is classified as "Accidental poisoning" (ICD10 codes X40 to X44), "Intentional self-poisoning" (X60 to X69), "Assault by drugs, medicaments and biological substances" (X85), or "Poisoning with undetermined intent" (Y10 to Y14). Among these records, we designate deaths with a contributing cause of death classified as "Poisoning by and adverse effect of heroin" (ICD10 code T40.1), deaths with a contributing cause of death classified as "Poisoning by, adverse effect of and underdosing of other opioids" (T40.2), and "Poisoning by, adverse effect of and underdosing of other synthetic narcotics" (T40.4) as deaths due to heroin overdoses, prescription opioid overdoses, and synthetic opioid overdoses, respectively. We also define deaths with a contributing cause of deaths involving any opioid or unspecified narcotics

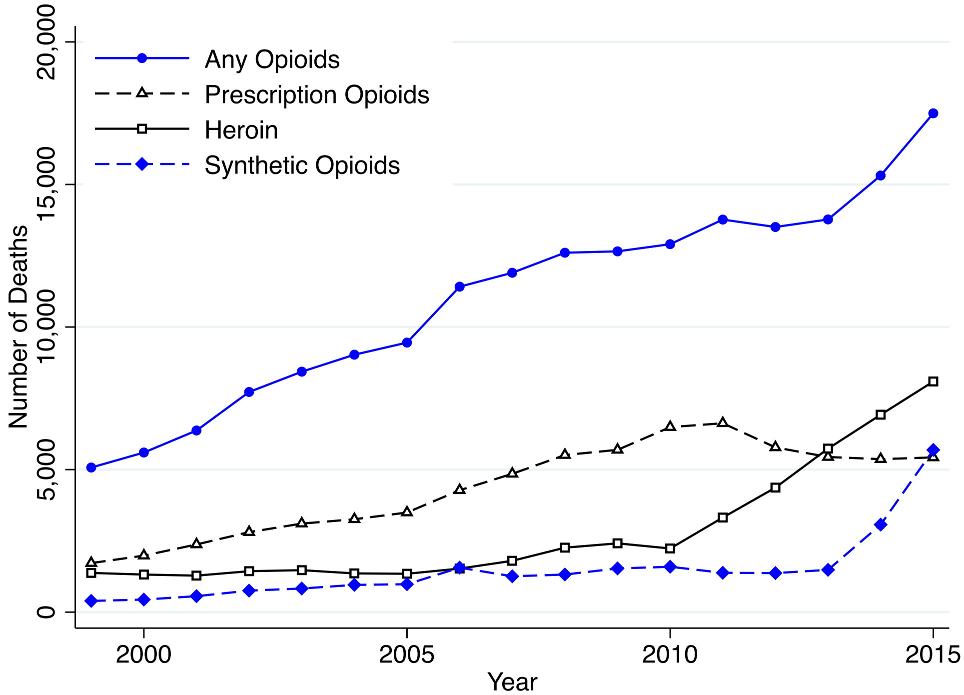



Figure 1: Number of deaths due to opioid overdoses among non-Hispanic white men aged 15 to 54 per year, from 1999 to 2015.

(T40.0 to T40.4 and T40.6) as deaths related to any opioid. In addition to death records that specify a particular type of narcotic, we identify potential heroin- and opioid-related deaths among deaths that were classified as "Poisoning by other and unspecified drugs, medicaments and biological substances" (T50.9) using the imputation method proposed by Ruhm (2018). That is, we estimate year-specific probit regressions that use demographics and location and time of death as explanatory variables to predict whether a death classified as caused by an unspecified drug is actually related to a opioid or heroin overdose.

We then limit the sample to non-Hispanic white men who were aged 15 to 54 at the time of their death.[4] To obtain county-level mortality levels, we sum all deaths due to any opioid, prescription opioid, heroin, and synthetic opioid overdoses, respectively, by year and county of residence. Annual numbers of deaths due to opioid overdoses from 1999 to 2015 appear in Figure 1. The graph shows a sharply increasing trend in opioid-related mortality in this demographic group, increasing from 5,000 per year in 1999 to 17,500 in 2015. While the first 10 years of this period were characterized by rising overdose mortality involving prescription opioids, heroin-related overdoses have sharply increased since 2010, and the number of deaths

[4]88% of all white non-hispanic men who died from any opioid overdose were between 15 and 54 years old at the time of their death.

Table 1: Number of Counties With Medical Cannabis Dispensaries

| | Total Counties | Counties With Dispensaries | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Pre-2009 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
| Arizona | 15 | 0 | 0 | 0 | 0 | 0 | 4 | 14 | 15 |
| California | 58 | 23 | 27 | 38 | 44 | 46 | 46 | 46 | 47 |
| Colorado | 64 | 2 | 4 | 29 | 31 | 30 | 31 | 34 | 37 |
| Connecticut | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| Washington DC | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Maine | 16 | 0 | 0 | 0 | 0 | 4 | 8 | 8 | 8 |
| Michigan | 83 | 0 | 0 | 7 | 17 | 24 | 21 | 18 | 18 |
| Montana | 56 | 0 | 0 | 4 | 5 | 4 | 4 | 5 | 6 |
| Nevada | 17 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| New Jersey | 21 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 |
| New Mexico | 33 | 0 | 0 | 2 | 6 | 7 | 7 | 7 | 10 |
| Oregon | 36 | 0 | 0 | 4 | 11 | 12 | 12 | 13 | 19 |
| Rhode Island | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| Vermont | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| Washington | 39 | 0 | 0 | 3 | 8 | 9 | 15 | 18 | 25 |

