Received: 19 February 2021 | Revised: 31 May 2021 | Accepted: 7 June 2021

DOI: 10.1002/hec.4377

HEALTH ECONOMICS LETTER

Health Economics WILEY

Recreational cannabis laws and opioid-related emergency department visit rates

Coleman Drake[1] | **Jiebing Wen**[2] | **Jesse Hinde**[3] | **Hefei Wen**[2]

[1]Department of Health Policy and Management, University of Pittsburgh Graduate School of Public Health, Pittsburgh, Pennsylvania, USA

[2]Department of Population Medicine, Harvard Pilgrim Health Care Institute, Boston, Massachusetts, USA

[3]RTI International, Research Triangle Park, North Carolina, USA

Correspondence
Coleman Drake, Department of Health Policy and Management, Graduate School of Public Health, University of Pittsburgh, 130 DeSoto Street, Pittsburgh, PA 15261, USA.
Email: cdrake@pitt.edu

Funding information
National Institute on Drug Abuse: K01D1051761

Abstract

The opioid epidemic in the United States has accelerated during the COVID-19 pandemic. As of 2021, roughly a third of Americans now live in a state with a recreational cannabis law (RCL). Recent evidence indicates RCLs could be a harm reduction tool to address the opioid epidemic. Individuals may use cannabis to manage pain, as well as to relieve opioid withdrawal symptoms, though it does not directly treat opioid use disorder. It is thus unclear whether RCLs are an effective policy tool to reduce adverse opioid-related health outcomes. In this study, we examine the impact of RCLs on a key opioid-related adverse health outcome: opioid-related emergency department (ED) visit rates. We estimate event study models using nearly comprehensive ED data from 29 states from 2011 to 2017. We find that RCLs reduce opioid-related ED visit rates by roughly 7.6% for two quarters after implementation. These effects are driven by men and adults aged 25–44. These effects dissipate after 6 months. Our estimates indicate RCLs did not increase opioid-related ED visits. We conclude that, while cannabis liberalization may offer some help in curbing the opioid epidemic, it is likely not a panacea.

KEYWORDS
cannabis, difference-in-differences, emergency department, opioid use disorder

1 | INTRODUCTION

The opioid epidemic in the United States has accelerated during the COVID-19 pandemic. Over 81,000 drug overdose deaths occurred between June 2019 and May 2020—the highest ever recorded in a one-year period (The Centers for Disease Control and Prevention, 2020). Meanwhile, 17 states have legalized recreational cannabis. Over a third of the U.S. population now lives in a state with a recreational cannabis law (RCL) (ProCon.Org, 2021; U.S. Census Bureau, 2021).

RCLs were not originally adopted to mitigate the opioid epidemic, though they may have the potential to reduce opioid use. Recent empirical evidence suggests cannabis is a substitute for prescription opioids in pain management (Shi et al., 2019; Wen & Hockenberry, 2018; Wen et al., 2021). In addition, there is some clinical evidence suggesting cannabis may mitigate opioid withdrawal symptoms (Wiese & Wilson-Poe, 2018). These findings are promising because RCLs, unlike medical cannabis laws (MCLs), make cannabis available to the entire population and thus have a larger imspact on cannabis use (Hollingsworth et al., 2020). However, cannabis does not directly treat the symptoms of opioid use disorder, for which medications for opioid use disorder are the only clinically effective treatment.

It is thus unclear whether RCLs are an effective policy tool to reduce adverse opioid-related health outcomes. Prior studies have primarily considered the mortality effects of RCLs, and the evidence is mixed. Livingston et al. (2017) found RCLs were associated with fewer opioid-related deaths in Colorado prior to 2015, but Alcocer (2020) found no such relationship when they extended the study period to 2017. Chan et al. (2020) found RCLs were associated with fewer synthetic opioid-related deaths, but Shover et al. (2019) found no evidence of a relationship between RCLs and opioid-related overdose deaths. Jayawardhana and Fernandez (2021) did not find a significant association between RCLs and opioid-related emergency department (ED) visits, though they found a positive association between RCLs and opioid-related hospitalizations in some specifications.

