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ABSTRACT

Recent studies have concluded that state laws legalizing medical marijuana can reduce deaths from opioid overdoses. Using data from the National Survey on Drug Use and Health, a survey uniquely suited to assessing drug misuse, we examine the relationship between recreational marijuana laws (RMLs) and the use of opioids. Standard difference-in-differences (DD) regression estimates indicate that RMLs do not affect the likelihood of misusing prescription pain relievers such as OxyContin, Percocet, and Vicodin. Although DD regression estimates provide evidence that state laws legalizing recreational marijuana can reduce the frequency of misusing prescription pain relievers, event-study estimates are noisy and suggest that any effect on the frequency of misuse is likely transitory.

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1. INTRODUCTION

Prescription pain reliever misuse, particularly of opioid analgesics, constitutes a major public health crisis in the United States. Approximately 10 million Americans misuse opioid analgesics every year; overdose deaths, hospitalizations, and emergency department admissions involving opioid analgesics are placing a substantial strain on health care delivery systems across the country (Florence et al., 2016; Hagemeier, 2018; McCance-Katz, 2020). Moreover, there is evidence that the misuse of prescription opioids can lead to the use of more potent, but less expensive, "street opioids" such as heroin and illicit fentanyl, greatly increasing the risk of lethal overdose (Rudd et al., 2016; Alpert et al., 2018).

In an effort to combat the misuse of opioid analgesics and related harms, states have implemented prescription drug monitoring programs (Ali et al., 2017) and passed naloxone access and Good Samaritan laws (McClellan et al., 2018; Abouk et al., 2019; Rees et al., 2019); abuse-deterrent formulations of oxycodone and hydrocodone were introduced in 2010 and 2014, respectively (Gasior et al., 2016; Wolff et al., 2020). Although the initial push for states to legalize the use of marijuana for medicinal purposes was not in response to the opioid epidemic, recent studies have produced evidence of a negative relationship between medical marijuana laws (MMLs) and deaths involving opioids (Bachhuber et al., 2014; Powell et al., 2018; Chan et al., 2020). State policymakers have, with some frequency, referred to these studies when explaining their support for legalizing both medical and recreational marijuana (Sfondeles, 2018; Taylor, 2019; Wang, 2018).

To date, recreational marijuana laws (RMLs) have been adopted by 18 states and the District of Columbia (Table 1). Unlike most MMLs, RMLs do not require a doctor's

recommendation as a condition of possessing and using marijuana; adults can cultivate marijuana at home or purchase it at a recreational dispensary upon showing proof of age.[1]

RMLs are associated with fewer deaths involving opioids (Bachhuber et al., 2014; Powell et al., 2018; Chan et al., 2020), suggesting that marijuana and opioids are treated as substitutes. There is also strong evidence that young adults treat alcohol and marijuana as substitutes (DiNardo and Lemieux, 2001; Crost and Guerrero, 2012; Anderson et al., 2013; Kelly and Rasul, 2014; Sabia et al., 2017; Dragone et al., 2019; Baggio et al., 2020; Miller and Seo, forthcoming). Because overdoses can involve multiple substances (Scholl et al., 2019), and because the combination of alcohol and opioids is especially deadly (Koski et al., 2003; Jones et al., 2014), it is possible that RMLs are related to deaths involving opioids through their effects on alcohol consumption and binge drinking.[2]

This is the first study to examine the relationship between RMLs and the misuse of opioids (i.e., using an opioid in a way not directed by a doctor) as opposed to opioid-related mortality or the prescribing of opioids. Our data cover the period 2004-2018 and come from the National Survey on Drug Use and Health (NSDUH), which is uniquely suited to exploring the determinants of substance use. NSDUH respondents are asked a series of questions about their substance use, the answers to which allow us to estimate a first-stage equation−that is, we estimate the association between RMLs and the consumption of marijuana. Answers to the NSDUH questions on substance use also allow us to examine what can be thought of as second-

[1] All but three RMLs allow marijuana plants to be grown at home (Anderson and Rees forthcoming). In Illinois, New Jersey, and Washington, home cultivation of recreational marijuana is prohibited. In Washington DC, home cultivation is allowed, but its RML prohibits the exchange of money, goods, or services for marijuana; transfers of up to an ounce of marijuana, however, are legal.

[2] If, for instance, gaining legal access to marijuana for recreational purposes reduced binge drinking, it could be associated with fewer deaths involving opioids even if opioid use did not change.

stage indirect outcomes, including the use of prescription pain relievers, heroin, and alcohol. To our knowledge, the NSDUH is the only U.S. micro data that contains information on both marijuana and opioid use among adults.

Standard difference-in-differences (DD) regression estimates provide evidence that RMLs increase the consumption of marijuana. For instance, RML adoption is associated with a 48 percent increase in past-month marijuana use and a 36 percent increase in past-year marijuana use. DD regression estimates also provide evidence that the legalization of medical marijuana discourages alcohol consumption, a pattern of results that could, at least in part, explain the negative association between MMLs and opioid-related deaths found by previous researchers such as Bachhuber et al. (2014) and Powell et al. (2018). By contrast, the estimated effects of RMLs on alcohol consumption are generally positive, although often imprecise.

Finally, our results with regard to the misuse of opioids are decidedly mixed. We find little evidence that RMLs affect the likelihood of misusing prescription pain relievers such as OxyContin, Percocet, and Vicodin. Although our DD estimates suggest that legalizing recreational marijuana may reduce the frequency of opioid misuse, our event-study estimates are imprecise and noisy. Moreover, they suggest that any reduction in the frequency of opioid misuse is quite transitory: two to three years after RML-adoption, the estimated effects on frequency become positive.

2. BACKGROUND

2.1. The opioid overdose crisis

The misuse of opioids has become an urgent public health concern over the course of the last two decades. Drug overdose deaths involving opioids have increased more than five-fold

since 2000, exceeding 65,000 by 2017 (Ahmad et al., 2018) and resulting in over 1.6 million years of life lost in 2016 alone (Gomes et al., 2018).

The opioid overdose crisis was initially driven by the misuse of prescription opioids (Dhalla et al., 2011). Mortality related to the misuse of prescription opioids plateaued in 2010 (Dart et al., 2015), but heroin deaths sustained the upward trend in opioid-related mortality (Compton et al. 2016). After 2013, the introduction of inexpensive synthetic opioids, particularly illicit fentanyl, drove opioid-related mortality to record highs (Iwanicki et al., 2018), prompting state lawmakers to consider the adoption of alternative policies, including legalizing recreational marijuana (Voelker, 2018).

Estimates of past-month/past-year prescription opioid misuse based on NSDUH data do not exhibit an upward trend through 2010 (Substance Abuse and Mental Health Services Administration (SAMHSA), 2017), leading Jones (2017) to argue that the increase in opioid-related mortality during the first stage of the crisis may have been driven by riskier use. There is, in fact, evidence from the NSDUH that the intensity of prescription opioid misuse increased during this period (Jones 2017), lending support to this argument. Since 2011, prescription opioid misuse has decreased steadily in the NSDUH, while heroin use and heroin dependency have surged (Marsh et al., 2018; Kertesz and Gordon, 2019).

2.2. Legalizing recreation marijuana

The legalization of recreational marijuana is a relatively recent phenomenon. In November of 2012, Colorado and Washington became the first states to adopt RMLs; recreational dispensaries, or "pot shops," did not open in these states until 2014. Writing shortly before recreational dispensaries in Colorado and Washington opened, Anderson and Rees

(2014a, p. 222) predicted that "legalizing the recreational use of marijuana is likely to improve public health." This prediction was based on what they described as "clearly defined natural experiments," the results of which suggested that alcohol and marijuana are substitutes, at least among young adults.[3]

Six years later, several studies have examined the public health consequences of legalizing recreational, as opposed to medical, marijuana (Cerdá et al., 2017; Kerr et al., 2017; Chan et al. 2020; Hollingsworth et al., 2020). For instance, using Monitoring the Future (MTF) data for the period 2010-2015, Cerdá et al. (2017) found that marijuana use increased among 8th, 10th and 12th graders in Colorado after the legalization of recreational marijuana;[4] Kerr et al. (2017) found that marijuana use among Oregon college undergraduates increased after the legalization of recreational marijuana; and Chan et al. (2020) found that allowing the sale of marijuana for recreational purposes was associated with a sharp reduction in opioid-related mortality.[5] This latter result is consistent with those from earlier studies showing a negative association between MMLs and opioid-related mortality (Bachhuber et al., 2014; Powell et al., 2018) and suggests that marijuana and opioids are substitutes.

[3] Specifically, Anderson and Rees (2014a) cited DiNardo and Lemieux (2001), Crost and Guerrero (2012), and Anderson et al. (2013). Since the publication of Anderson and Rees (2014a), additional evidence that alcohol and marijuana are substitutes has been produced (Kelly and Rasul, 2014; Sabia et al. 2017; Miller and Seo, 2018; Baggio et al., 2020), although it is worth noting that, using NSDUH data, Wen et al. (2015) found a positive relationship between MMLs and alcohol consumption. This relationship is revisited below using NSDUH data and alternative strategies for measuring the legalization of medical marijuana.

[4] By contrast, there was no change in marijuana use among 8th, 10th and 12th graders in Washington.

[5] Chan et al. (2020) excluded 23 states and the district of Columbia from their main analysis, making it difficult to compare their results to those of other studies such as Shover et al. (2019), who found that RML adoption was associated with a (statistically insignificant) 14 percent decrease in opioid-related mortality.

Hollingsworth et al. (2020), who analyzed NSDUH data for the period 2001-2002 through 2016-2017, found that RMLs were associated with a 15-16 percent increase in past-month marijuana use among young adults and a 13-15 percent increase among teenagers. By contrast, there was little evidence that legalizing recreational marijuana led to changes in alcohol or tobacco use.[6] Although Hollingsworth et al. (2020) used data from the NSDUH, they did not have access to the restricted NSDUH micro data and were instead forced to rely on published averages at the state level based on adjacent years of the NSDUH microdata; if legalization took effect in the second of these adjacent years, their RML indicator took on a value of zero. For example, the Oregon RML took effect on July 1, 2015. Hollingsworth et al. coded Oregon as untreated in 2014-2015 and treated in 2015-2016, potentially biasing their coefficients towards zero.

2.3. Legalizing medical marijuana

To date, 36 states, the District of Columbia, and Puerto Rico have legalized the use of marijuana for medicinal purposes. Unlike RMLs, MMLs are quite heterogeneous. For instance, licensed patients typically have the option of buying marijuana from retail establishments, known as dispensaries, either by themselves or designating a caregiver to do so on their behalf. However, not all states provide legal protections for dispensaries and many states explicitly prohibit patients from growing their own marijuana at home (Powell et al., 2018).

Previous studies provide evidence that MMLs can impact a variety of outcomes, including alcohol consumption, traffic fatalities, workplace fatalities, and even violent crimes

[6] Hollingsworth et al. (2020) also found evidence, albeit tentative, that legalizing recreational marijuana increases the use of cocaine. Taken at face value, these estimates are consistent with the hypothesis that marijuana and cocaine are complements.

such as assaults and homicides (Anderson et al., 2013; Chu, 2014, 2015; Morris et al., 2014; Hasin et al., 2017; Pacula et al., 2015; Wen et al., 2015; Anderson et al., 2019).[7] At least two studies have found a negative association between opioid-related deaths and MMLs (Bachhuber et al., 2014; Powell et al., 2018), a result that provides evidence that marijuana and opioids are substitutes: as patients gain access to legal (and less expensive) marijuana, their demand for prescription opioids and heroin goes down.[8] Additional evidence for this interpretation comes from studies showing a negative association between opioid prescribing and the legalization of marijuana (Bradford and Bradford, 2016, 2017; Ozluk, 2017; Bradford et al., 2018; Wen and Hockenberry, 2018; McMichael et al., 2020), but prescribing opioids is not the same thing as using (or misusing) opioids, and it is possible that the negative association between legalization and opioid prescribing is driven by concurrent policies, such as increasing naloxone availability or expanding insurance coverage (Shover et al., 2019, p. 12626).