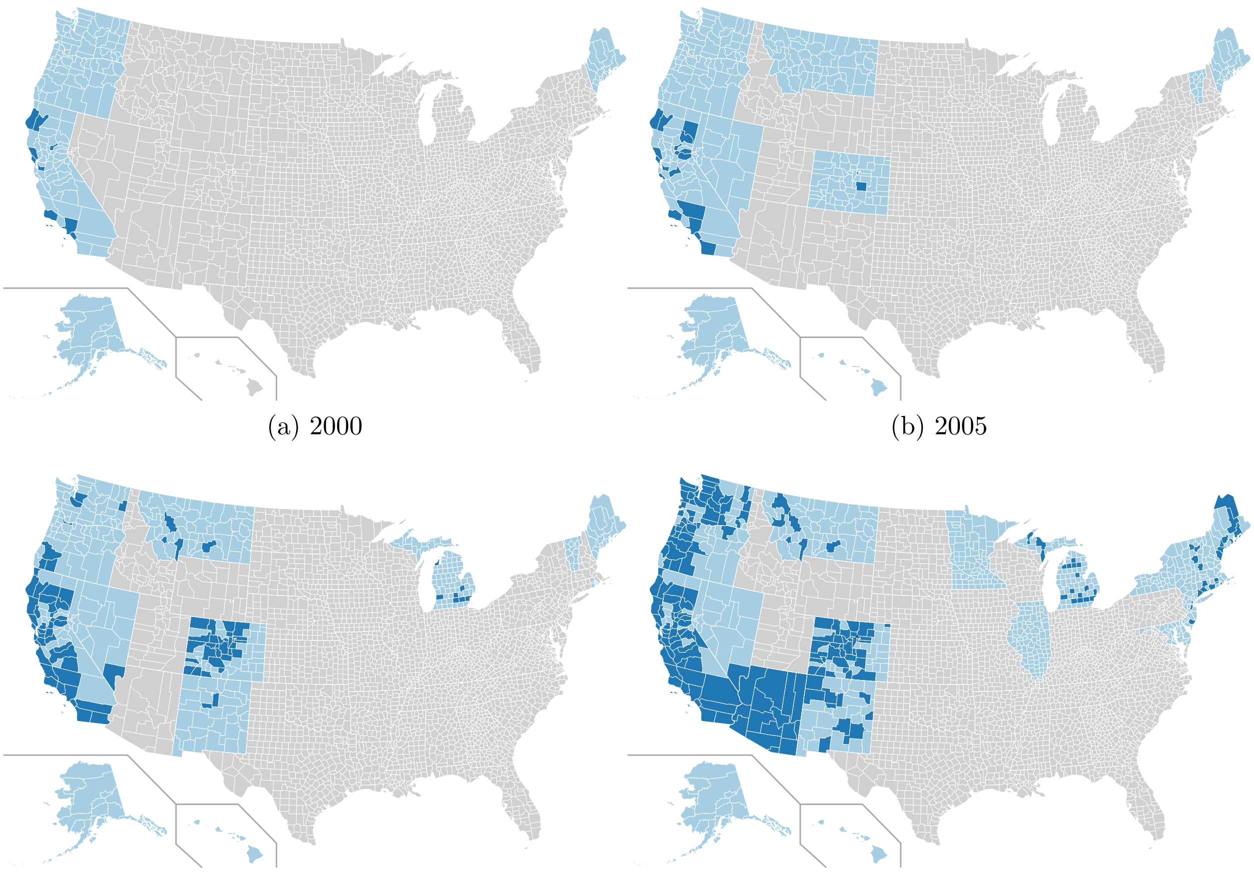
*Notes:* At least one dispensary must be present for the entire calendar year for a county to be considered a dispensary county.

due to synthetic opioid overdoses started increasing in 2013. In the last year of our sample period, 2015, heroin was the most common drug involved in fatal overdoses, followed by synthetic opioids and prescription opioids.

We combine county-level mortality rates with dispensary information collected from multiple sources by Smith (2017). Within medical cannabis states, dispensary openings (and closings) are located using state registries, news articles, dispensary-locating websites, transaction reviews, social media accounts, and cannabis-friendly internet discussion boards.[5] We define a dispensary as any business that facilitates the transfer of cannabis for money. This definition includes gray-market establishments that operated in states prior to dispensary regulations being enacted.[6] The first dispensaries in California opened shortly after the enactment of the state's MCL in 1996. Colorado is the only other state to witness a dispensary opening prior to the rapid expansion in 2009 following the Ogden memorandum. In total, 220 counties across 15 states experienced a dispensary opening for an entire calendar year within the sample period. Table 1 shows the number of counties with operating dispensaries

[5] See Smith (2017) for details on the data collection.

[6] In contrast, Powell, Pacula, and Jacobson (2018) define operating and legally protected dispensaries on the state level.



(a) 2000 (b) 2005

(c) 2010 (d) 2015

Figure 2: Counties With MCL and Dispensaries.

*Notes:* Light blue counties are in states with an MCL and dark blue counties have at least one operating medical cannabis dispensary.

by state and year. Most states with an MCL exhibit a relatively slow diffusion of dispensary openings. By 2015, the majority of states only have dispensaries in a small fraction of counties.

Figure 2 shows states where MCL were in effect and counties that had at least one operating dispensary in 2000, 2005, 2010 and 2015. In 2000, only five states (California, Oregon, Washington, Alaska, and Maine) had legalized medical cannabis, and only a few counties in California had operating dispensaries. By 2005, a few more states had implemented an MCL, but dispensaries were still confined to California and two counties in Colorado. In 2010, after the Ogden Memorandum was issued, 13 states had legalized medical cannabis, but dispensaries were not operating in many counties outside of California and Colorado. Between 2010 and 2015, eight more states legalized medical cannabis, and in MCL states, dispensaries opened in almost 200 counties.

We combine the dispensary data with information on other relevant policies. Data on MCL are obtained from a database maintained by procon.org. We retrieve information on PDMP from Meinhofer (2017) and on naloxone access laws and Good Samaritan laws from Rees et al. (2017). We also add data on beer tax rates from the Beer Institute's Brewers' Almanac. Finally, we obtain county-level unemployment rates from the Local Area Unemployment Statistics of the Bureau of Labor Statistics and county population data from the Surveillance, Epidemiology, and End Results Program of the National Cancer Institute.