In this study, we examine the impact of RCLs on opioid-related ED visits. We are the first, to our knowledge, to examine the causal effects of RCLs on this important opioid-related adverse health outcome. Estimating an event study model with nearly comprehensive state-quarter ED visit data from 29 states from 2011 to 2017, we find RCLs are associated with a roughly 7.6% decrease in opioid-related ED visits in the first two quarters after implementation. These effects are driven by men and adults aged 25–44. However, these effects dissipate after the second quarter.

2 | METHODS

2.1 | Data

Our primary data source is the Healthcare Cost and Utilization Project (HCUP) Fast Stats database (AHRQ, 2020). These data are drawn from the HCUP Emergency Department Databases and are reported at the state-quarter level. They report our primary outcome, the number of opioid-related ED visits per 100,000 population from non-federal, non-rehabilitation hospitals. Here, ED visits include treat-and-release ED visits and those that result in an inpatient admission. The data define opioid-related ED visits as including poisoning by opioids, heroin, synthetic narcotics, and other narcotics, as well as disorders related to the misuse of opioids (e.g., opioid-induce psychotic disorders, opioid withdrawal). The data are stratified by age, income, and sex.

We augment the Fast Stats data with state-level data on RCL and MCL implementation dates from the RAND-USC Schaeffer Opioid Policy Tools and Information Center (RAND-USC OPTIC, 2021), other opioid-related state policies from RAND-USC Schaeffer and the Kaiser Family Foundation, and socioeconomic characteristics primarily from the American Community Survey. See Appendix A for details.

2.2 | Sample

Our sample consists of 812 state-quarters in 29 states from 2011 to 2017. We begin our study period in 2011 because the reformulation of Oxycontin in 2010 affected changes to the opioid epidemic that varied across states (Maclean et al., 2020). The year 2017 is the last in which many states report Fast Stats data. To maintain a balanced panel, we limit our sample to states that were included in the HCUP Fast Stats for all quarters. Figure 1 visualizes our sample. The treatment states are California, Maine, Massachusetts, and Nevada, all of which implemented RCLs in the first quarter of 2017.

Figure 2 and Appendix Table A1 report unadjusted trends in log opioid-related ED visit rates over time among treatment and comparison states. Opioid-related ED visit rates increased substantially over our study period for both groups. Outcome levels are higher among the treatment group, though trends between the two groups appear to be similar. Mean opioid-related ED visits per 100,000 population were 258.1 and 261.1 in 2016 and 2017 among the comparison states, and 368.1 and 343.8 in 2016 and 2017 among the treatment states.

2.3 | Empirical strategy

We employ an event study model to estimate the causal effect of RCLs on opioid-related ED visit rates. An event study model is similar to a difference-in-differences analysis, but it identifies treatment effects relative to the time period in which a policy is implemented. Several studies have found dynamic treatment effects related to cannabis legalization (e.g., Powell et al., 2018; Wen et al., 2021). Accordingly, we use an event study model as our baseline model to examine variation in treatment effects over time. Our baseline specification is