3. DATA AND METHODS

Our analysis draws upon micro data from the National Survey on Drug Use and Health (NSDUH) for the period 2004-2018. The NSDUH is a survey of non-institutionalized individuals over the age of 11, and is used by the Substance Abuse and Mental Health Services

[7] Interestingly, we do not know as much about the effects of MMLs on the use of marijuana. Several studies have shown that MMLs are essentially unrelated to the use of marijuana by teenagers (Anderson et al., 2015; Hasin et al., 2015; Keyes et al., 2016; Sarvet et al., 2018; Anderson et al., 2019), but, because of data limitations, far fewer studies have examined the association between legalization and the use of marijuana by adults. Chu (2014) showed that the adoption of an MML was associated with a 15-20 percent increase in marijuana arrests among adult males. Wen et al. (2015) and Hasin et al. (2017) also provide evidence that legalizing medical marijuana encourages marijuana use among adults.

[8] Anderson et al. (2013) showed that MMLs substantially reduce the price of high-quality marijuana in the recreational market, a result that lends support to the often-voiced fear that medical marijuana will be diverted to the recreational market (Reed, 2018; International Narcotics Control Board, 2019).

Administration (SAMHSA) to produce official, representative estimates of drug use at both the state and national levels. Throughout the analysis, the focus is on adults; our sample is restricted to NSDUH respondents 19 years of age and over.

The outcomes under study pertain to the use/abuse of 4 substances: marijuana, prescription pain relievers such as such as OxyContin, Percocet, and Vicodin (i.e., opioid analgesics), heroin, and alcohol. For each of these substances, the NSDUH asks its respondents about use in the past month, use in the past year, and past-year dependency (i.e., whether the respondent had a substance use disorder). If the respondent was an active user, he or she is also asked about frequency of use during the past year.[9]

Two previous studies have explored the relationship between legalizing medical marijuana and the misuse of prescription opioids using NSDUH data (Wen et al., 2015; Segura et al., 2019). Although neither study found evidence that legalization increased abuse, both were

[9] Specifically, for marijuana, alcohol and heroin use, respondents were asked: "How long has it been since you last used [substance]? Within 30 days, more than 30 days but within the past 12 months, or more than 12 months ago." Prior to 2015, opioid analgesic misuse was assessed by asking: "How long has it been since you last used any prescription pain reliever that was not prescribed for you or that you took only for the experience or feeling it caused?" While the wording does not allow for a distinction between opioid and non-opioid analgesics, the use of non-opioid analgesics is extremely rare. For example, lifetime use of Fioricet and Fiorinal was only 0.14 and 0.11 percent (respectively) in 2013. In 2015, the NSDUH substantially redesigned the questions pertaining to opioid use. A screener first asks whether the respondent has ever used specific types of opioid- based pain relievers, and then follows up by asking if "In the past 12 months, did you use [opioid] in any way a doctor did not direct you to use?" and "In the Past 30 days…did you use [opioid] in any way a doctor did not direct you to use?" Additionally, the new questionnaire shifted from asking yearly frequency of opioid misuse to monthly frequency, and the definition of binge drinking for women was changed from five drinks or more per occasion to four drinks or more per occasion. As with any survey regarding sensitive topics, the NSDUH is vulnerable to underreporting issues. The NSDUH implements several strategies to reduce this bias (SAMHSA, 2019), however it is unclear the extent to which these efforts are successful. Compared to other surveys of youth substance use behavior, the NSDUH routinely underestimates prevalence, although this could be due to differences in questioning (SAMHSA, 2012). However, other validation studies have found roughly similar rates of under and over reporting, suggesting minimal reporting bias in aggregated statistics (Harrison et al., 2007). To the extent that drug use reporting suffers from misreporting, so long as it is independent of marijuana law adoption, our results will be unbiased, but suffer larger standard errors, leading to potential type I errors in inference.

focused on the extensive margin (e.g., any use). Interestingly, rates of prescription opioid abuse in the NSDUH are not closely associated with opioid-related mortality (SAMHSA, 2017), suggesting that the opioid epidemic is being driven by more intensive and/or risker use (Jones, 2017) and highlighting the importance of examining both the extensive and intensive margins of use.

RML status is measured using one of two alternative indicators. The first is equal to one if recreational marijuana was legal (even if the rules and infrastructure necessary for legal sales were not yet implemented) in respondent *i*'s state at the time of the NSDUH interview (and equal to zero otherwise), while the second is an indicator for whether recreational sales had begun in *i*'s state at the time of the interview. RMLs are observed taking effect in 9 states and the District of Columbia during the period under study; 7 states and the District of Columbia are observed allowing recreational sales.[10] It is worth emphasizing that RMLs allow for the possession of limited amounts of marijuana even before the first recreational dispensaries open.[11]

We are also interested in estimating the effects of MMLs on the substance use measures available in the NSDUH. Our preferred specification uses a simple dichotomous indicator for MML adoption, but we acknowledge that this approach could mask important differences across MMLs (Anderson and Rees, 2014b; Smart, 2015; Powell et al., 2018; Anderson and Rees

[10] Table 1 provides effective RML dates and when recreational sales began. It is important to note that medical marijuana was legal in all of the states that adopted RMLs during the period under study. For Washington, D.C., we code effective and implementation date as the same because its RML provides for transfers of one ounce or less of marijuana between individuals. One common practice is for an individual to buy a trinket of nominal value at an inflated price and receive a "gift" of marijuana with the purchase, effectively allowing for the sale and purchase of marijuana (Peischel, 2019).

[11] In addition, all but three RMLs (Illinois, New Jersey, and Washington) allow home cultivation. While a number of states have decriminalized marijuana for personal use, the civil penalties and restrictions on production and sale of marijuana still restrict widespread access.

forthcoming). We conducted sensitivity analyses distinguishing between MMLs based on whether they provided legal protection to dispensaries and whether they allowed home cultivation.[12] We also experimented with interacting cultivation restrictions with an indicator for the Ogden memo, which changed enforcement at the federal level.[13] In general, the estimated effects of RMLs on substance use were not sensitive to how medical marijuana laws are coded.

3.1. Empirical strategy

We begin by using a standard DD identification strategy to estimate impacts of RMLs and MMLs on marijuana use. Specifically, we estimate the following regression equation:

$$(1)\quad Marijuana\ Use_{istm} = \beta_0 + \beta_1 RML_{stm} + \beta_2 MML_{stm} + \boldsymbol{X}_{istm}\boldsymbol{\beta}_3 + \boldsymbol{Z}_{stm}\boldsymbol{\beta}_4 + \nu_s + \gamma_{tm} + \varepsilon_{istm},$$

where the outcome is a measure of respondent *i*'s marijuana use in the past month or the past year (Table 3) from the date of the interview, *s* indexes state of residence, *t* indexes year of interview, and *m* indexes month of interview. Our primary interest is in the coefficients β_1 and β_2. The first of these, β_1, represents the effect of RML adoption; the second, β_2, represents the effect of MML adoption.

The vector $\boldsymbol{X}$ is composed of individual characteristics. These include age, gender, educational attainment, race, ethnicity (i.e., Hispanic), marital status, income (measured as a

[12] More information on MMLs adopted during the period under study (including dates of adoption and dispensary activity) is available in Table 2.

[13] The Ogden memo was released in October of 2009. It instructed United States Attorneys to "not focus federal resources in your States on individuals whose actions are in clear and unambiguous compliance with existing state laws providing for the medical use of marijuana" and arguably created a "green rush," dramatically expanding access to medical marijuana (Smart, 2015).

percentage of the federal poverty threshold) and insurance coverage status.[14] The vector $\boldsymbol{Z}$ includes the unemployment rate in state *s*, year *t*, and month *m*, an indicator for whether a PDMP was operational, an indicator for whether a naloxone access law was in effect, and an indicator for whether a Good Samaritan law was in effect. Information on PDMPs, naloxone access laws, and Good Samaritan laws was obtained from a variety of published sources (Ali et al., 2017; McClellan et al., 2018; Rees et al., 2019).[15]

Finally, in addition to the individual- and state-level controls, we include state fixed effects (v_s) and month-by-year fixed effects (γ_{tm}) on the right-hand side of equation (1). The state fixed effects ensure that identification is based on within-state variation; the month-by-year fixed effects capture common shocks such as changes in preferences and federal policy. Standard errors are corrected for clustering at the state level (Bertrand et al., 2004).

Equation (1) can easily be modified to explore the effects of legalization on second-stage outcomes. Because of wording changes between 2014 and 2015 to questions about binge drinking and prescription pain medication, NSDUH administrators required that we estimate:

$$\begin{aligned}(2)\quad \textit{Substance Use}_{istm} = {} & \alpha_0 + \alpha_1 RML_{stm} \times Y2004\text{-}Y2014_t + \alpha_2 RML_{stm} \times Y2015\text{-}Y2018_t + \\ & \alpha_3 MML_{stm} \times Y2004\text{-}Y2014_t + \alpha_4 MML_{stm} \times Y2015\text{-}Y2018_t + \\ & \boldsymbol{X}_{istm}\boldsymbol{\alpha}_5 + \boldsymbol{Z}_{stm}\boldsymbol{\alpha}_6 + v_s + \gamma_{tm} + \varepsilon_{istm},\end{aligned}$$

[14] Given by separate indicators for private insurance coverage, Medicare coverage, Medicaid coverage, and no insurance coverage.

[15] Descriptive statistics can be found in Table 3 for our variables of interest and Appendix Table 1 for our covariates. Almost 6 percent of NSDUH respondents reported using marijuana in the past month in 2004; 1.6 percent reported misusing prescription pain-relievers in the past month in 2004; and 54.8 percent reported consuming alcohol in the past month in 2004.

where $Y2004\text{-}Y2014_t$ and $Y2015\text{-}Y2018_t$ are two mutually exclusive indicators for the periods 2004-2014 and 2015-2018, respectively. In the first period, 2004-2014, the relationship between RMLs and the outcome under study is given by α_1; in the second period, 2015-2018, the relationship between RMLs and the outcome under study is given by α_2.

5. RESULTS

5.1. Estimates of the effect of legalization on marijuana use

In Table 4, we report estimates of the relationship between legalization and the use of marijuana. Our initial focus is on the effects of MML and RML adoption as opposed to when retail sales were allowed. We explore the effects of allowing retail sales of marijuana for recreational purposes in Section 5.3, below.

The estimates reported in Table 4 provide very little evidence that the adoption of MMLs actually increased marijuana use. Although the estimated coefficients of the MML indicator are positive, they are small in magnitude and, with the exception of past-year frequency of use, not statistically distinguishable from zero.[16] There is, however, evidence that the legalization of

[16] Wen et al. (2015), who also used data from the NSDUH, report that legalizing medical marijuana is associated with a 1.32 percentage point increase in marijuana use among adults (ages 21 and above). These authors had access to NSDUH data for the period 2004-2012, did not weight their regression estimates, and distinguished between different MML provisions (e.g., they included an indicator for MMLs that allow patients to register based on non-specific pain and those that did not). Following Wen et al. (2015), we limited our sample to NSDUH respondents ages 21 and above for the period 2004-2012, distinguished between MML provisions, and included state-specific linear time trends. This produced an unweighted OLS estimated effect of legalization equal to .0072 with a standard error of .0072 (p-value = .32). When we estimated our equation (1) using the NSDUH weights for the same sample (i.e., respondents ages 21 and above for the years 2004-2012), this produced an estimate of .0073 with a standard error of .0040 (p-value = .067). This pattern of results is consistent with the hypothesis that recently adopted MMLs--what Williams et al. (2016) labeled more "medicalized" MMLs--have not had the same effect on marijuana use as MMLs passed in the early to mid-2000s by, for instance, Arizona and Michigan.

recreational marijuana leads to a substantial increase in marijuana use. Specifically, the adoption of an RML is associated with a .035 increase in the probability of having used marijuana in the past month, which represents a 49 percent increase relative to the mean (.072).[17] The adoption of an RML is also associated with a .042 increase in the probability of past-year marijuana use (or 36 percent relative to the mean), a .003 increase in the probability of marijuana use disorder (or 21 percent relative to the mean), and a .022 increase in the probability of being a frequent user of marijuana (or 40 percent relative to the mean).