# 3 Empirical Strategy

Figure 2 illustrates the geographic (within and across states) and temporal variation within counties that we use to determine the effect of dispensaries on opioid-related mortality. Most states that legalized medical cannabis had counties with and without operating dispensaries, and these dispensaries opened at different points in time. We use this source of variation to implement a county-level difference-in-differences framework to estimate the causal impact of dispensaries on opioid overdose mortality. In addition to county fixed effects that control for time-invariant differences across counties, we include state-specific time trends to account for the varying severity of the opioid epidemic. We also control for other policies aimed at reducing opioid overdoses and economic conditions.

To focus on the role of dispensaries beyond the legal status of medical cannabis, we restrict the sample to counties that were located in states that had implemented an MCL before 2014. California is also omitted because the first dispensaries open there prior to our sample period and cannabis delivery services are significantly more prevalent in California than in other MCL states. In robustness checks, we include counties in states that did not have an MCL during the sample period and California.

We estimate the effect of medical cannabis dispensaries on opioid overdose mortality using a Poisson regression model. Modeling county-level mortality as a Poisson process instead of using an ordinary least squares regression is appropriate for two reasons. First, our outcome variables contain many zeros. For example, 47% of county-year-level observations do not experience an opioid-related death. Second, opioid overdose mortality is highly skewed with a median of one death and a 99th percentile of 49 deaths per county and year. Using mortality rates instead of levels as the outcome variable could have been an alternative, but this would not change the large number of zeros. Moreover, mortality rates are also highly skewed distribution. Deaths due to any opioids per 100,000 population have a median of 4.6 and a 99th percentile of 76, for instance.

We specify the following Poisson regression model:

$$E[Y_{cst}] = \exp\left(\theta D_{ct} + pol'_{st}\beta + \gamma ue_{ct} + \ln(pop_{ct}) + \alpha_c + \delta_t + \mu_s \times t\right), \tag{1}$$

where $E[Y_{cst}]$ is the expected number of opioid-related deaths in county $c$, state $s$, and year $t$. $D_{ct}$ is a dummy variable that takes on the value one if a medical cannabis dispensary was operating in county $c$ in year $t$. The vector $pol_{st}$ includes policies that vary on the state level (MCL, PDMP, naloxone access laws, Good Samaritan laws, Pill Mill Bills, and the beer tax rate). County-level average annual unemployment rates are included as $ue_{ct}$ to control for local level macroeconomic conditions, and $pop_{ct}$ is the non-Hispanic white male population aged 15 to 54 residing in county $c$ in year $t$. By setting the coefficient of $\ln(pop_{ct})$ to one we implicitly adjust mortality levels for the size of the population at risk. Finally, $\alpha_c$ is a county fixed effect, $\delta_t$ is a year fixed effect, and $\mu_s \times t$ is a state-specific linear time trend. We report the estimated coefficients as incidence rate ratios, i.e. $\exp\left(\hat{\theta}\right)$ etc., in the regression tables.

Since we include county fixed effects in the Poisson regression, we effectively drop counties that did not have any opioid-related deaths throughout the sample period (Cameron and Trivedi, 2005, p. 806). For overdose deaths related to any opioid, this exclusion affects 35 counties, out of which 2 had an operating medical cannabis dispensary. Mean population size in the excluded counties is 847. It is therefore unlikely that excluding these counties from the analysis has a substantial effect on the estimates. We nevertheless test the robustness of our results by estimating our main specification with county random effects instead of fixed effects, which allows us to include counties that never any experienced opioid-related mortality during the sample period.

# 4 Results

## 4.1 Main Results

We first provide graphical evidence on the effect of medical cannabis dispensaries on opioid overdose mortality. Specifically, we consider changes in unconditional mortality rates between 2009 and 2015 in counties that did not have a dispensary in 2009. As shown in Table 1, the period from 2009 to 2015 experienced the highest number of dispensary openings. While opioid mortality rates likely increased in all counties during this period, we are interested in whether this mortality growth was slower in counties with operating cannabis dispensaries.

Figure 3 shows that counties where a dispensary opened between 2009 and 2015 indeed