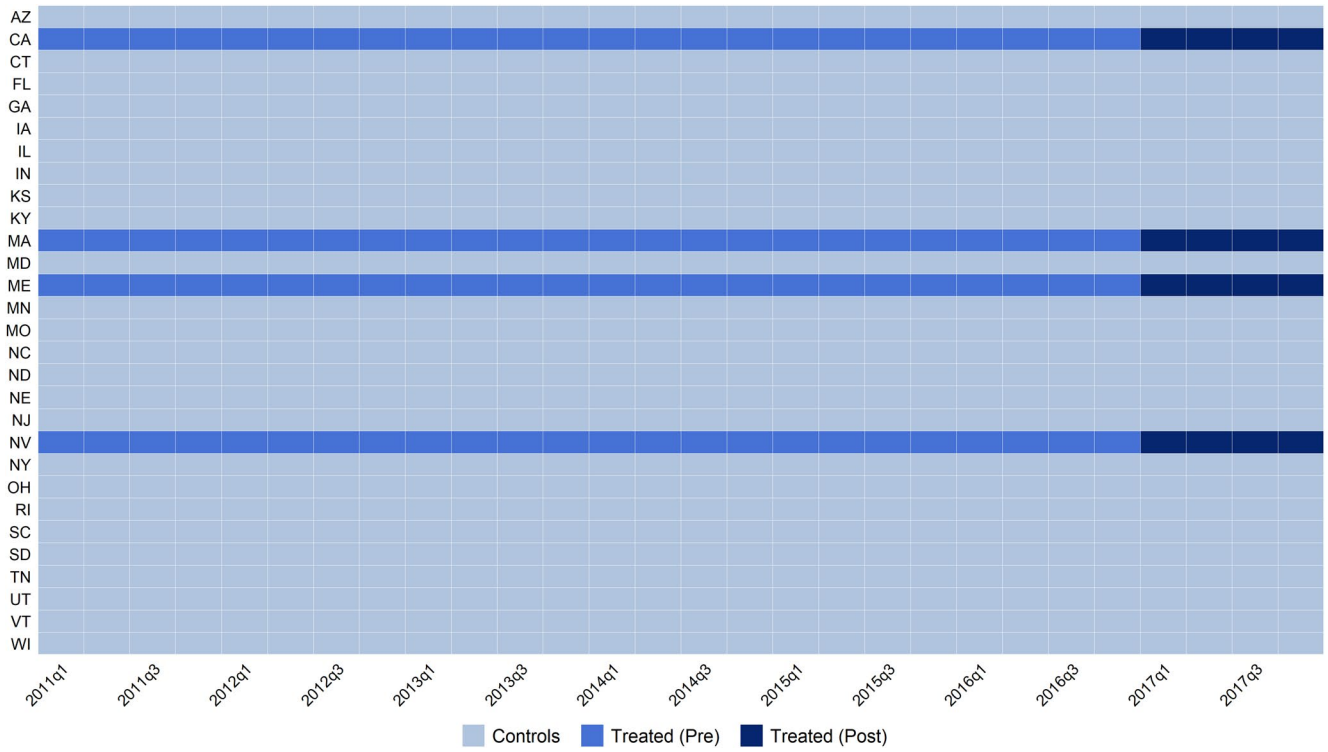

FIGURE 1 Recreational cannabis law (RCL) implementation among sample states. *Note*. We obtained RCL implementation date data from the RAND Corporation's Opioid Policy Tools and Information Center (RAND-USC OPTIC, 2021). We limited sample states to those that contributed to is the Agency for Health Research and Quality's (AHRQ) Healthcare Cost and Utilization Project Fast Stats database (AHRQ, 2020). Our sample includes 812 state-quarters [Colour figure can be viewed at wileyonlinelibrary.com]