5.2. Estimates of the effect of legalization on alcohol consumption

Next, we turn our attention to the relationship between legalization and the consumption of alcohol. Using data from the Behavioral Risk Factor Surveillance System (BRFSS), Anderson et al. (2013) and Sabia et al. (2017) found evidence that MML adoption led to a reduction in alcohol consumption, especially among young adults. By contrast, Wen et al. (2015), who used NSDUH data, found a positive association between MML adoption and alcohol consumption.

In Table 5, we report estimates of the effects of legalization on several alcohol-related outcomes. Taken together, they are consistent with the argument that the negative association between MMLs and opioid-related mortality (Bachhuber et al., 2014; Powell et al., 2018) could be driven, at least in part, by the effect of legalization on alcohol consumption.

Specifically, the adoption of a MML is associated with a .010 reduction in the probability of alcohol use in the past month (or 1.8 percent relative to the mean), a .010 reduction in the

[17] Using published NSDUH data at the state-year level, Hollingsworth et al. (2020) found that RMLs were associated with a 13-15 percent increase past-month marijuana use among adolescents, a 15-16 percent among young adults (ages 18-25), and a 21-34 percent among older adults (ages 26+).

probability of past-year alcohol use (or 1.4 percent relative to the mean), and a .006 reduction in the conditional frequency of use (which is less than 0.1 percent of the mean).[18] By contrast, there is no evidence that RMLs reduce alcohol consumption: the estimated coefficients of the RML indicators reported in Table 5 are small and positive; the association between RMLs and binge drinking is statistically significant in the period 2015-2018; likewise, the association between RMLs and conditional frequency of alcohol use is statistically significant, although the magnitude is trivially small.[19]

5.3. Estimates of the effect of legalization on the use of opioids

The primary contribution of this study is to provide estimates of the relationship between the legalization of marijuana and the misuse of opioids. DD regression estimates of this relationship are reported in Tables 6 and 7. Specifically, estimates of the effects of legalization on the misuse of opioid analgesics are reported in Table 6, and estimates of the effects on heroin use are reported in Table 7.

RML adoption is associated with a .001 decrease in the probability of heroin use in the past month, or nearly 100 percent of the mean (Table 7, first column). Other estimates reported in Tables 6 and 7 provide more evidence that legalizing marijuana reduces the use of opioids,

[18] Following Wen et al. (2015), we limited our sample to NSDUH respondents ages 21 and above for the period 2004-2012, distinguished between MML provisions, and included state-specific linear time trends. This produced an unweighted OLS estimated effect of legalization on alcohol use in the past month equal to -.0103 with a standard error of .0096 (p-value = 0.281). When we estimated our equation (1) using the NSDUH weights for the same sample (i.e., respondents ages 21 and above for the years 2004-2012), this produced an estimate of -.012 with a standard error of .0103 (p-value = .227).

[19] Hollingsworth et al. (2020) also explored the relationship between RML adoption and alcohol consumption, albeit briefly. Their estimates, based on published state-level estimates of alcohol use from the NSDUH, were generally small and statistically indistinguishable from zero.

although they are often small and imprecise. For instance, the estimates of α_2, α_3, and α_4 reported in Table 6 are equal to -.002 (or 13 percent of the mean), but only the estimate of α_4 is statistically significant at conventional levels.

The strongest evidence that legalization of marijuana could reduce opioid misuse is on the intensive margin. In the period 2004-2014, RMLs are associated with a .004 reduction in the probability of being a frequent misuser of opioid analgesics, defined as using opioids at least 52 times or more per year, or 40 percent of the mean. Conditional on using heroin, RML adoption is associated with a reduction of 52.07 in the number of times heroin was used during the past 12 months, or 45 percent of the conditional mean.

6. EXTENSIONS AND ROBUSTNESS CHECKS

6.1. Estimates of the effects of recreational sales

Up to this point in the analysis, we have focused on whether an MML or RML was in effect in state *s* and year *t*. In Tables 8-11, we estimate the effects of retail sales for recreational use by substituting an indicator for recreational sales for the RML indicator in equation (1). As noted above, we observe recreational dispensaries opening in 7 states and the District of Columbia during the period under study.

Again, there is strong evidence that legalization of recreational marijuana leads to a substantial increase in marijuana use. Specifically, allowing retail sales for recreational purposes is associated with a .029 increase in the probability of having used marijuana in the past month, and .037 increase in the probability of past-year marijuana use. It is also associated with a .003

increase in the probability of marijuana use disorder, although there is little evidence of impacts on the other substance use outcomes under study perhaps due to lack a lack of power.[20]

6.2. Including state-specific linear trends

There is no consensus in the literature as to whether state-specific trends belong on the right-hand side of the estimating model. For instance, Wen et al. (2015) included them in all of their estimations, but Powell et al. (2018) and Hollingsworth et al. (2020) did not.

In Table 12-15, we report estimates of (1) and (2) augmented with state-specific linear trends on the right-hand side. To be clear, we are not claiming that the specification with state-specific linear trends is unambiguously correct. In fact, we recognize the possibility, raised by Wolfers (2006) and others, that these trends are capturing the effects of treatment. Given this possibility, we view the estimates reported in Tables 12-15 as lower bounds.

With the state-specific linear trends included on the right-hand side of the regression model, RMLs are associated with a .009 increase in the probability of past-year marijuana use or 8 percent of the mean. RMLs are also associated with reasonably large increases in the frequent use of alcohol. Finally, the negative relationship between RMLs and frequent opioid use is generally robust to including the state-specific trends on the right-hand side of the regression model: in the period 2004-2014, RMLs are associated with a .003 reduction in the probability of being a frequent abuser of prescription pain relievers; conditional on misusing prescription

[20] Recreational dispensaries in California and Massachusetts did not open until 2018. The first Nevada recreational dispensary opened in July of 2017.

opioids, RMLs are also associated with a substantial decrease in the frequency of misusing prescription opioids during this period.[21]

6.3. Event-Studies

Event-study estimates of the effects of legalizing recreational marijuana are shown in Figures 1-4. Specifically, we report estimates from the following equation:

$$(3) \quad Substance\ Use_{istm} = \beta_0 + v_s + \gamma_{tm} + \boldsymbol{X}_{istm}\boldsymbol{\beta}_1 + \boldsymbol{Z}_{stm}\boldsymbol{\beta}_2 + \beta_3 MML_{stm} + \sum_{y=-4}^{-2} \pi_y D_s 1\,(t - T_s^* = y) + \sum_{y=0}^{4} \pi_y D_s 1\,(t - T_s^* = y) + \varepsilon_{istm},$$

where D_s is an indicator of ever having been treated, equal to 1 if state *s* legalized recreational marijuana during period under study. The estimates of π_y, the coefficients of D_s interacted with the event-year dummies (y), characterize the effects of legalizing recreational marijuana. The event-year dummies, y, are equal to 1 when the year of observation is $y = -4,\ldots,0,\ldots,4$ years from T_s^*, the year in which the RML took effect in state *s*.[22]

Inconsistent with the parallel-trends assumption, we find evidence that past-month and past-year marijuana use was increasing in the years leading up to the legalization of recreational marijuana. Specifically, before Year 0 (the year in which recreational marijuana was legalized), the estimated coefficients are often negative and statistically significant; after legalization, the estimated coefficients appear to continue on a pre-existing upward trend. The event-studies for

[21] Estimates of the effects of MMLs and RMLs on heroin use obtained from a regression model with state-specific linear trends on the right-hand side are reported in Table 15. Conditional on using heroin, RML adoption is associated with a (statistically insignificant) 26.26 reduction in the past-year frequency of heroin use, which is about half the size of the estimate obtained without controlling for state-specific linear trends (Table 7).

[22] Static DD regression estimates, such as those based on equations (1) or (2), can be biased if the effect of treatment is dynamic (Goodman-Bacon 2021). Event-study estimates, such as those based on equation (3), can be biased if dynamic treatment effects are heterogeneous across cohorts (Sun and Abrahm 2021).

the other marijuana-related outcomes provide no evidence that the legalization increases marijuana use disorder or the frequency marijuana use.

The event studies do not provide evidence that RMLs affect alcohol or heroin use. In Years 1 and 2, however, there is a -0.0035 to -0.0022 reduction in the probability of frequent opioid analgesic misuse, although the estimated effect turns positive after 3 years. Similarly, the estimated effect on the conditional frequency of opioid analgesic misuse is negative in Year 1 but becomes positive (and statistically significant) in Year 2. The event-studies provide no evidence that legalization affects opioid use on the extensive margin.

6.4. Younger vs. older adults

There is very little evidence that MMLs are related to the use of marijuana by teenagers (Sarvet et al., 2018; Anderson et al., 2019). By contrast, young adults appear to be particularly responsive to the legalization of marijuana (Anderson et al., 2013; Smart, 2015; Hollingsworth et al., 2020).

To explore whether younger adults are particularly responsive to RMLs, we divided our sample into respondents between the ages 19-29 vs. ages 30 and older. The results are reported in Appendix Tables 2-9. RML adoption is associated with increased marijuana use among both groups. Among young adults (ages 19-29), the probability of past-month use increases by .044, or 27 percent relative to the mean (Appendix Table 2); among older adults (ages 30+), past-month use increases by .026, or 53 percent (Appendix Table 6). RML adoption is also associated with increased past-year use among both younger and older adults.

The results with regard to the other substances under study are mixed. While RML adoption is not associated with alcohol use among younger adults (Appendix Table 3), it is

associated with a .015 increase in the probability of binge drinking and .011 increase in the probability of frequent use among older adults (Appendix Table 7). Among younger adults, RML adoption is associated with a .012 decrease in the probability of past-year misuse of opioid analgesics (Appendix Table 4), but a 45-day increase in the conditional frequency of heroin use. None of the other estimated coefficients are statistically significant at conventional levels for this group. Among older adults, RML adoption is associated with reductions in the frequency of heroin use.

7. DISCUSSION AND CONCLUSION

This work adds to the still-emerging literature on the impacts of legalizing recreational marijuana by examining its effect on marijuana, alcohol, and opioid use. Previous studies of MMLs suggest that marijuana substitutes for alcohol and opioids (Anderson et al., 2013; Bachhuber et al., 2014; Sabia et al., 2017; Powell et al., 2018), but RMLs are much broader in scope than MMLs and, as such, offer a chance to reexamine the public health consequences of making marijuana more accessible to the general public. To our knowledge, this is the first study to examine the relationship between RMLs and the use of opioids (as opposed to the prescribing of opioids or opioid-related mortality), and it is the first to use individual-level data from states other than Colorado, Oregon and Washington to examine their effects on alcohol and marijuana use.[23]

Estimating standard difference-in-differences regression models and using micro data from the NSDUH, we find that RMLs are associated with increased marijuana use, particularly

[23] Colorado, Oregon and Washington were among the first states to legalize recreational marijuana and have received the lion's share of attention from previous researchers, including Kerr et al. (2017) and Cerdá et al. (2017).

among younger adults. It should be noted, however, that event-study analyses provide evidence that marijuana use in the treated states may have been trending upwards prior to legalization, casting doubt on whether there is in fact a first-stage effect of RMLs.

The primary contribution of this study is to explore whether RMLs could curb the misuse of prescription pain relievers and the use of heroin. Contrary to the results of previous studies focused on opioid prescribing and opioid-related mortality, the evidence is, at best, mixed. On the extensive margin, the estimated effects of legalizing marijuana for recreational purposes are generally small and imprecise. On the intensive margin, difference-in-differences regression estimates provide evidence that RMLs reduce the frequency of use, but the event-study estimates do not provide evidence of sustained declines in frequency.