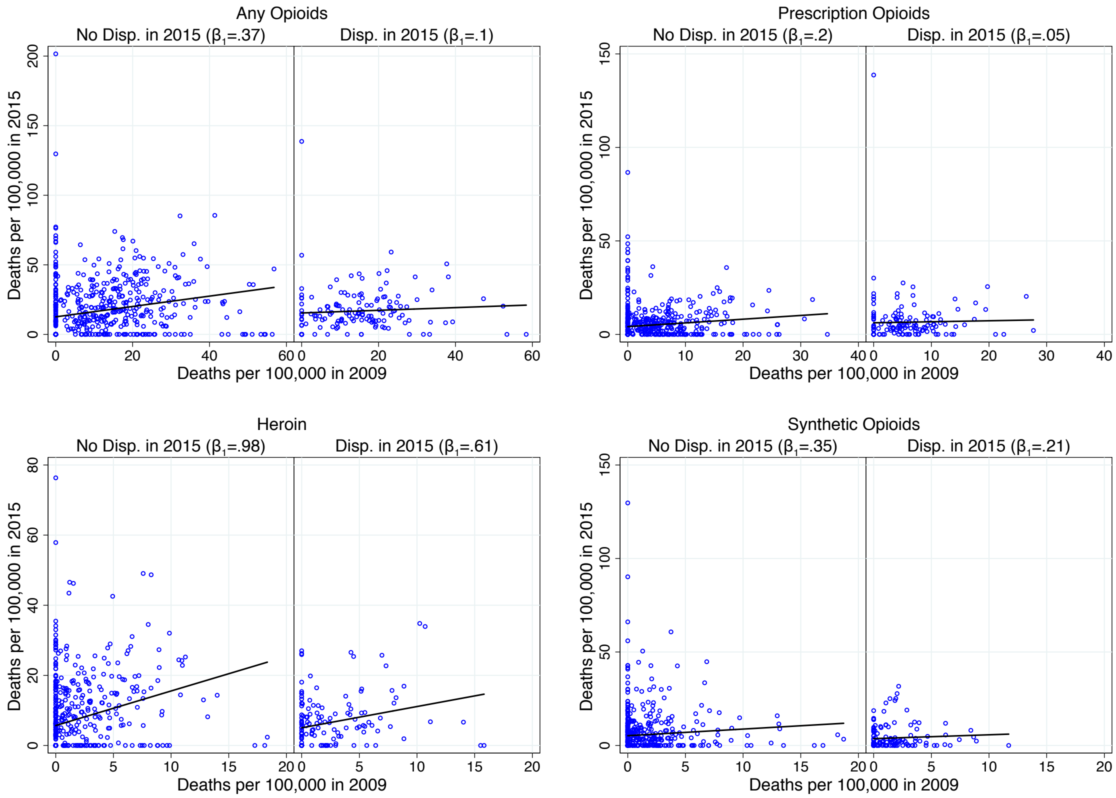



Figure 3: Mortality Rates Due to Opioid Overdoses Among Non-Hispanic White Men.

*Notes:* Each observation corresponds to one county. Only counties that did not have a medical cannabis dispensary in 2009 are included. The left panels refer to counties that did not have a dispensary in 2015 and the right panels refer to counties where at least one dispensary opened between 2009 and 2015. The lines indicate the best linear fit. The $\beta_1$s in the panel headings show the estimated slope coefficients of the respective fit lines.

experienced slower growth in mortality than counties that continued not having a dispensary. On average, the mortality rate due to any opioid overdose increased by 0.07 per 100,000 population in dispensary-counties between 2009 and 2015 and by 0.37 in counties without a dispensary as indicated by the respective slope coefficients of the best linear fit. The difference between the slope coefficients is statistically significant with $p = 0.01$. Prescription opioid mortality rates increased by 0.05 in dispensary-counties and rose by 0.2 in non-dispensary counties ($p = 0.25$). For heroin overdoses, mortality rates increased by 0.61 and 0.98 per 100,000 population in counties with and without dispensaries, respectively ($p = 0.06$). For synthetic opioid overdoses, the respective average changes were 0.2 for dispensary-counties and 0.35 for counties without dispensaries ($p = 0.50$). The graphs overall suggest that opioid overdose mortality increased slower in counties where a medical cannabis dispensary opened than in counties without dispensaries. Aside from displaying a steeper relationship between

2009 and 2015 mortality rates, Figure 3 also shows that counties without a dispensary had higher overdose deaths rates on an absolute level. For instance, many more counties without a dispensary had any-opioid mortality rates exceeding 50 per 100,000 population in 2015 than counties where a dispensary was operational.

Table 2 shows our main regression results. The coefficients from the Poisson regressions are reported as incidence rate ratios, i.e. an estimate below one implies that the corresponding regressor reduces mortality. For each mortality outcome, we estimate two separate regressions. The first specification includes dummy variables for medical cannabis dispensaries and policies that aim to reduce opioid mortality (PDMP, naloxone access laws, and Good Samaritan laws) whereas the second specification also contains a dummy variable for MCL. The dispensary coefficient in the first set of regressions measures the average marginal effect of an operating dispensary compared to counties that did not have a dispensary independent of whether there was an effective MCL. In contrast, in the second set of regressions, the dispensary coefficient indicates the effect of a dispensary conditional on the legal status of medical cannabis. Notice that we only include counties in this regression where medical cannabis was legalized at some point between 2009 and 2015.

The regression results show that operating medical cannabis dispensaries generally reduce mortality due to opioid overdoses. These effects are similar across the two specifications, i.e. independent of whether we also control for the legal status of medical cannabis. The average reduction in overdose mortality due to medical cannabis dispensaries equals 8.2% for any opioids, 9.3% for prescription opioids, and 10.5% for heroin. Conditional on MCL status, counties with dispensaries have 6.1% fewer deaths due to any opioid, 8.6% lower mortality levels related to prescription opioids, and a 10.1% reduction in heroin-induced mortality compared to counties without a dispensary. These estimates are statistically significant at least at the 5% level for any and prescription opioids and at or close to the 10% level for heroin ($p = 0.083$ and $p = 0.103$, respectively). In contrast, medical cannabis dispensaries have no statistically significant effect on synthetic opioid overdose mortality. MCL themselves have a positive effect on opioid-related mortality. Mortality due to any opioid, prescription opioids, and synthetic opioids is 25.9%, 12.0%, and 21.3% higher in counties where medical cannabis is legalized. Heroin-related mortality is a notable exception in that it is not affected by MCL in a statistically significant manner. The joint effect of legalizing medical cannabis and providing access through dispensaries on heroin overdose mortality is therefore negative overall. While legalizing medical cannabis does not lower opioid overdose mortality, the presence of dispensaries has a large negative impact on the number of opioid-related deaths. This effect is particularly strong for heroin overdoses, which have not been successfully

Table 2: Poisson Regression Results for Opioid Overdose Mortality – Main Results

| | Any Opioid | | Prescription Opioids | | Heroin | | Synthetic Opioids | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| County Dispensary | 0.918*** | 0.939** | 0.907** | 0.914** | 0.895* | 0.899 | 0.992 | 1.003 |
| | (0.0297) | (0.0285) | (0.0403) | (0.0389) | (0.0572) | (0.0588) | (0.0719) | (0.0740) |
| Medical Marijuana Law | | 1.259*** | | 1.120** | | 1.055 | | 1.213** |
| | | (0.0454) | | (0.0576) | | (0.0629) | | (0.108) |
| Prescription Drug Monitoring Program | 1.078 | 1.070 | 1.020 | 1.012 | 1.138 | 1.134 | 1.076 | 1.068 |
| | (0.0512) | (0.0466) | (0.0490) | (0.0488) | (0.111) | (0.110) | (0.105) | (0.102) |
| Naloxone Access Law | 1.022 | 1.083* | 0.934 | 0.961 | 0.958 | 0.974 | 1.096 | 1.144 |
| | (0.0501) | (0.0520) | (0.0526) | (0.0514) | (0.0644) | (0.0664) | (0.116) | (0.112) |
| Good Samaritan Law | 1.106* | 1.021 | 1.083 | 1.043 | 1.205 | 1.189 | 0.939 | 0.874 |
| | (0.0648) | (0.0582) | (0.0626) | (0.0626) | (0.150) | (0.149) | (0.124) | (0.110) |
| Number of counties | 533 | 533 | 517 | 517 | 492 | 492 | 498 | 498 |
| Observations | 9,036 | 9,036 | 8,764 | 8,764 | 8,344 | 8,344 | 8,441 | 8,441 |
| Mean of the outcome | 5.747 | 5.747 | 1.842 | 1.842 | 1.808 | 1.808 | 0.757 | 0.757 |