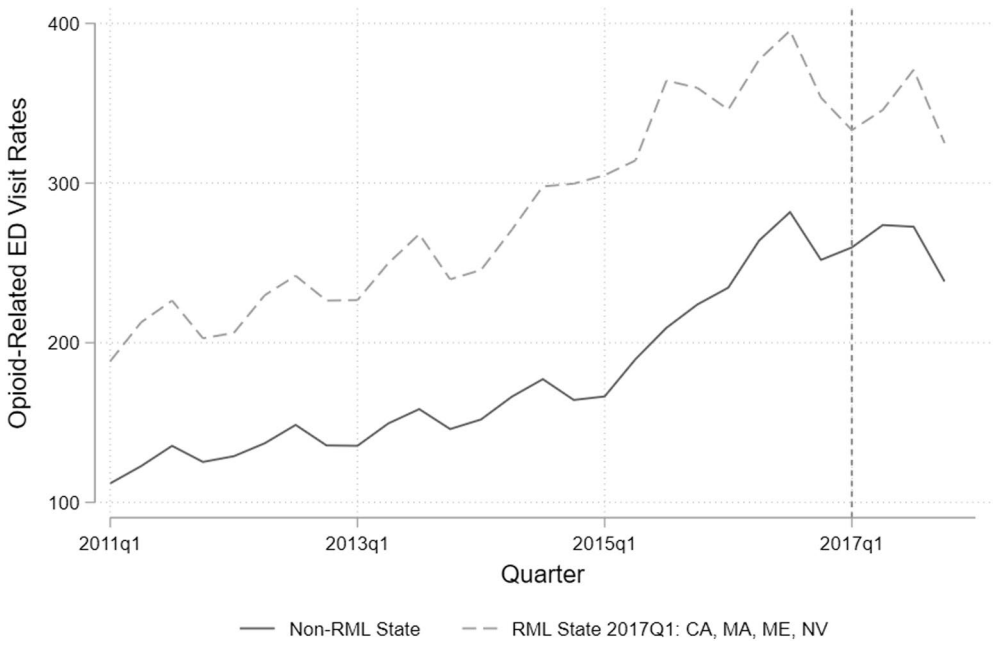

FIGURE 2 Unadjusted trends in log opioid-related emergency department (ED) visit rates. *Note*. All sample states are listed in Appendix A and are shown in Figure 1

$$\ln\left(EDrate_{st}\right)=\alpha+\sum_{j=-5,\,j\neq 1}^{3}\beta_t RCL_{st}\left(t=k+j\right)+\gamma Pol_{st}+\delta Dem_{st}+\theta_s+\tau_t+\epsilon_{st}. \quad (1)$$

The outcome, $\ln\left(EDrate_{st}\right)$, is the log opioid-related ED visit rates per 100,000 population in state s in quarter t. In the summation term $\sum_{j=-5}^{3}\beta_t RCL_{st}\left(t=k+j\right)$, j indexes the quarter relative to the implementation of a RCL in a treatment state—implementation occurs at $j=0$—and k represents the quarter in which a RCL was implemented. We observe three periods after RCL implementation, so the summation ends with 3. We also include "leads" in the model where $j<0$ to test for differential pre-trends between treatment and comparison states. The reference category is $j=-1$. The furthest lead, $j=-5$, serves as a catch-all term for pre-treatment periods where $j\leq -5$. Pol_{st} is a vector of state-quarter policy indicators including: a MCL; a mandatory prescription drug monitoring program; Medicaid expansion; a good Samaritan law; a Naloxone access law. Dem_{st} is a vector of state-year socioeconomic variables including: the poverty rate; median household income; the unemployment rate; community hospital beds per 1000 population. We also include state and quarter fixed effects θ_s and τ_t. We cluster the error term, ϵ_{st}, at the state level. See Appendix A for further details.

Our identifying assumption is that opioid-related ED visit rates would have trended similarly in states that legalized recreational cannabis in the absence of legalization. We lend support to this assumption by testing whether the lead coefficients are statistically different from zero.

3 | RESULTS

3.1 | Baseline results

We present the results from our baseline model in Figure 3 and Appendix Table A2. Relative to mean opioid-related ED visits per 100,000 population of 265.9 in the quarter prior to treatment (2016Q4), we find that RCLs are associated with 7.8% (95% CI = −13.6 to −2.0) and 7.7% (95% CI = −13.8 to −1.5) decreases in opioid-related ED visit rates in the first two quarters following implementation. However, these effects dissipate in the third and fourth quarters following implementation, when RCLs are associated with insignificant 3.0% (95% CI = −9.8 to 3.7) and 2.4% (95% CI = −9.5 to 4.8) decreases. Overall, RCLs are associated with a marginally significant 5.2% (95% CI = −10.7 to 0.2, $p=0.06$) decrease in opioid-related ED visit rates over the study period.