Finally, there are two important limitations to our analysis that should be mentioned. First, the survey design of the NSDUH changed in 2015, breaking trends in several of our key measures. Although the direct comparison of means for these outcomes across time periods is not possible, our analysis exploits within-state variation in RML status; common shocks (due to, for instance, changes in how the survey is worded) are accounted for by the difference-in-differences design. Second, measures of opioid misuse in the NSDUH do not closely track opioid-related mortality prior to 2015. Although it is possible that the NSDUH's intensive measures of opioid use are more salient to the epidemic, the imprecise results on opioid misuse should be interpreted with caution. The aforementioned NSDUH redesign sought to address any shortcomings in the extensive opioid misuse measures, and future work using fully post-redesign data may yield more precise results.

7. REFERENCES

Abouk, Rahi, Rosalie L. Pacula, and David Powell. 2019. "Association between State Laws Facilitating Pharmacy Distribution of Naloxone and Risk of Fatal Overdose." *JAMA Internal Medicine,* 179 (6): 805-811.

Ahmad, F.B., L.A. Escobedo, L.M Rossen, M.R. Spencer, M. Warner, and P. Sutton. 2019. "Provisional Drug Overdose Death Counts." National Center for Health Statistics. Available at: https://www.cdc.gov/nchs/nvss/vsrr/drug-overdose-data.htm.

Ali, Mir M., William N. Dowd, Timothy Classen, Ryan Mutter, and Scott P. Novak. 2017. "Prescription Drug Monitoring Programs, Nonmedical use of Prescription Drugs, and Heroin Use: Evidence from the National Survey of Drug Use and Health." *Addictive Behaviors,* 69: 65-77.

Alpert, Abby, David Powell, and Rosalie Liccardo Pacula. 2018. "Supply-Side Drug Policy in the Presence of Substitutes: Evidence from the Introduction of Abuse-Deterrent Opioids." *American Economic Journal: Economic Policy*, 10 (4): 1–35.

Anderson, D. Mark, Benjamin Hansen, and Daniel I Rees. 2013. "Medical Marijuana Laws, Traffic Fatalities, and Alcohol Consumption." *Journal of Law and Economics,* 56 (2), 333-369.

Anderson, D. Mark, Benjamin Hansen, Daniel I. Rees, and Joseph J. Sabia. 2019. "Marijuana Laws and Teen Marijuana Use: New Estimates from the Youth Risk Behavior Surveys." *JAMA Pediatrics,* 173 (9): 879-881.

Anderson, D. Mark, Benjamin Hansen, and Daniel I. Rees. 2015. "Medical Marijuana Laws and Teen Marijuana Use." *American Law and Economics Review*, 17 (2): 495-528.

Anderson, D. Mark and Daniel I. Rees. 2014a. "The Legalization of Recreational Marijuana: How Likely is the Worst-Case Scenario?" *Journal of Policy Analysis and Management,* 33 (1): 221-232.

Anderson, D. Mark and Daniel I. Rees. 2014b. "The Role of Dispensaries: The Devil *is* in the Details." *Journal of Policy Analysis and Management*, 33 (1): 235-240.

Anderson, D. Mark, and Daniel I. Rees. Forthcoming. "The Public Health Effects of Legalizing Marijuana." *Journal of Economic Literature*.

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.

Baggio, Michele, Alberto Chong, and Sungoh Kwon. 2020. "Marijuana and Alcohol: Evidence using Border Analysis and Retail Sales Data." *Canadian Journal of Economics,* 53(2): 563-591.

Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan. 2004. "How Much Should We Trust Differences-In-Differences Estimates?" *Quarterly Journal of Economics*, 119 (1): 249-275.

Bradford, Ashley C., W. David Bradford, Amanda Abraham, 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.

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.

Bradford Ashley C. and David W. Bradford. 2017. "Medical Marijuana Laws May Be Associated with a Decline in the Number of Prescriptions for Medicaid Enrollees." *Health Affairs*, 36
(5): 945-951.

Cerdá, Magdalena, Melanie Wall, Tianshu Feng, Katherine M. Keyes, Aaron L. Sarvet, John Schulenberg, Patrick M. O'Malley, Rosalie L. Pacula, Sandro Galea, and Deborah S. Hasin. 2017. "Association of State Recreational Marijuana Laws with Adolescent Marijuana Use." *JAMA Pediatrics*, 171 (2):142-149.

Chan, Nathan W., Jesse Burkhardt, and Matthew Flyr. 2020. "The Effects of Recreational Marijuana Legalization and Dispensing on Opioid Mortality." *Economic Inquiry*, 58(2): 589-606.

Chu, Yu-Wei Luke. 2014. "The Effects of Medical Marijuana Laws on Illegal Marijuana Use." *Journal of Health Economics*, 38: 43-61.

Chu, Yu-Wei Luke. 2015 "Do Medical Marijuana Laws Increase Hard-Drug Use?" *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, no. 2: 154-163.

Crost, Benjamin and Santiago Guerrero. 2012. "The Effect Alcohol Availability on Marijuana Use: Evidence from the Minimum Legal Drinking Age." *Journal of Health Economics,* 31 (1): 112- 121.

Dart, Richard C., Hilary L. Surratt, Theodore J. Cicero, Mark W. Parrino, S. Geoff Severtson, Becki Bucher-Bartelson, and Jody L. Green. 2015. "Trends in Opioid Analgesic Abuse and Mortality in the United States." *New England Journal of Medicine*, 372 (3): 241-248.

Dhalla, Irfan A., Navindra Persaud, and David N. Juurlink. 2011. "Facing Up to the Prescription Opioid Crisis." *Bmj*, 343.

DiNardo, John and Thomas Lemieux. 2001. "Alcohol, Marijuana, and American Youth: the Unintended Consequences of Government Regulation." *Journal of Health Economics*, 20: 991-1010.

Dragone, Davide, Giovanni Prarolo Paolo, and Vanin Giulio Zanella. 2019. "Crime and the Legalization of Recreational Marijuana." *Journal of Economic Behavior and Organization*, 159: 488-501.

Florence, Curtis S., Chao Zhou, Feijun Luo, and Likang Xu. 2016. "The Economic Burden of Prescription Opioid Overdose, Abuse, and Dependence in the United States, 2013." *Medical Care*, 54 (10): 901-906.

Gasior, Maciej, Mary Bond, and Richard Malamu. 2016. "Routes of Abuse of Prescription Opioid Analgesics: A Review and Assessment of the Potential Impact of Abuse-Deterrent Formulations." *Postgraduate Medicine*, 128 (1): 85–96.

Gomes, Tara, Mina Tadrous, Muhammad M. Mamdani, Michael Paterson, and David N. Juurlink. 2018. "The Burden of Opioid-Related Mortality in the United States." *JAMA Network Open*, 1 (2): e180217-e180217.

Goodman-Bacon, Andrew. 2021. "Difference-in-Differences with Variation in Treatment Timing." *Journal of Econometrics*, In Press.

Hagemeier, Nicholas E. 2018. "Introduction to the Opioid Epidemic: The Economic Burden on the Healthcare System and Impact on Quality of Life." *The American Journal of Managed Care*, 24 (10): S200-S206.

Harrison, Lana D., Steven S. Martin, Tihomir Enev, and Deborah Harrington. 2007. "Comparing Drug Testing and Self-Report of Drug use Among Youths and Young Adults in the General Population." Department of Health and Human Resources (DHHS) Publication No. SMA 07-4249, Methodology Series M-7. Rockville, MD: Substance Abuse and Mental Health Services Administration, Office of Applied Studies.

Hasin, Deborah S., Aaron L. Sarvet, Magdalena Cerdá, Katherine M. Keyes, Malka Stohl, Sandro Galea, and Melanie M. Wall. 2017. "US Adult Illicit Cannabis Use, Cannabis Use Disorder, and Medical Marijuana Laws 1991-1992 to 2012-2013." *JAMA Psychiatry*, 74 (6):579-588.

Hasin, Deborah S., Melanie Wall, Katherine M. Keyes, Magdalena Cerdá, John Schulenberg, Patrick M. O'Malley, Sandro Galea, Rosalie L. Pacula, and Tianshu Feng. 2015. "Medical Marijuana Laws and Adolescent Marijuana Use in the USA from 1991 to 2014: Results from Annual, Repeated Cross-Sectional Surveys. *Lancet Psychiatry*, 2: 601–608.

Hollingsworth, Alex, Coady Wing, and Ashley Bradford. 2020. "Unintended Consequences of Recreational and Medical Marijuana Laws on Adult and Youth Drug Use." Available at SSRN: https://ssrn.com/abstract=3400519 or http://dx.doi.org/10.2139/ssrn.3400519.

International Narcotics Control Board. 2019. "Report of the International Narcotics Control Board for 2018." Vienna, Austria: The United Nations.

Iwanicki, Janetta L., S. Geoff Severtson, Zachary Margolin, Nabarun Dasgupta, Jody L. Green, and Richard C. Dart. 2018. "Consistency between Opioid-Related Mortality Trends Derived from Poison Center and National Vital Statistics System, United States, 2006–2016." *American Journal of Public Health*, 108 (12): 1639-1645.

Jones, Christopher M. 2017. "The Paradox of Decreasing Nonmedical Opioid Analgesic Use and Increasing Abuse or Dependence—An Assessment of Demographic and Substance Use Trends, United States, 2003–2014." *Addictive Behaviors*, 65: 229-235.

Jones, Christopher M., Leonard J. Paulozzi, and Karin A. Mack, 2014. "Alcohol Involvement in Opioid Pain Reliever and Benzodiazepine Drug Abuse–Related Emergency Department Visits and Drug-Related Deaths — United States, 2010." *MMWR*, 63 (40): 881–885.

Kelly, Elaine and Imran Rasul 2014. "Policing Cannabis and Drug Related Hospital Admissions: Evidence from Administrative Records." *Journal of Public Economics*, 112: 89-114.

Kerr, David C. R., Harold Bae, Sandi Phibbs, and Adam C. Kern. 2017. "Changes in Undergraduates' Marijuana, Heavy Alcohol and Cigarette Use Following Legalization of Recreational Marijuana Use in Oregon." *Addiction*, 112 (11): 1992-2001.

Kertesz, Stefan G. and Adam J. Gordon. 2019. "A Crisis of Opioids and the Limits of Prescription Control: United States." *Addiction*, 114 (1): 169-180.

Keyes, Katherine M., Melanie Wall, Magdalena Cerdá, John Schulenberg, Patrick M. O'Malley, Sandro Galea, Tianshu Feng, and Deborah S. Hasin. 2016. "How Does State Marijuana Policy affect US Youth? Medical marijuana Laws, Marijuana Use and Perceived Harmfulness: 1991–2014. *Addiction*, 111 (12): 2187-2195.

Koski, Anna, Ilkka Ojanpera, and Erkki Vuori. 2003. "Interaction of Alcohol and Drugs in Fatal Poisonings." *Human and Experimental Toxicology*, 22 (5) 281-287.

Marsh, Jeanne, Keunhye Park, Yu-An Lin, Cliff Bersamira. 2018. "Gender differences in trends for heroin use and nonmedical prescription opioid use, 2007–2014." *Journal of Substance Abuse Treatment*, 87: 79-85.

McCance-Katz, Elinore F. 2020. "The National Survey on Drug Use and Health: 2019." Substance Abuse and Mental Health Services Administration, U.S. Department of Health and Human Services. Available at: https://www.samhsa.gov/data/sites/default/files/reports/rpt29392/Assistant-Secretary-nsduh2019_presentation/Assistant-Secretary-nsduh2019_presentation.pdf

McClellan, Chandler, Barrot H. Lambdin, Mir M. Ali, Ryan Mutter, Corey S. Davis, Eliza Wheeler, Michael Pemberton, and Alex H. Kral. 2018. "Opioid-Overdose Laws Association with Opioid Use and Overdose Mortality." *Addictive Behaviors*, 86: 90-95.