*Notes:* This table shows incidence rate ratios (exponentiated coefficients) along with standard errors from Poisson regressions of county-year-level counts of opioid overdose deaths among non-Hispanic white men aged 15 to 54 as the dependent variables. All regressions include the county-level annual unemployment rate, the beer tax rate, county fixed effects, log-population, year fixed effects, and state-specific linear time trends. The coefficient on log-population is set to one. The sample consists of counties located in states that legalized medical cannabis before 2015, excluding California, and the sample period ranges from 1999 to 2015. Standard errors are clustered on the county level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

lowered by any other policy. It is worth emphasizing that this effect would not have been captured with more aggregated data and it underscores the importance of a more granular approach to measure the impact of access to medical cannabis on opioid-related mortality.

Other policies that states have implemented to contain the opioid epidemic such as prescription drug monitoring programs, naloxone access laws, and Good Samaritan laws do not appear to reduce opioid-related deaths. In some instances, these policies may even be associated with increased opioid mortality rates. These results are consistent with the literature.[7]

Finally, we use the regression results shown in Table 2 to predict how many fewer non-Hispanic white men would have died between 2009 and 2015 if dispensaries had operated in more counties. Based on our estimation sample of counties where medical cannabis was legalized before 2014, we consider two alternative scenarios. Under the first exercise, we assume that dispensaries started to operate in all counties as soon as a statewide MCL was enacted. Under the second, the implementation of the MCL is assumed to have occurred in 2009 and we also assume that dispensaries open in all counties as soon as medical cannabis is legalized, i.e. in 2009. Thus, our counterfactual predictions do not change states' overall medical cannabis policies but only the timing of MCL implementations and dispensary openings.

The results in Table 3 show that for all types of drugs except synthetic opioids, predicted mortality is lower under the two alternative predictions than under actual dispensary and MCL status. For overdoses due to any opioid, opening dispensaries immediately after legalizing medical cannabis would have reduced the number of deaths by 9.7 per 100,000 population, and legalizing medical cannabis and opening dispensaries in 2009 in counties where medical cannabis was only legalized during part of the period would have prevented another 5.4 per 100,000 overdose deaths. For comparison, the mean annual mortality rate was 13.6 in these counties. For prescription opioids, the number of deaths would have declined by 3.5 plus 1.6 per 100,000 and for heroin by 5.3 plus 2.1 per 100,000. The latter decline exceeds the mean heroin mortality rate of 7.2 per 100,000 in 2015 when the number of heroin overdose deaths was highest. For synthetic opioids, mortality rates would have been slightly higher under the alternative predictions. Overall, these predictions show that substantially fewer non-Hispanic white men would have died between 2009 and 2015 if (1) all counties where medical cannabis was legal also had dispensaries and (2) the states that legalized medical cannabis before 2014 had done so by 2009.

[7]See for instance Paulozzi, Kilbourne, and Desai (2011); Rees et al. (2017); Doleac and Mukherjee (2018), and Li et al. (2014).

Table 3: Predicted Opioid Overdose Mortality per 100,000 Non-Hispanic White Males

| | MCL-Counties Without Disp. | | Partial-MCL-Counties | |
|---|---|---|---|---|
| | Actual Disp. | All Disp. | Actual MCL | All MCL and Disp. |
| | (1) | (2) | (3) | (4) |
| Any Opioids | 117.22 | 107.61 | 65.81 | 60.41 |
| Prescription Opioids | 37.89 | 34.35 | 18.11 | 16.42 |
| Heroin | 47.13 | 42.19 | 18.66 | 16.71 |
| Synthetic Opioids | 23.33 | 23.14 | 6.66 | 6.00 |
| Number of Counties | 449 | | 174 | |

*Notes:* This table shows the total predicted numbers of overdose deaths per 100,000 population among non-Hispanic white men for the years 2009 to 2015. The predictions are based on the regression results shown in Table 2, columns (1), (3), (5), and (7). The first two columns refer to county-year observations where an MCL was in effect but no dispensary was operating. Column (1) shows the predicted number of deaths under the actual dispensary status and column (2) shows predicted mortality under the counterfactual that these counties had an operating dispensary whenever medical cannabis was legalized. The last two columns refer to county-year observations where no MCL was in effect (among counties that had an MCL by 2014). Column (3) shows the predicted number of deaths under the actual MCL and dispensary status. The counterfactual in column (4) assumes that these counties had an MCL and an operating dispensary in all years.

## 4.2 Robustness Checks

We conduct four robustness checks for our main Poisson regression results. First, Table 4 shows regression results for the sample of all counties with at least one death related to the respective opioid (excluding California again) instead of limiting the sample to counties where medical cannabis was legalized between 1999 and 2015. In these regressions, medical cannabis dispensaries have no statistically significant effect on opioid overdose mortality, but the point estimates for prescription opioids and heroin point to a reduction in mortality due to dispensaries. Since these regressions include a majority of counties that cannot have a dispensaries because they are located in states that never legalized medical cannabis, we prefer our main results in Table 2 that focus on counties were a dispensary was legally possible at some point before 2015.