We proceed by testing for differential trends in treatment states prior to RCL implementation. The lead terms also are displayed in Figure 3. We do not find that the lead terms included in our event study model (i.e., a year prior to RCL implementation) are jointly significant ($F=0.31$, $P=0.82$). We do note the lead term for 5+ quarters is significant (Appendix Table A1). As shown in Figure 2, this lead term appears to capture a historical level difference between RCL and non-RCL states prior to 2016.

We re-estimate our baseline models for socioeconomic sub-groups. The results suggest our findings are driven by men and, to a lesser extent, adults aged 25–44. Men and adults aged 25–44 experience 11.5% (95% CI = −17.9 to −5.0) and 10.6% (95% CI = −17.3 to −4.0) reductions in opioid-related ED visits in the first quarter of RCL implementation, respectively. These effects also dissipate over time, though the overall result is significant for men (beta = −8.6%, 95% CI = −15.4 to −1.8). Results for adults aged 25–44, men, and women are shown in Figure 3; results for all sub-groups are shown in Appendix Table A3. Only the results for men withstand a Bonferroni adjustment for multiple hypothesis testing, so we interpret the other results with caution.

3.2 | Robustness checks

We conduct a series of robustness checks that support a causal interpretation of our findings. First, we test whether our results are driven by a particular state by iteratively excluding treatment states from our analysis (Appendix Table A4). Doing so has a negligible effect on our findings. Second, we re-estimate our baseline model with HCUP Fast Stats data dating back to 2006 to test whether our findings are sensitive to the chosen study period. After adding state-year linear time trends to our model to account for the dynamics of the first and second waves of the opioid epidemic, we find that our results are robust (see Appendix Table A5).