McMichael, Benjamin J., Lawrence Van Horn, and W. Kip Viscusi. 2020. "The Impact of Cannabis Access Laws on Opioid Prescribing." *Journal of Health Economics*, 69: Article 102273.

Miller, Keaton and Boyoung Seo. Forthcoming. "The Effect of Cannabis Legalization on Substance Demand and Tax Revenues." *National Tax Journal*.

Morris, Robert G., Michael TenEyck, J. C. Barnes, and Tomislav V. Kovandzic. 2014. "The Effect of Medical Marijuana Laws on Crime: Evidence from State Panel Data, 1990-2006." *PloS One*, 9 (3): e92816.

Ozluk, Pelin. 2017. "The Effects of Medical Marijuana Laws on Utilization of Prescribed Opioids and Other Prescription Drugs." Working paper available at SSRN: https://ssrn.com/abstract=3056791.

Pacula, Rosalie Liccardo, David Powell, Paul Heaton, Eric L. Sevigny. 2015. "Assessing the Effects of Medical Marijuana Laws on Marijuana Use: The Devil is in the Details." *Journal of Policy Analysis and Management*, 34 (1), 7-31.

Peischel, Will. 2019. "Five Objects People are Buying to Get Marijuana in DC." *Washingtonian*. May 30. Available at: https://www.washingtonian.com/2019/05/30/five-objects-people-are-buying-to-get-marijuana-in-dc/

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.

Reed, Jack K. 2018. "Impacts of Marijuana Legalization in Colorado: A Report Pursuant to Senate Bill 13-283." Denver, CO: Colorado Division of Criminal Justice, Office of Research and Statistics.

Rees, Daniel I., Joseph J. Sabia, Laura M. Argys, Dhaval Dave, and Joshua Latshaw. 2019. "With a Little Help from My Friends: The Effects of Naloxone Access and Good Samaritan Laws on Opioid-Related Deaths." *Journal of Law and Economics*, 62 (1): 1-27.

Rudd, Rose A., Puja Seth, Felicita David, and Lawrence Scholl. 2016. "Increases in Drug and Opioid-Involved Overdose Deaths—United States, 2010–2015." *MMWR*, 65.

Sabia, Joseph J., Jeffery Swigert, and Timothy Young. 2017. "Medical Marijuana Laws and Body Weight." *Health Economics*, 26 (1): 6-34.

Sarvet, Aaron L., Melanie M. Wall, David S. Fink, Emily Greene, Aline Le, Anne E. Boustead, Rosalie Liccardo Pacula, Katherine M. Keyes, Magdalena Cerdá, Sandro Galea, and Deborah S. Hasin. 2018. "Medical Marijuana Laws and Adolescent Marijuana Use in the United States: A Systematic Review and Meta-Analysis." *Addiction*, 113 (6):1003-1016.

Scholl, Lawrence, Puja Seth, Mbabazi Kariisa, Nana Wilson, and Grant Baldwin. 2019. "Drug and Opioid-Involved Overdose Deaths – United States, 2013-2017." *Morbidity and Mortality Weekly Report (MMWR),* 67(51-52), 1419.

Segura, Luis E., Christine M. Mauro, Natalie S. Levy, Nicole Khauli, Morgan M. Philbin, Pia M. Mauro, and Silvia S. Martins. 2019. "Association of US Medical Marijuana Laws with Nonmedical Prescription Opioid Use and Prescription Opioid Use Disorder." *JAMA Network Open*, 2 (7):e197216.

Sfondeles, Tina. 2018. "Rauner Oks Medical Marijuana to Replace Opioids, Passes on Recreational Pot." *Chicago Sun Times*, August 28. Available at: https://chicago.suntimes.com/news/illinois-medical-marijuana-alternative-opioids-bruce-rauner/

Shover, Chelsea L., Corey S. Davis, Sanford C. Gordon, and Keith Humphreys. 2019. "Association between Medical Cannabis Laws and Opioid Overdose Mortality Has Reversed Over Time." *PNAS*, 116 (26): 12624-12626.

Smart, Rosanna. 2015. "The Kids Aren't Alright but Older Adults Are Just Fine: Effects of Medical Marijuana Market Growth on Substance Use and Abuse." Available at SSRN: https://ssrn.com/abstract=2574915 or http://dx.doi.org/10.2139/ssrn.2574915.

Substance Abuse and Mental Health Services Administration (SAMHSA). 2012. "Comparing and Evaluating Youth Substance Use Estimates from the National Survey on Drug Use and Health and Other Surveys." HHS Publication No. SMA 12-4727, Methodology Series M-9. Rockville, MD: Substance Abuse and Mental Health Services Administration.

Substance Abuse and Mental Health Services Administration (SAMHSA). 2017. "Opioid Misuse Increases Among Older Adults." *The CBHSQ Report*, July 25. Available at: https://www.samhsa.gov/data/sites/default/files/report_3186/Spotlight-3186.html

Substance Abuse and Mental Health Services Administration (SAMHSA). 2019. *2018 National Survey on Drug Use and Health: Methodological Summary and Definitions*. Rockville, MD: Center for Behavioral Health Statistics and Quality, Substance Abuse and Mental Health Services Administration. Available at: https://www.samhsa.gov/data/

Sun, Liyang and Sarah Abraham. 2021. "Estimating Dynamic Treatment Effects in Event Studies with Heterogeneous Treatment Effects." *Journal of Econometrics*, In Press.

Taylor, Kate. 2019. "Legalize Pot? Amid Opioid Crisis, Some New Hampshire Leaders Say No Way." *New York Times*, Feb. 20. Available at: https://www.nytimes.com/2019/02/20/us/weed-opioids-new-hampshire.html

Wang, Vivian. 2018. "Cuomo Moves to Legalize Recreational Marijuana in New York within Months." *New York Times*, December 17. Available at: https://www.nytimes.com/2018/12/17/nyregion/marijuana-legalization-cuomo.html?action=click&module=RelatedCoverage&pgtype=Article&region=Footer&login=email&auth=login-email

Voelker, Rebecca. 2018. “States Move to Substitute Opioids with Medical Marijuana to Quell Epidemic.” *JAMA,* 320 (23): 2408-2410.

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

Wen, Hefei, Jason M. Hockenberry, and Janet R. Cummings. 2015. “The Effect of Medical Marijuana Laws on Adolescent and Adult Use of Marijuana, Alcohol, and other Substances.” *Journal of Health Economics, 42*: 64-80.

Williams, Robin, Mark Olfson, June H. Kim, Silvia S. Martins, and Herbert D. Kleber. 2016. “Older, Less Regulated Medical Marijuana Programs Have Much Greater Enrollment Rates than Newer ‘Medicalized’ Programs.” *Health Affairs,* 35(3): 480-488.

Wolfers, Justin. 2006. “Did Unilateral Divorce Laws Raise Divorce Rates? A Reconciliation and New Results.” *American Economic Review,* 96 (5): 1802-1820.

Wolff, Carolyn, William N. Dowd, Mir M. Ali, Chandler McClellan, Angelica Meinhofer, Lukas Glos, Ryan Mutter, Matthew Rosenberg, and Andreas Schick. 2020. “The Impact of the Abuse-Deterrent Reformulation of Extended-Release OxyContin on Prescription Pain Reliever Misuse and Heroin Initiation.” *Addictive Behavior,* 105: Article 106268.

Table 1. Recreational Marijuana Law Dates, 2012-2021

State	RML Came into Effect	RML Sales Allowed
Alaska	2/24/2015	10/29/2016
Arizona	11/30/20	--
California	11/9/2016	1/1/2018
Colorado	12/10/2012	1/1/2014
Connecticut	7/1/2021	--
Illinois	1/1/2020	1/1/2020
Maine	1/31/2017	10/9/2020
Massachusetts	12/15/2016	11/20/2018
Michigan	12/06/2018	12/01/2019
Montana	1/1/2021	--
Nevada	1/1/2017	7/1/2017
New Jersey	2/22/2021	--
New Mexico	6/29/2021	--
New York	3/21/2021	--
Oregon	7/1/2015	10/1/2015
Vermont	7/1/2018	--
Virginia	7/1/2021	--
Washington	12/6/2012	7/8/2014
Washington, D.C.	2/26/2015	2/26/2015

Note: Based on primary research of state legislative databases, news articles, and Anderson and Rees (forthcoming, Table 1).

Table 2. Medical Marijuana Law Dates, 1996-2018

State	MML	Dispensaries Legal and Active	Collective Cultivation	Home Cultivation
Alaska	3/4/1999			3/4/1999
Arkansas	11/9/2016			
Arizona	4/14/2011	12/1/2012		4/14/2011
California	11/6/1996	1/1/2004	11/6/1996	11/6/1996
Colorado	6/1/2001	6/1/2010	6/1/2001	6/1/2001
Connecticut	10/1/2012	8/1/2014		
Washington, DC	7/27/2010	4/1/2013		
Delaware	7/1/2011			
Florida	1/1/2017			
Hawaii	12/28/2000			12/28/2000
Illinois	1/1/2014			
Massachusetts	1/1/2013			1/1/2013
Maryland	6/1/2014			
Maine	12/22/1999	3/1/2011		12/22/1999
Michigan	12/4/2008			12/4/2008
Minnesota	5/1/2014		5/1/2014	
Missouri	12/6/2018	1/24/2020		
Montana[†]	11/2/2004		11/2/2004 – 7/1/2011	11/2/2004
North Dakota	12/1/2016			
New Hampshire	7/1/2013			
New Jersey	10/1/2010	12/1/2012		
New Mexico	7/1/2007	7/1/2009		
Nevada	10/1/2001	3/1/2015	10/1/2001	10/1/2001
New York	7/1/2014			
Ohio	8/1/2016			
Oklahoma	7/26/2018	10/26/2018		
Oregon	12/3/1998	3/1/2014	12/3/1998	12/3/1998
Pennsylvania	5/1/2016			
Rhode Island	1/3/2006	4/1/2013	1/3/2006	1/3/2006
Utah	12/3/2018	3/2/2020		
Vermont	7/1/2004	6/1/2013		7/1/2004
Washington	11/3/1998		11/3/1998	11/3/1998
West Virginia	8/1/2017			

[†]In July of 2011, Montana passed SB 423 which, combined with dispensary raids by the DEA, significantly curtailing collective cultivation.

Note: We begin with Anderson, et al. (2013) as our source for MML dates, and Powell, et al (2017) for dispensary dates. Cultivation provisions are defined following Anderson et al (2013). We extend these dates through primary research of state legislative databases and news articles.