Second, we add counties in California, which legalized medical cannabis in 1996, i.e. before the start of our sample period. Table 5 shows statistically insignificant coefficients on county dispensary. For any opioids and heroin, the point estimates suggest a reduction in mortality, however. These less precisely estimated effects may be due to the fact that California mostly uses a delivery-based model for the sale of medical cannabis. Local effects on the county level are therefore less relevant. Since our focus is on local access to medical cannabis, we prefer our main results.

Third, we include quadratic state-specific time trends instead of linear time trends in the regression shown in Table 6. Due to the steep increase in opioid-related mortality in recent years, there is a concern that a linear time trend is unable to match this pattern and may therefore lead to biased estimates. We find, however, that the estimated coefficients in Table 6 do not differ substantially from our main regression results. In contrast to Table 2, we find a decline in mortality related to synthetic opioids, but it is not statistically significant. Overall, these results suggest that controlling for state-specific linear time trends is sufficient.

Finally, Table 7 shows regression results based on a random effects Poisson model instead of a Poisson regression that includes county fixed effects. The advantage of a random effects model is that it allows us for the small number of counties that did not experience any opioid-related mortality over our sample period, but it has the drawback that we need to assume independence of the random effects from the covariates entering the model. The results in Table 7 are slightly less precise than our main results, but overall we estimate similar coefficients. One difference is that we find larger and more precisely estimated effects of dispensaries on prescription opioid mortality.

# 5 Conclusion

As of now, no policy response has been successful in alleviating the opioid epidemic, the most common cause of accidental death in the United States. Policies have been particularly ineffective in reducing mortality due to heroin overdoses. Using a unique dataset of medical cannabis dispensaries, we examine the effect increased access to cannabis has on opioid- and heroin-related mortality rates at the county level.

With our more granular approach, we depart from prior literature and argue that changes in cannabis access drive the negative relationship between cannabis and opioids. We find that within MCL-adopting states, counties with dispensaries experience 6% to 8% fewer opioid-related deaths among non-Hispanic white men, while mortality due to heroin overdose declines by more than 10%. These effects are smaller than the 20% to 25% reductions in opioid-related mortality found by existing studies using a state-level approach (Bachhuber et al., 2014; Powell, Pacula, and Jacobson, 2018). While the geographical coverage and the sample periods in these studies prevent us from drawing direct comparisons, our granular approach can arguably better control for unobserved geographic heterogeneity, thereby bringing our results closer to a causal interpretation.

Extrapolating our results implies that, for every 100,000 non-Hispanic white men, 10 fewer opioid-induced fatalities would have occurred between 2009 and 2015 if dispensaries were present and operating in every county within each MCL state.

# References


Bachhuber, Marcus A., Brendan Saloner, Chinazo O. Cunningham, and Colleen L. Barry. 2014. "Medical Cannabis Laws and Opioid Analgesic Overdose Mortality in the United States, 1999-2010." *JAMA Internal Medicine* 174 (10):1668–1673.

Bradford, Ashley C. and W. David Bradford. 2016. "Medical Marijuana Laws Reduce Prescription Medication Use In Medicare Part D." *Health Affairs* 35 (7):1230–1236.

———. 2017. "Medical Marijuana Laws May Be Associated With A Decline In The Number Of Prescriptions For Medicaid Enrollees." *Health Affairs* 36 (5):945–951.

Bradford, Ashley C., W. David Bradford, Amanda Abraham, and Grace Bagwell Adams. 2018. "Association Between US State Medical Cannabis Laws and Opioid Prescribing in the Medicare Part D Population." *JAMA Internal Medicine* 178 (5):667–672.

Buchmueller, Thomas C. and Colleen Carey. 2018. "The Effect of Prescription Drug Monitoring Programs on Opioid Utilization in Medicare." *American Economic Journal: Economic Policy* 10 (1):77–112.

Cameron, A. Colin and Pravin K. Trivedi. 2005. *Microeconometrics. Methods and Applications.* New York: Cambridge University Press.

Case, Anne and Angus Deaton. 2015. "Rising Morbidity and Mortality in Midlife among White Non-Hispanic Americans in the 21st Century." *Proceedings of the National Academy of Sciences* 112 (49):15078–15083.

Chu, Yu-Wei Luke. 2015. "Do Medical Marijuana Laws Increase Hard-Drug Use?" *The Journal of Law and Economics* 58 (2):481–517.

Compton, Wilson M., Christopher M. Jones, and Grant T. Baldwin. 2016. "Relationship between Nonmedical Prescription-Opioid Use and Heroin Use." *New England Journal of Medicine* 374 (2):154–163.

Dave, Dhaval M., Anca M. Grecu, and Henry Saffer. 2017. "Mandatory Access Prescription Drug Monitoring Programs and Prescription Drug Abuse." NBER Working Paper 23537.

Doleac, Jennifer L. and Anita Mukherjee. 2018. "The Moral Hazard of Lifesaving Innovations: Naloxone Access, Opioid Abuse, and Crime." https://ssrn.com/abstract=3135264.

Fergusson, David M., Joseph M. Boden, and L. Horwood. 2006. "Testing the Cannabis Gateway Hypothesis: Replies to Hall, Kandel et Al. and MacCoun (2006)." *Addiction* 101 (4):474–476.

Finney, John W., Keith Humphreys, and Alex H.S. Harris. 2015. "What Ecologic Analyses Cannot Tell Us about Medical Marijuana Legalization and Opioid Pain Medication Mortality." *JAMA Internal Medicine* 175 (4):655–656.

Hall, Wayne and Michael Lynskey. 2005. "Is Cannabis a Gateway Drug? Testing Hypotheses about the Relationship between Cannabis Use and the Use of Other Illicit Drugs." *Drug and Alcohol Review* 24 (1):39–48.

Hall, Wayne, Robert West, John Marsden, Keith Humphreys, Jo Neale, and Nancy Petry. 2018. "It Is Premature to Expand Access to Medicinal Cannabis in Hopes of Solving the US Opioid Crisis." *Addiction* 113 (6):987–988.

Hurd, Yasmin L. 2017. "Cannabidiol: Swinging the Marijuana Pendulum From Weed to Medication to Treat the Opioid Epidemic." *Trends in Neurosciences* 40 (3):124–127.