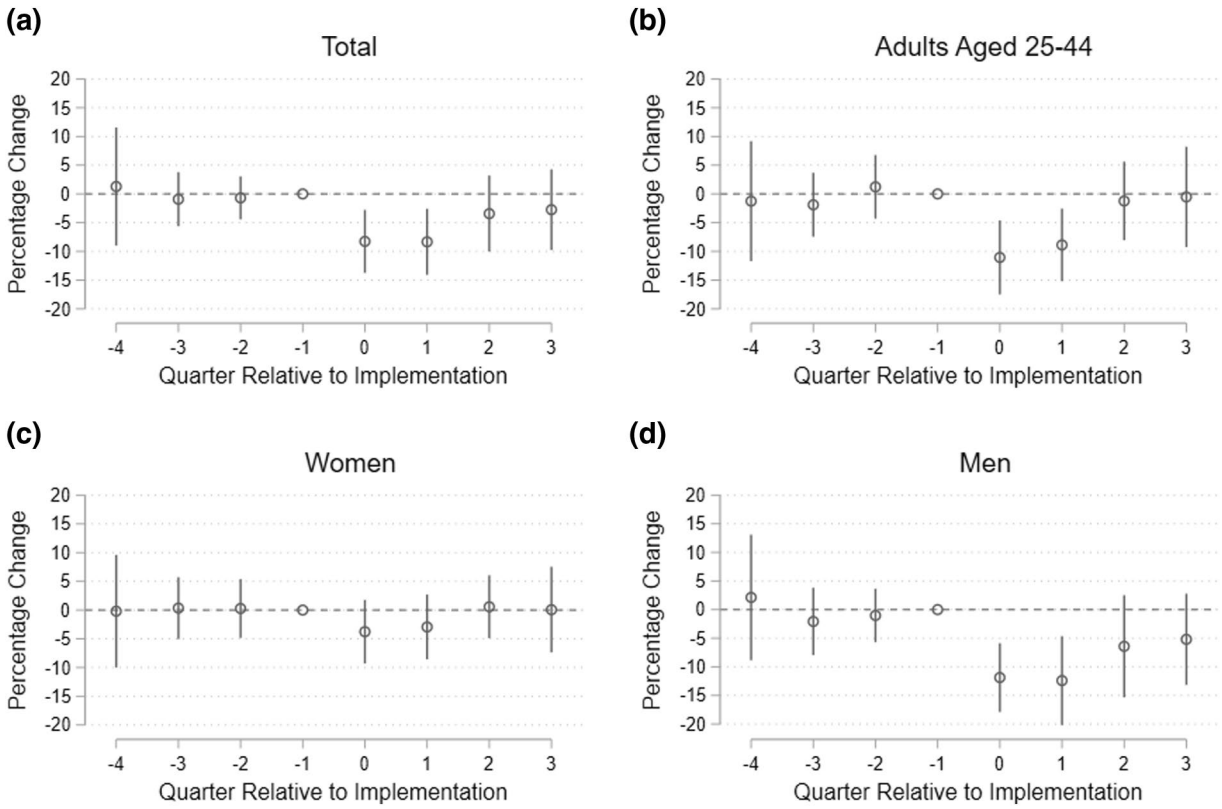

FIGURE 3 Event study estimates of recreational cannabis laws' effect on the number of opioid-related emergency department visits per 100,000 population. *Note*. Estimates correspond to the baseline model described in Section 2.3 and Appendix A. Exact point estimates and confidence intervals are ped in Appendix Tables A2 and A3. Coefficients are retransformed to represent percentage changes in rates, and standard errors are calculated using the delta method. (a) Total; (b) Adults aged 25–44; (c) Women; (d) Men

4 | DISCUSSION

We provide novel evidence of the effects of RCLs on a key opioid-related adverse health event, opioid-related ED visits. We find RCLs reduce opioid-related ED visits by roughly 7.6% for two quarters after RCL implementation. These effects are driven by men and adults aged 25–44, which is consistent with prior literature finding that men and young adults account for the majority of persons using cannabis (Kerr et al., 2018), and that men'|'s health outcomes may be more responsive to cannabis legalization (Anderson et al., 2014). Our overall findings and those for young adults and men dissipate in magnitude and are no longer significant in the third and fourth quarters. Only the results for men are significant when we aggregate the four post-treatment quarters. Still, the upper bounds of the confidence intervals for our aggregated results allow us to rule out that RCLs affected any meaningful increase in opioid-related ED visit rates (i.e., greater than 0.2%). We also are able to rule out any increase in opioid-related ED visits for men. Broadly, our findings are consistent with Jayawardhana and Fernandez (2021), who also did not find an association between RCLs and opioid-related ED visits. Our findings also are consistent with studies that have not found an association between RCLs and mortality (Alcocer, 2020; Shover et al., 2019).

Our results indicate that RCLs may only affect a temporary reduction in opioid-related ED visits. Cannabis legalization may increase cannabis use for pain relief, acting as a substitute for opioids (Wen and Hockenberry 2018). However, cannabis is not a clinically effective treatment for opioid use disorder. Persons with opioid use disorder may attempt to use cannabis after the passage of a RCL, find that it is not a sufficient substitute, and then increase use of closer substitutes, including illicit opioids, such as heroin or fentanyl. While cannabis liberalization may offer some help in curbing the opioid crisis, our results suggest that it is not a panacea.

We note three limitations. First, we are unable to distinguish ED visits related to different types of opioids (e.g., heroin, fentanyl vs. prescription opioids) and diagnoses (e.g., opioid use disorder vs. overdose) because the HCUP Fast Stats data are not stratified as such. Second, our sample excludes four states with RCLs—Alaska, Colorado, Oregon, and Washington—that are not consistently present in the HCUP Fast Stats data during the sample period. Third, RCLs may have different effects in other states and over longer time periods. Future research should continue to explore the relationships

between RCLs and opioid-related health outcomes in newly legalizing states, over longer treatment periods, for different populations, and for different health outcomes.