Table 3. Summary Statistics for Outcomes, RMLs and MMLs

	All 2004	RML States 2004	Non-RML States 2004	All 2018	RML States 2018	Non-RML States 2018
Marijuana Past Month	0.056	0.065	0.054	0.103	0.144	0.092
Marijuana Past Year	0.097	0.11	0.093	0.159	0.214	0.145
Marijuana Disorder	0.015	0.018	0.014	0.015	0.021	0.013
Marijuana Frequency (past year)	102.627	105.914	101.636	129.297	130.165	128.955
Marijuana Frequent User	0.041	0.046	0.04	0.079	0.105	0.073
Alcohol Past Month	0.543	0.574	0.535	0.558	0.595	0.548
Alcohol Past Year	0.688	0.707	0.684	0.703	0.734	0.695
Alcohol Disorder	0.078	0.083	0.077	0.058	0.075	0.053
Binge Drinker	0.239	0.222	0.244	0.266	0.276	0.264
Alcohol Frequency (past year)	90.355	98.303	88.259	92.043	97.546	90.496
Alcohol Frequent User	0.304	0.333	0.296	0.321	0.352	0.313
Opioid Past Month	0.016	0.014	0.017	0.011	0.01	0.011
Opioid Past Year	0.041	0.044	0.041	0.037	0.04	0.036
Opioid Disorder	0.005	0.004	0.005	0.006	0.007	0.006
Opioid Frequency (past year)	40.839	37.892	41.648	87.138	60.618	93.367
Opioid Frequent User	0.008	0.008	0.008	0.005	0.003	0.005
Heroin Past Month	0.001	0	0.001	0.001	0.001	0.001
Heroin Past Year	0.002	0.001	0.002	0.003	0.003	0.003
Heroin Disorder	0.001	0.001	0.001	0.002	0.001	0.002
Heroin Frequency (past year)	104.305	119.024	102.418	111.113	67.351	122.996
Heroin Frequent User	0.999	0.999	0.999	0.998	0.998	0.998
Recreational Marijuana Law	0	0	0	0.189	0.899	0
Medical Marijuana Law	0.189	0.879	0.013	0.629	1	0.53
Observations	42,200	6,200	36,000	48,700	8,200	40,500

Table 4. RMLs and Marijuana-Related Outcomes

	Marijuana Past-Month	Marijuana Past-Year	Marijuana Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	.003	-.0004	.001	4.88*	.002
	(.003)	(.004)	(.001)	(2.81)	(.003)
Recreational Marijuana Law	.035***	.042***	.003***	1.06	.022***
	(.009)	(.012)	(.001)	(2.86)	(.007)
Observations	660,400	660,400	660,400	123,000	660,400
Adjusted R^2	.080	.120	.025	.076	.072
Outcome Mean	.072	.117	.014	118.0	.055

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 5. RMLs and Alcohol-Related Outcomes

	Alcohol Past-Month	Alcohol Past-Year	Alcohol Disorder	Binge Drinker	Frequency (past-year)	Frequent User
Medical Marijuana Law	-.010***	-.010***	-.001		-.006*	-1.46
	(.004)	(.003)	(.002)		(.003)	(.920)
Recreational Marijuana Law	.005	.008	.001		.009*	.803
	(.007)	(.007)	(.002)		(.005)	(.869)
Medical Marijuana Law x Y2004-Y2014				-.007		
				(.005)		
Recreational Marijuana Law x Y2004-Y2014				-.009		
				(.007)		
Medical Marijuana Law x Y2015-Y2018				-.007		
				(.005)		
Recreational Marijuana Law x Y2015-Y2018				.012**		
				(.005)		
Observations	660,400	660,400	660,400	660,400	497,800	660,400
Adjusted R^2	.141	.151	.046	.111	.067	.091
Outcome Mean	.560	.703	.069	.251	91.49	.317
Joint P-Value for RML				.000		

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 6. RMLs and Opioid-Related Outcomes

	Opioid Past-Month	Opioid Past-Year	Opioid Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law x Y2004-Y2014	.0001	.001	.0001	.829	.0003
	(.001)	(.002)	(.001)	(4.21)	(.001)
Recreational Marijuana Law x Y2004-Y2014	-.002	-.006	-.001**	-12.70	-.004***
	(.002)	(.004)	(.001)	(9.416)	(.001)
Medical Marijuana Law x Y2015-Y2018	-.002**	.001	.001	-.267	-.0003
	(.001)	(.002)	(.001)	(5.870)	(.001)
Recreational Marijuana Law x Y2015-Y2018	-.002	-.002	.0005	-7.31	-.0003
	(.001)	(.002)	(.001)	(7.43)	(.001)
Observations	660,400	660,400	660,400	35,700	660,400
Adjusted R^2	.013	.030	.009	.085	.010
Outcome Mean	.016	.043	.007	52.06	.009
Joint P-Value for RML	.873	.329	.031	.627	.000

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 7. RMLs and Heroin-Related Outcomes

	Heroin Past-Month	Heroin Past-Year	Heroin Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	.0003 (.0002)	.001 (.0004)	.0004 (.0003)	.77 (12.48)	.00003 (.0002)
Recreational Marijuana Law	-.001* (.0003)	-.00004 (.001)	.0002 (.0004)	-52.07*** (17.33)	-.0005 (.0004)
Observations	660,400	660,400	660,400	2,800	660,400
Adjusted R^2	.003	.007	.005	.157	.003
Outcome Mean	.001	.003	.002	115.51	.999

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 8. Recreational Marijuana Sales and Marijuana-Related Outcomes

	Marijuana Past-Month	Marijuana Past-Year	Marijuana Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	.004 (.003)	.0004 (.003)	.001 (.001)	4.91 (2.98)	.002 (.003)
Recreational Marijuana Sales	.029*** (.008)	.037*** (.01)	.003** (.001)	.950 (3.40)	.018*** (.007)
Observations	660,400	660,400	660,400	123,000	660,400
Adjusted R^2	.08	.12	.025	.076	.072
Outcome Mean	.072	.117	.014	118.02	.055

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 9. Recreational Marijuana Sales and Alcohol-Related Outcomes

	Alcohol Past-Month	Alcohol Past-Year	Alcohol Disorder	Binge Drinker	Frequency (past-year)	Frequent User
Medical Marijuana Law	-.010***	-.01***	-.001		-1.58*	-.007*
	(.004)	(.003)	(.002)		(.98)	(.004)
Recreational Marijuana Sales	.006	.007	.001		.008	.006
	(.007)	(.007)	(.002)		(1.412)	(.007)
Medical Marijuana Law x Y2004-Y2014				-.010**		
				(.005)		
Recreational Marijuana Sales x Y2004-Y2014				-.012		
				(.012)		
Medical Marijuana Law x Y2015-Y2018				-.006		
				(.005)		
Recreational Marijuana Sales x Y2015-Y2018				.004		
				(.006)		
Observations	660,400	660,400	660,400	660,400	497,800	660,400
Adjusted R^2	.141	.151	.046	.111	.067	.091
Outcome Mean	.56	.703	.069	.251	91.49	.317
Joint P-Value for RML				0.31		

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 10. Recreational Marijuana Sales and Opioid-Related Outcomes

	Opioid Past-Month	Opioid Past-Year	Opioid Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law x Y2004-Y2014	.0005	.001	.0002	.997	.00004
	(.001)	(.002)	(.001)	(4.34)	(.001)
Recreational Marijuana Sales x Y2004-Y2014	-.003**	-.008*	-.001	-2.37	-.002**
	(.001)	(.005)	(.001)	(5.12)	(.001)
Medical Marijuana Law x Y2015-Y2018	-.002**	.001	.001	.057	-.0002
	(.001)	(.002)	(.001)	(5.91)	(.001)
Recreational Marijuana Sales x Y2015-Y2018	-.001	-.001	.001	-9.44	-.001
	(.001)	(.002)	(.001)	(11.57)	(.001)
Observations	660,400	660,400	660,400	35,700	660,400
Adjusted R^2	.013	.030	.009	.085	.010
Outcome Mean	.016	.043	.007	52.06	.009
Joint P-Value for RML	.147	.308	.571	.354	.858

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 11. Recreational Marijuana Sales and Heroin-Related Outcomes

	Heroin Past-Month	Heroin Past-Year	Heroin Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	.0003 (.0002)	.001 (.0004)	.0004 (.0003)	4.59 (11.94)	.0001 (.0002)
Recreational Marijuana Sales	-.0002 (.001)	.0001 (.0005)	-.00005 (.0003)	-15.17 (18.67)	-.0001 (.0003)
Observations	660,400	660,400	660,400	2,800	660,400
Adjusted R^2	.003	.007	.005	.154	.003
Outcome Mean	.001	.003	.002	115.51	.999

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 12. RMLs and Marijuana-Related Outcomes: Including State-Specific Linear Time Trends

	Marijuana Past-Month	Marijuana Past-Year	Marijuana Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	.001 (.002)	-.004 (.003)	.001 (.001)	5.06 (3.57)	.0004 (.002)
Recreational Marijuana Law	.007 (.005)	.009* (.005)	-.0003 (.001)	-5.55 (5.46)	.001 (.006)
Observations	660,400	660,400	660,400	123,000	660,400
Adjusted R^2	.081	.12	.025	.076	.072
Outcome Mean	.072	.117	.014	118.02	.055

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects month-by-year fixed effects, and state-specific linear time trends. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 13. RMLs and Alcohol-Related Outcomes: Including State-Specific Linear Time Trends

	Alcohol Past-Month	Alcohol Past-Year	Alcohol Disorder	Binge Drinker	Frequency (past-year)	Frequent User
Medical Marijuana Law	-.012**	-.005	-.001		-3.51**	-.010*
	(.005)	(.004)	(.002)		(1.45)	(.006)
Recreational Marijuana Law	.008	.010	-.003*		3.89***	.021***
	(.008)	(.007)	(.002)		(1.14)	(.007)
Medical Marijuana Law x Y2004-Y2014				-.012**		
				(.005)		
Recreational Marijuana Law x Y2004-Y2014				-.008**		
				(.004)		
Medical Marijuana Law x Y2015-Y2018				-.017***		
				(.005)		
Recreational Marijuana Law x Y2015-Y2018				.007		
				(.005)		
Observations	660,400	660,400	660,400	660,400	497,800	660,400
Adjusted R^2	.141	.151	.046	.111	.067	.091
Outcome Mean	.56	.703	.069	.251	91.49	.317
Joint P-Value for RML				.123		

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects month-by-year fixed effects, and state-specific linear time trends. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 14. RMLs and Opioid-Related Outcomes: Including State-Specific Linear Time Trends

	Opioid Past-Month	Opioid Past-Year	Opioid Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law x Y2004-Y2014	.001	.004	.0004	1.448	.0004
	(.001)	(.002)	(.001)	(4.38)	(.001)
Recreational Marijuana Law x Y2004-Y2014	-.003	-.005	-.001	-17.608*	-.003**
	(.003)	(.004)	(.001)	(9.79)	(.001)
Medical Marijuana Law x Y2015-Y2018	-.003**	.003	.001	2.088	.0003
	(.001)	(.003)	(.001)	(6.22)	(.001)
Recreational Marijuana Law x Y2015-Y2018	-.003	-.002	.001	-7.724	.00001
	(.003)	(.004)	(.001)	(8.42)	(.002)
Observations	660,400	660,400	660,400	35,700	660,400
Adjusted R^2	.013	.03	.009	.087	.01
Outcome Mean	.016	.043	.007	52.06	.009
Joint P-Value for RML	.916	.402	.038	.321	.008

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects month-by-year fixed effects, and state-specific linear time trends. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Table 15. RMLs and Heroin-Related Outcomes: Including State-Specific Linear Time Trends

	Heroin Past-Month	Heroin Past-Year	Heroin Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	.0003 (.0003)	.001 (.0004)	.001** (.0002)	1.06 (14.83)	.0001 (.0002)
Recreational Marijuana Law	-.001 (.001)	-.0002 (.0004)	-.0004 (.0004)	-26.26 (22.89)	.0002 (.0003)
Observations	660,400	660,400	660,400	2,800	660,400
Adjusted R^2	.003	.007	.005	.168	.003
Outcome Mean	.001	.003	.002	115.51	.999

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects month-by-year fixed effects, and state-specific linear time trends. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Figure 1. Event-Study Graphs for Marijuana Outcomes