Hurd, Yasmin L., Michelle Yoon, Alex F. Manini, Stephanie Hernandez, Ruben Olmedo, Maria Ostman, and Didier Jutras-Aswad. 2015. "Early Phase in the Development of Cannabidiol as a Treatment for Addiction: Opioid Relapse Takes Initial Center Stage." *Neurotherapeutics* 12 (4):807–815.

Kandel, Denise. 1975. "Stages in Adolescent Involvement in Drug Use." *Science* 190 (4217):912–914.

Li, Guohua, Joanne E. Brady, Barbara H. Lang, James Giglio, Hannah Wunsch, and Charles DiMaggio. 2014. "Prescription Drug Monitoring and Drug Overdose Mortality." *Injury Epidemiology* 1 (9):1–8.

Meinhofer, Anglica. 2017. "Prescription Drug Monitoring Programs: The Role of Asymmetric Information on Drug Availability and Abuse." *American Journal of Health Economics* online first.

Morral, Andrew R., Daniel F. McCaffrey, and Susan M. Paddock. 2002. "Reassessing the Marijuana Gateway Effect." *Addiction* 97 (12):1493–1504.

Ogden, David W. 2009. "Memorandum for Selected United States Attorneys."

Patrick, Stephen W., Carrie E. Fry, Timothy F. Jones, and Melinda B. Buntin. 2016. "Implementation Of Prescription Drug Monitoring Programs Associated With Reductions In Opioid-Related Death Rates." *Health Affairs* 35 (7):1324–1332.

Paulozzi, Leonard J., Edwin M. Kilbourne, and Hema A. Desai. 2011. "Prescription Drug Monitoring Programs and Death Rates from Drug Overdose." *Pain Medicine* 12 (5):747–754.

Pohl, R. Vincent. 2018. "Time Trends Matter: The Case of Medical Cannabis Laws and Opioid Overdose Mortality." https://ssrn.com/abstract=3192703.

Powell, David, Rosalie Liccardo Pacula, and Mireille Jacobson. 2018. "Do Medical Marijuana Laws Reduce Addictions and Deaths Related to Pain Killers?" *Journal of Health Economics* 58:29–42.

Rees, Daniel I., Joseph J. Sabia, Laura M. Argys, Joshua Latshaw, and Dhaval Dave. 2017. "With a Little Help from My Friends: The Effects of Naloxone Access and Good Samaritan Laws on Opioid-Related Deaths." NBER Working Paper 23171.

Robins, Lee N., John E. Helzer, Michie Hesselbrock, and Eric Wish. 2010. "Vietnam Veterans Three Years after Vietnam: How Our Study Changed Our View of Heroin." *American Journal on Addictions* 19 (3):203–211.

Ruhm, Christopher J. 2018. "Corrected US Opioid-Involved Drug Poisoning Deaths and Mortality Rates, 1999-2015: Corrected Opioid-Involved Mortality Rates." *Addiction* 113 (7):1339–1344.

Smith, Rhet A. 2017. "The Effects of Medical Marijuana Dispensaries on Adverse Opioid Outcomes." https://ssrn.com/abstract=3012381.

Van Gundy, Karen and Cesar J. Rebellon. 2010. "A Life-Course Perspective on the "Gateway Hypothesis"." *Journal of Health and Social Behavior* 51 (3):244–259.

Wen, Hefei and Jason M. Hockenberry. 2018. "Association of Medical and Adult-Use Marijuana Laws With Opioid Prescribing for Medicaid Enrollees." *JAMA Internal Medicine* 178 (5):673–679.

Table 4: Poisson Regression Results for Opioid Overdose Mortality – Including Counties in Non-MCL States

| | Any Opioid | | Prescription Opioids | | Heroin | | Synthetic Opioids | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| main | | | | | | | | |
| County Dispensary | 1.019 | 1.017 | 1.000 | 0.998 | 0.923 | 0.923 | 1.081 | 1.075 |
| | (0.0299) | (0.0297) | (0.0390) | (0.0394) | (0.0573) | (0.0572) | (0.0845) | (0.0851) |
| Medical Marijuana Law | | 1.298*** | | 1.146*** | | 1.023 | | 1.150** |
| | | (0.0467) | | (0.0564) | | (0.0421) | | (0.0817) |
| Prescription Drug Monitoring Program | 0.955* | 0.948** | 0.942* | 0.938** | 1.008 | 1.006 | 1.057 | 1.052 |
| | (0.0264) | (0.0243) | (0.0301) | (0.0296) | (0.0490) | (0.0491) | (0.0496) | (0.0491) |
| Naloxone Access Law | 1.089*** | 1.086*** | 1.066* | 1.062* | 0.945 | 0.945 | 1.135** | 1.128** |
| | (0.0343) | (0.0343) | (0.0393) | (0.0382) | (0.0379) | (0.0378) | (0.0613) | (0.0616) |
| Good Samaritan Law | 1.090*** | 1.045 | 0.988 | 0.974 | 1.240*** | 1.238*** | 1.011 | 0.990 |
| | (0.0344) | (0.0319) | (0.0395) | (0.0374) | (0.0663) | (0.0653) | (0.0573) | (0.0557) |
| Number of counties | 2,816 | 2,816 | 2,705 | 2,705 | 2,536 | 2,536 | 2,603 | 2,603 |
| Observations | 47,833 | 47,833 | 45,946 | 45,946 | 43,078 | 43,078 | 44,212 | 44,212 |
| Mean of the outcome | 3.630 | 3.630 | 1.468 | 1.468 | 1.042 | 1.042 | 0.542 | 0.542 |

*Notes:* See notes to Table 2. The sample for the regressions in this table includes all counties with at least one death related to the respective opioid between 1999 and 2015 (excluding California).

Table 5: Poisson Regression Results for Opioid Overdose Mortality – Including Californian Counties

| | Any Opioid | | Prescription Opioids | | Heroin | | Synthetic Opioids | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| County Dispensary | 0.976 | 0.983 | 1.008 | 1.010 | 0.964 | 0.965 | 1.044 | 1.045 |
| | (0.0338) | (0.0324) | (0.0495) | (0.0492) | (0.0782) | (0.0778) | (0.0633) | (0.0639) |
| Medical Marijuana Law | | 1.268*** | | 1.112** | | 1.074 | | 1.244** |
| | | (0.0467) | | (0.0592) | | (0.0633) | | (0.111) |
| Prescription Drug Monitoring Program | 1.087* | 1.070 | 0.994 | 0.983 | 1.157 | 1.148 | 1.094 | 1.079 |
| | (0.0512) | (0.0457) | (0.0522) | (0.0511) | (0.114) | (0.112) | (0.103) | (0.0983) |
| Naloxone Access Law | 1.110*** | 1.132*** | 1.048 | 1.055 | 1.005 | 1.018 | 1.246*** | 1.270*** |
| | (0.0417) | (0.0390) | (0.0456) | (0.0454) | (0.0568) | (0.0572) | (0.103) | (0.0981) |
| Good Samaritan Law | 1.056 | 1.010 | 1.071 | 1.055 | 1.166 | 1.156 | 0.843 | 0.803** |
| | (0.0562) | (0.0539) | (0.0684) | (0.0714) | (0.121) | (0.118) | (0.0965) | (0.0875) |
| Number of counties | 590 | 590 | 574 | 574 | 549 | 549 | 555 | 555 |
| Observations | 10,005 | 10,005 | 9,733 | 9,733 | 9,313 | 9,313 | 9,410 | 9,410 |
| Mean of the outcome | 6.503 | 6.503 | 2.345 | 2.345 | 1.979 | 1.979 | 0.802 | 0.802 |

*Notes:* See notes to Table 2. The sample for the regressions in this table includes all counties in states that implemented an MCL before 2015 and with at least one death related to the respective opioid between 1999 and 2015.

Table 6: Poisson Regression Results for Opioid Overdose Mortality – Quadratic Time Trends

| | Any Opioid | | Prescription Opioids | | Heroin | | Synthetic Opioids | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| County Dispensary | 0.980 | 0.985 | 0.923* | 0.927* | 0.905 | 0.906 | 0.970 | 0.970 |
| | (0.0263) | (0.0256) | (0.0414) | (0.0406) | (0.0550) | (0.0559) | (0.0621) | (0.0623) |
| Medical Marijuana Law | | 1.142*** | | 1.094 | | 1.067 | | 1.073 |
| | | (0.0457) | | (0.0647) | | (0.0709) | | (0.127) |
| Prescription Drug Monitoring Program | 1.129*** | 1.127*** | 1.051 | 1.050 | 1.085 | 1.084 | 1.057 | 1.057 |
| | (0.0452) | (0.0433) | (0.0575) | (0.0581) | (0.0915) | (0.0901) | (0.109) | (0.109) |
| Naloxone Access Law | 1.114*** | 1.148*** | 1.008 | 1.030 | 0.996 | 1.008 | 1.117 | 1.129 |
| | (0.0440) | (0.0438) | (0.0547) | (0.0528) | (0.0624) | (0.0663) | (0.131) | (0.124) |
| Good Samaritan Law | 0.932 | 0.895** | 1.044 | 1.015 | 0.954 | 0.947 | 0.923 | 0.898 |
| | (0.0543) | (0.0475) | (0.0667) | (0.0669) | (0.112) | (0.115) | (0.139) | (0.124) |
| Number of counties | 533 | 533 | 517 | 517 | 492 | 492 | 498 | 498 |
| Observations | 9,036 | 9,036 | 8,764 | 8,764 | 8,344 | 8,344 | 8,441 | 8,441 |
| Mean of the outcome | 5.747 | 5.747 | 1.842 | 1.842 | 1.808 | 1.808 | 0.757 | 0.757 |

*Notes:* See notes to Table 2. Instead of linear state-specific time trends, the regressions in this table contain quadratic state-specific time trends.

Table 7: Poisson Regression Results for Opioid Overdose Mortality – County Random Effects

| | Any Opioid | | Prescription Opioids | | Heroin | | Synthetic Opioids | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| County Dispensary | 0.949 | 0.918** | 0.891** | 0.873*** | 0.917 | 0.909 | 1.014 | 0.974 |
| | (0.0347) | (0.0313) | (0.0408) | (0.0432) | (0.0651) | (0.0613) | (0.0789) | (0.0695) |
| Medical Marijuana Law | 1.267*** | | 1.147*** | | 1.087 | | 1.275** | |
| | (0.0415) | | (0.0538) | | (0.0575) | | (0.125) | |
| Prescription Drug Monitoring Program | 0.996 | 0.977 | 0.886 | 0.875 | 0.872 | 0.867 | 1.007 | 0.968 |
| | (0.0668) | (0.0907) | (0.0686) | (0.0855) | (0.203) | (0.208) | (0.0945) | (0.102) |
| Naloxone Access Law | 1.115** | 1.046 | 1.055 | 1.014 | 1.025 | 0.999 | 1.202* | 1.117 |
| | (0.0583) | (0.0529) | (0.0826) | (0.0744) | (0.0886) | (0.0854) | (0.115) | (0.118) |
| Good Samaritan Law | 0.984 | 1.063 | 0.957 | 0.994 | 1.187 | 1.210 | 0.840 | 0.907 |
| | (0.0626) | (0.0734) | (0.0654) | (0.0664) | (0.152) | (0.156) | (0.128) | (0.148) |
| Number of counties | 567 | 567 | 567 | 567 | 567 | 567 | 567 | 567 |
| Observations | 9,608 | 9,608 | 9,608 | 9,608 | 9,608 | 9,608 | 9,608 | 9,608 |
| Mean of the outcome | 5.405 | 5.405 | 1.681 | 1.681 | 1.570 | 1.570 | 0.665 | 0.665 |

*Notes:* See notes to Table 2. Instead of county fixed effects, the regressions in this table contain county random effects.