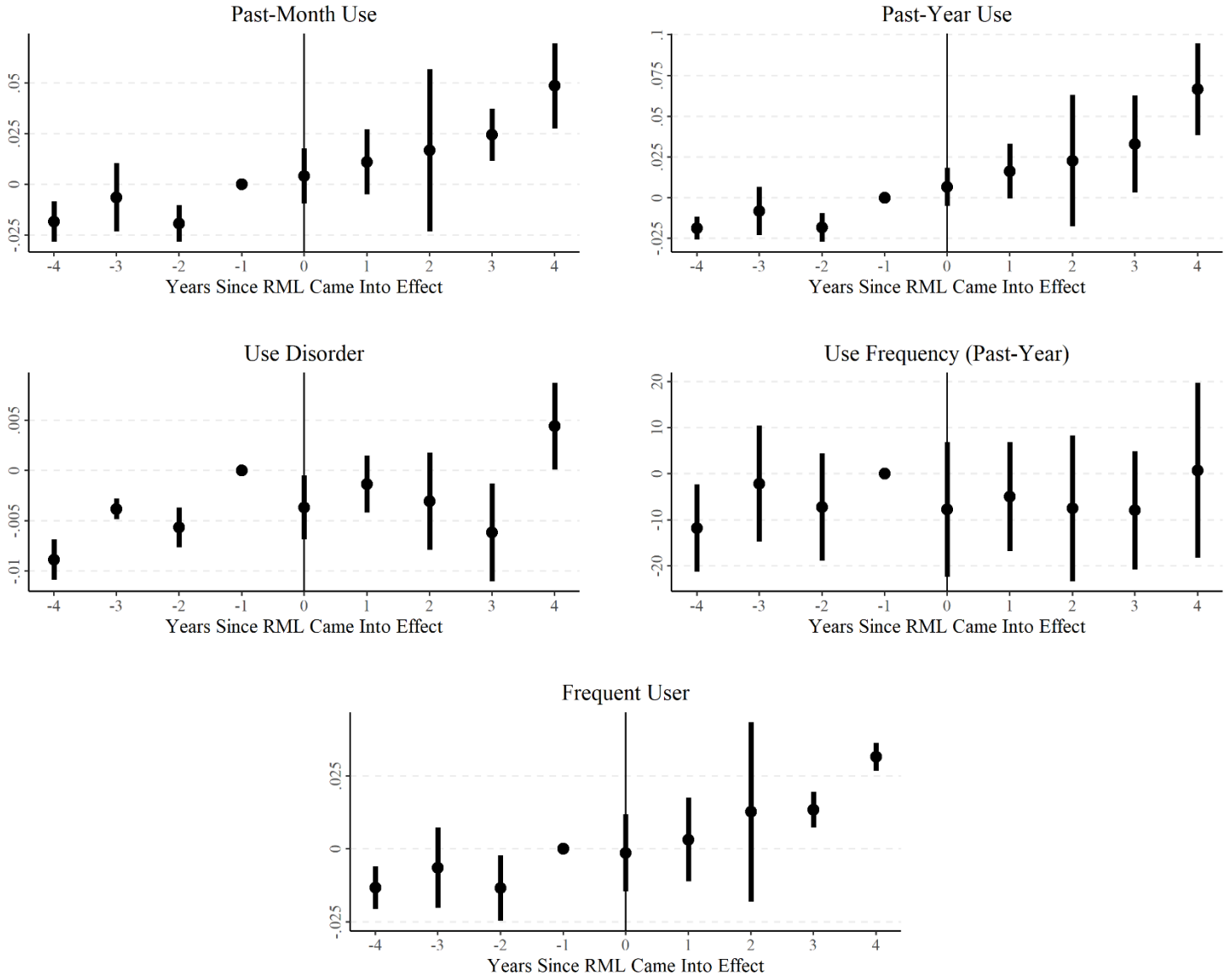


Figure 2. Event-Study Graphs for Alcohol Outcomes

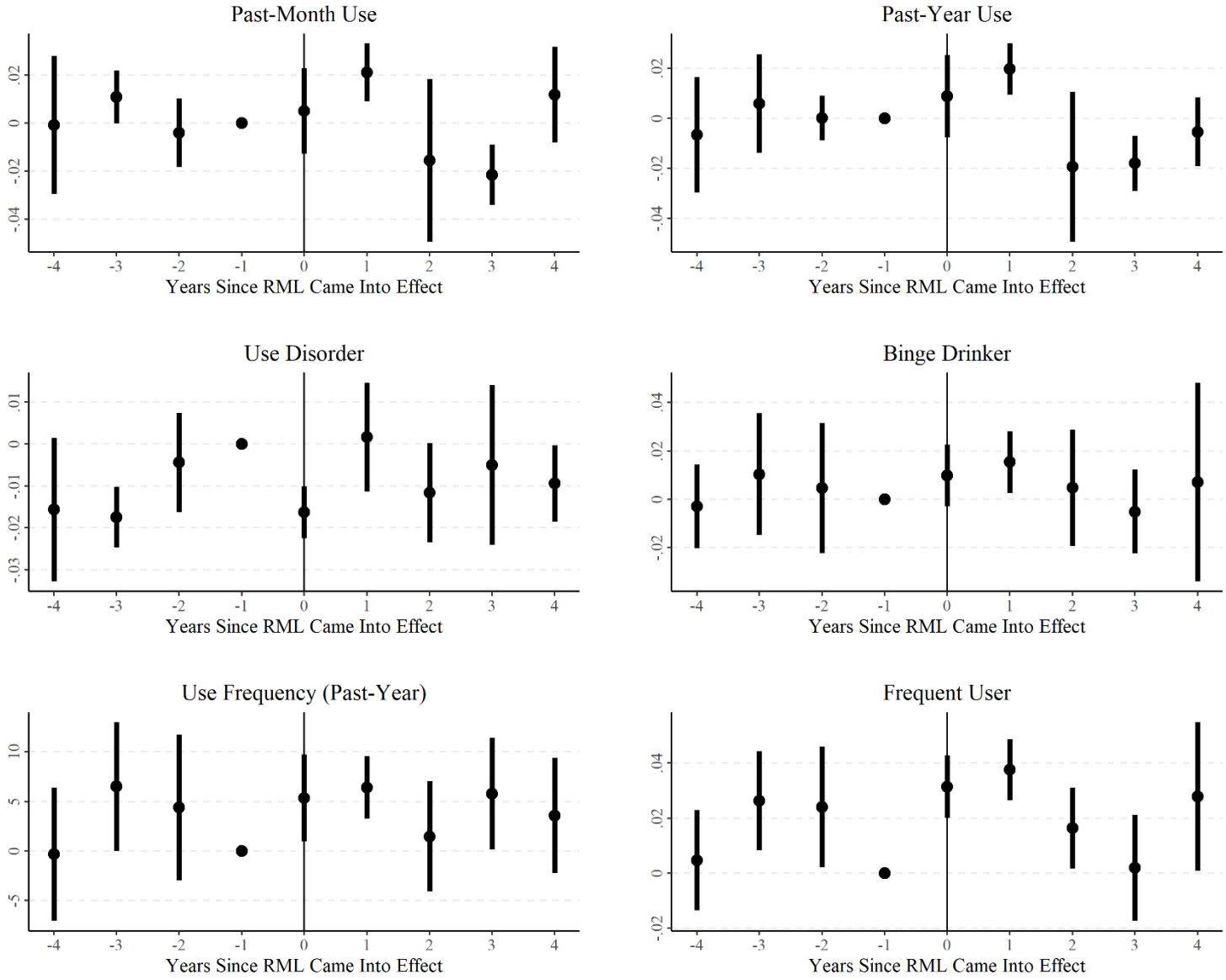


Figure 3. Event-Study Graphs for Opioid Outcomes

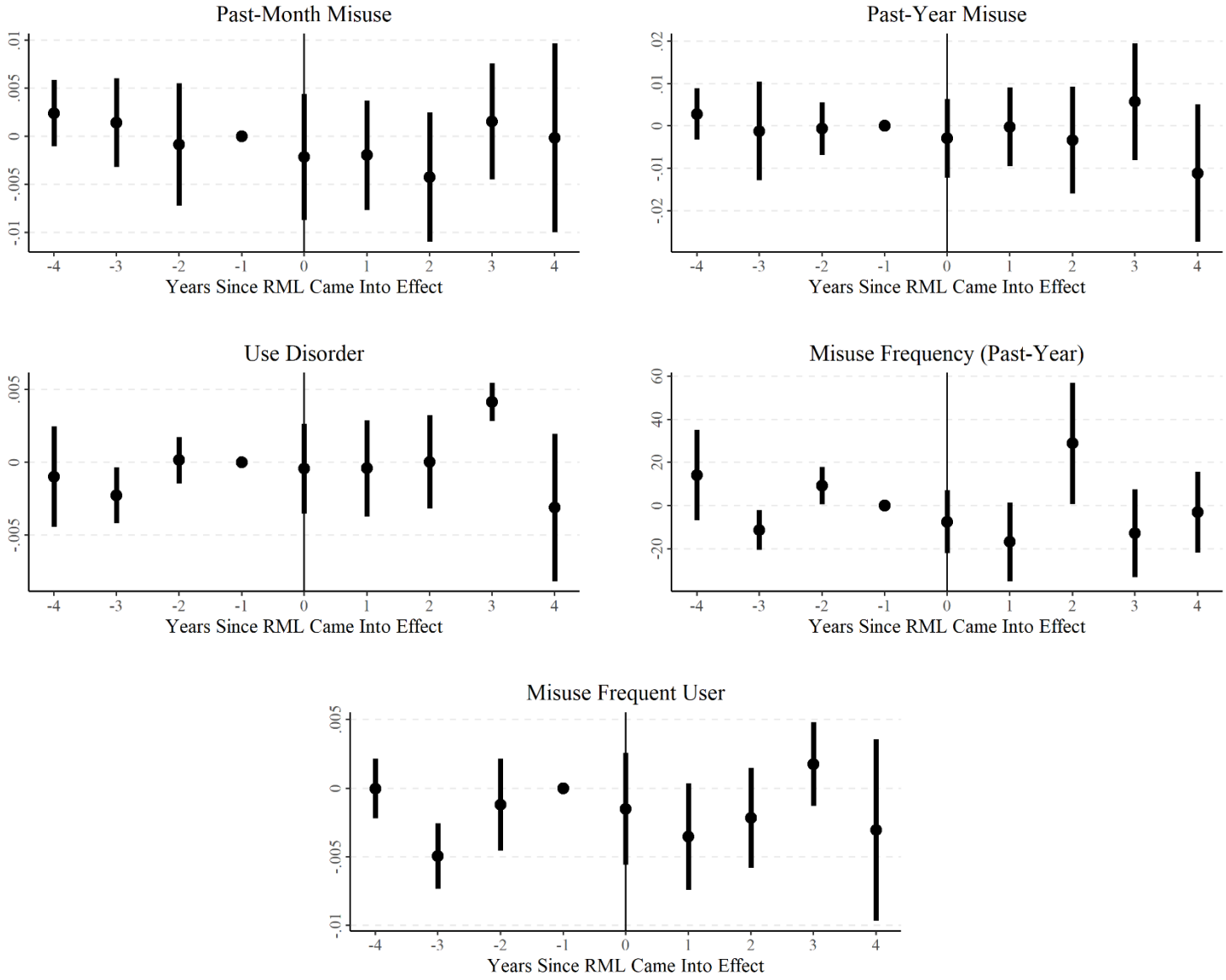
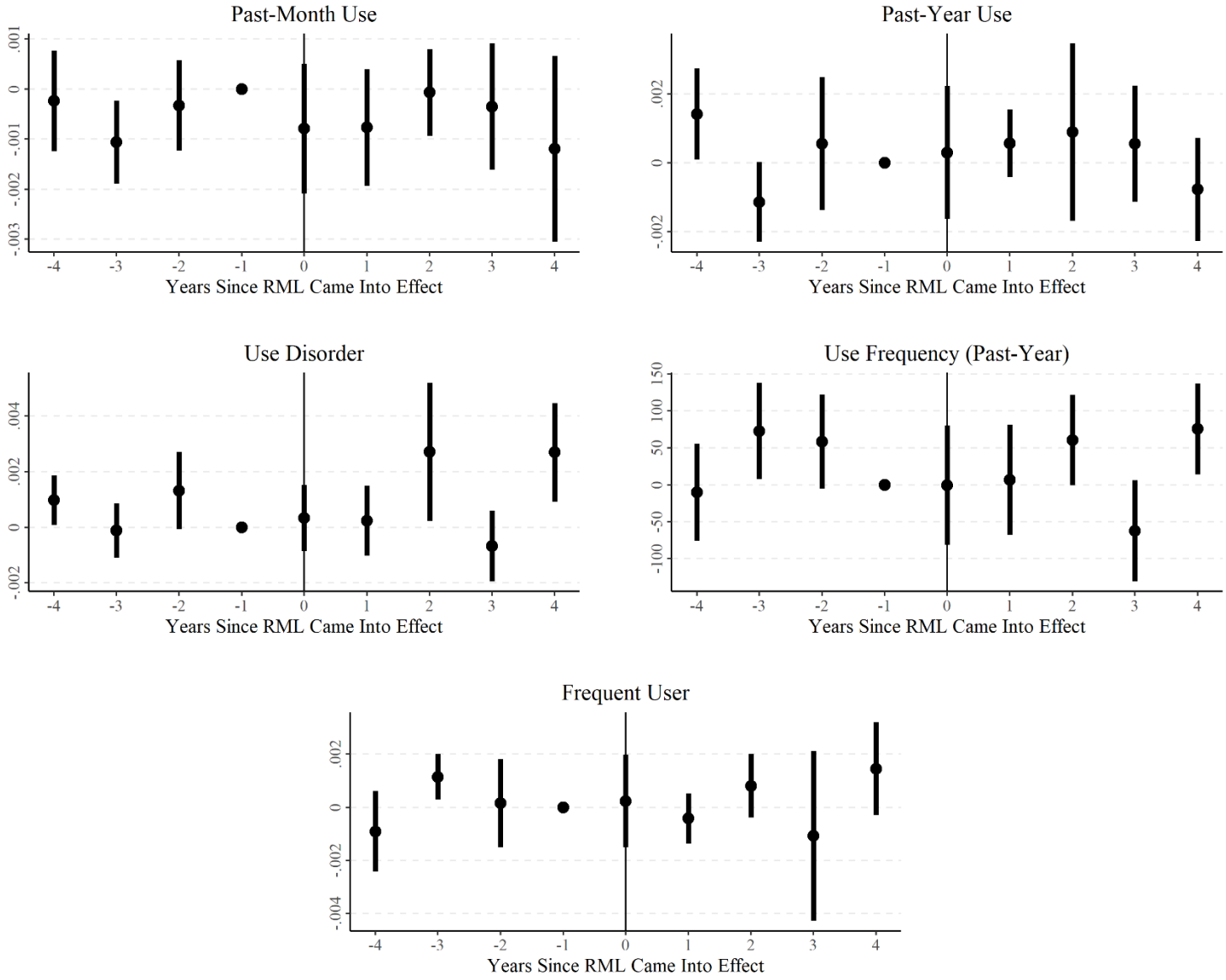


Figure 4. Event-Study Graphs for Heroin Outcomes



Appendix Table 1. Summary Statistics for Covariates

	All 2004	RML States 2004	Non-RML States 2004	All 2018	RML States 2018	Non-RML States 2018
Age	45.938	45.179	46.131	48.036	47.065	48.295
Male	0.48	0.487	0.478	0.482	0.487	0.48
White	0.82	0.815	0.822	0.779	0.764	0.784
African American	0.115	0.059	0.129	0.126	0.063	0.143
Asian	0.045	0.097	0.031	0.063	0.127	0.045
Hispanic	0.124	0.219	0.099	0.161	0.26	0.135
Less than high school	0.164	0.151	0.167	0.118	0.123	0.116
High school	0.312	0.262	0.325	0.245	0.185	0.26
Some college	0.259	0.284	0.252	0.313	0.305	0.315
College	0.265	0.302	0.256	0.325	0.387	0.308
Married	0.577	0.579	0.576	0.526	0.529	0.524
Divorced	0.06	0.046	0.063	0.058	0.044	0.062
Widowed	0.136	0.13	0.137	0.141	0.124	0.145
Single	0.228	0.246	0.224	0.276	0.302	0.269
Percentage FPL	377.208	401.42	371.033	388.903	426.756	378.82
Private Insurance	0.711	0.705	0.713	0.667	0.66	0.669
Medicare	0.181	0.158	0.187	0.23	0.201	0.238
Medicaid	0.076	0.078	0.076	0.145	0.194	0.131
Uninsured	0.146	0.155	0.144	0.102	0.078	0.108
Unemployment rate	5.545	6.089	5.406	3.913	4.117	3.859
PDMP	0.517	0.737	0.461	0.979	0.989	0.976
Naloxone Law	0.018	0	0.023	0.661	0.946	0.585
GSL	0	0	0	0.589	0.893	0.508
Observations	42,200	6,200	36,000	48,700	8,200	40,500

Appendix Table 2. RMLs and Marijuana-Related Outcomes: Adults Ages 19-29

	Marijuana Past-Month	Marijuana Past-Year	Marijuana Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	.007	.005	.002	1.3	.004
	(.004)	(.005)	(.002)	(2.87)	(.004)
Recreational Marijuana Law	.044***	.06***	.007**	1.07	.028**
	(.013)	(.013)	(.003)	(3.57)	(.012)
Observations	312,500	312,500	312,500	88,700	312,500
Adjusted R^2	.057	.074	.02	.082	.057
Outcome Mean	.166	.273	.043	123.67	.132

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Appendix Table 3. RMLs and Alcohol-Related Outcomes: Adults Ages 19-29

	Alcohol Past-Month	Alcohol Past-Year	Alcohol Disorder	Binge Drinker	Frequency (past-year)	Frequent User
Medical Marijuana Law	-.011**	-.011**	-.002		.905	-.005
	(.005)	(.005)	(.003)		(.84)	(.007)
Recreational Marijuana Law	-.001	.002	.0001		1.68	.001
	(.010)	(.012)	(.004)		(1.36)	(.009)
Medical Marijuana Law x Y2004-Y2014				-.010		
				(.007)		
Recreational Marijuana Law x Y2004-Y2014				-.021		
				(.016)		
Medical Marijuana Law x Y2015-Y2018				-.003		
				(.006)		
Recreational Marijuana Law x Y2015-Y2018				-.002		
				(.009)		
Observations	312,500	312,500	312,500	312,500	250,600	312,500
Adjusted R^2	.11	.088	.036	.08	.059	.082
Outcome Mean	.56	.703	.069	.251	91.49	.317
Joint P-Value for RML				.40		

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Appendix Table 4. RMLs and Opioid-Related Outcomes: Adults Ages 19-29

	Opioid Past-Month	Opioid Past-Year	Opioid Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law x Y2004-Y2014	-.0004	-.005	-.002	-2.32	-.001
	(.004)	(.006)	(.002)	(4.34)	(.002)
Recreational Marijuana Law x Y2004-Y2014	-.006	-.021***	-.002	2.09	-.005*
	(.006)	(.007)	(.002)	(6.15)	(.003)
Medical Marijuana Law x Y2015-Y2018	-.003	-.003	-.003**	6.16	.0001
	(.002)	(.004)	(.001)	(7.94)	(.002)
Recreational Marijuana Law x Y2015-Y2018	-.005	-.012**	.002	12.21	.001
	(.004)	(.005)	(.002)	(14.59)	(.002)
Observations	312,500	312,500	312,500	26,100	312,500
Adjusted R^2	.014	.025	.01	.082	.014
Outcome Mean	.033	.09	.014	48.66	.018
Joint P-Value for RML	.740	.243	.142	.381	.052

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Appendix Table 5. RMLs and Heroin-Related Outcomes: Adults Ages 19-29

	Heroin Past-Month	Heroin Past-Year	Heroin Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	-.0002	.0004	.001	17.24	.001
	(.001)	(.001)	(.001)	(15.74)	(.001)
Recreational Marijuana Law	-.001	-.0005	.0004	44.91**	.001
	(.001)	(.002)	(.001)	(18.7)	(.001)
Observations	312,500	312,500	312,500	2,000	312,500
Adjusted R^2	.005	.008	.007	.162	.004
Outcome Mean	.003	.006	.004	113.43	.997

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Appendix Table 6. RMLs and Marijuana-Related Outcomes: Adults Ages 30 and Older

	Marijuana Past-Month	Marijuana Past-Year	Marijuana Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law	.003	-.001	.001	7.28*	.001
	(.003)	(.004)	(.001)	(4.14)	(.003)
Recreational Marijuana Law	.026***	.031***	.002**	-.63	.016***
	(.007)	(.01)	(.001)	(4.37)	(.006)
Observations	348,000	348,000	348,000	34,200	348,000
Adjusted R^2	.053	.073	.010	.074	.046
Outcome Mean	.049	.078	.006	113.03	.036

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Appendix Table 7. RMLs and Alcohol-Related Outcomes: Adults Ages 30 and Older

	Alcohol Past-Month	Alcohol Past-Year	Alcohol Disorder	Binge Drinker	Frequency (past-year)	Frequent User
Medical Marijuana Law	-.010**	-.010**	-.001		-2.16*	-.007
	(.005)	(.004)	(.002)		(1.12)	(.005)
Recreational Marijuana Law	.007	.009	.001		.433	.011**
	(.007)	(.006)	(.003)		(1.12)	(.005)
Medical Marijuana Law x Y2004-Y2014				-.006		
				(.005)		
Recreational Marijuana Law x Y2004-Y2014				-.004		
				(.012)		
Medical Marijuana Law x Y2015-Y2018				-.009		
				(.006)		
Recreational Marijuana Law x Y2015-Y2018				.015***		
				(.005)		
Observations	348,000	348,000	348,000	348,000	247,300	348,000
Adjusted R^2	.146	.156	.031	.093	.068	.094
Outcome Mean	.56	.703	.069	.251	91.49	.317
Joint P-Value for RML				0.05		

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Appendix Table 8. RMLs and Opioid-Related Outcomes: Adults Ages 30 and Older

	Opioid Past-Month	Opioid Past-Year	Opioid Disorder	Frequency (past-year)	Frequent User
Medical Marijuana Law x Y2004-Y2014	.00002 (.001)	.002 (.002)	.0005 (.001)	3.68 (5.65)	.001 (.001)
Recreational Marijuana Law x Y2004-Y2014	-.001 (.002)	-.002 (.006)	-.001** (.001)	-20.31 (13.45)	-.003*** (.001)
Medical Marijuana Law x Y2015-Y2018	-.002 (.001)	.001 (.002)	.001 (.001)	-3.46 (6.30)	-.0005 (.001)
Recreational Marijuana Law x Y2015-Y2018	-.001 (.001)	.001 (.002)	.0003 (.001)	-10.10 (9.00)	-.0003 (.002)
Observations	348,000	348,000	348,000	9,600	348,000
Adjusted R^2	.009	.018	.008	.102	.008
Outcome Mean	.016	.043	.007	52.06	.009
Joint P-Value for RML	.973	.686	.098	.518	.04

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.

Appendix Table 9. RMLs and Heroin-Related Outcomes: Adults Ages 30 and Older

	Heroin Past Month	Heroin Past Year	Heroin Disorder	Frequency (past year)	Frequent User
Medical Marijuana Law	.0004 (.0003)	.001 (.0004)	.0003 (.0003)	-3.41 (2.18)	-.0001 (.0002)
Recreational Marijuana Law	-.0001 (.001)	.0003 (.001)	-.0001 (.0003)	-66.93*** (24.51)	-.0004 (.0004)
Observations	348,000	348,000	348,000	800	348,000
Adjusted R^2	.003	.006	.005	.268	.003
Outcome Mean	.001	.002	.001	117.37	.999

Notes: Based on data from the National Survey on Drug Use and Health 2004-2018. Each column represents the results of an OLS regression of substance use on state marijuana policies and a set of controls. Controls include demographic characteristics, time-varying state characteristics, state fixed effects, and month-by-year fixed effects. Regressions are weighted by NSDUH population weights. Observations are rounded to nearest 100s for disclosure purposes. Standard errors, corrected for clustering at the state level, are in parentheses. Frequency (past-year) of use is conditional on any past-year use. *p<0.05, **p<0.01, ***p<0.001.