ACKNOWLEDGMENTS

The authors are grateful to David Bradford and Alex Hollingsworth for their helpful feedback in developing this manuscript. Drake acknowledges support from the National Institute on Drug Abuse under award number K01D1051761.

CONFLICT OF INTEREST

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ORCID

Coleman Drake https://orcid.org/0000-0002-0618-0626
Hefei Wen https://orcid.org/0000-0001-5064-2501

REFERENCES

Agency for Health Research and Quality. (2020). *HCUP Fast Stats*. https://www.hcupus.ahrq.gov/faststats/landing.jsp

Alcocer, J. J. (2020). Exploring the effect of Colorado's recreational marijuana policy on opioid overdose rates. *Public Health*, *185*, 8–14. https://doi.org/10.1016/j.puhe.2020.04.007

Anderson, D. M., Rees, D. I., & Sabia, J. J. (2014). Medical marijuana laws and suicides by gender and age. *American Journal of Public Health*, *104*(12), 2369–2376. https://doi.org/10.2105/AJPH.2013.301612

Chan, N. W., Burkhardt, J., & Flyr, M. (2020). The effects of recreational marijuana legalization and dispensing on opioid mortality. *Economic Inquiry*, *58*(2), 589–606. https://doi.org/10.1111/ecin.12819

Hollingsworth, A., Wing, C., & Bradford, A. (2020, August 19). Comparative effects of recreational and medical marijuana laws on drug use among adults and adolescents. *SocArXiv Papers*. https://doi.org/10.31235/osf.io/drx9f

Jayawardhana, J., & Fernandez, J. M. (2021). The associations of medical marijuana policies with opioid-related health care utilization. *Health Services Research*, *56*(2), 299–309. https://doi.org/10.1111/1475-6773.13632

Kerr, W. C., Lui, C., & Ye, Y. (2018). Trends and age, period and cohort effects for marijuana use prevalence in the 1984–2015 US National Alcohol Surveys. *Addiction*, *113*(3), 473–481. https://doi.org/10.1111/add.14031

Livingston, M. D., Barnett, T. E., Delcher, C., & Wagenaar, A. C. (2017). Recreational cannabis legalization and opioid-related deaths in Colorado, 2000–2015. *American Journal of Public Health*, *107*(11), 1827–1829. https://doi.org/10.2105/AJPH.2017.304059

Maclean, J. C., Mallatt, J., Ruhm, C. J., & Simon, K. (2020). *Review of Economic Studies on the Opioid Crisis*. NBER Working Paper, 28067. http://www.nber.org/papers/w28067

Powell, D., Pacula, R. L., & Jacobson, M. (2018). Do medical marijuana laws reduce addictions and deaths related to pain killers? *Journal of Health Economics*, *58*, 29–42. https://doi.org/10.1016/j.jhealeco.2017.12.007

ProCon.Org. (2021). *Legal Recreational Marijuana States and DC*. https://marijuana.procon.org/legalrecreational-marijuana-states-and-dc/

RAND-USC OPTIC. (2021). OPTIC-Vetted Policy Data Sets. Retrieved February 10, 2021, from https://www.rand.org/health-care/centers/optic/resources/datasets.html

Shi, Y., Liang, D., Bao, Y., An, R., Wallace, M. S., & Grant, I. (2019). Recreational marijuana legalization and prescription opioids received by Medicaid enrollees. *Drug and Alcohol Dependence*, *194*, 13–19. https://doi.org/10.1016/j.drugalcdep.2018.09.016

Shover, C. L., Davis, C. S., Gordon, S. C., & Humphreys, K. (2019). Association between medical cannabis laws and opioid overdose mortality has reversed over time. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(26), 12624–12626. https://doi.org/10.1073/pnas.1903434116

The Centers for Disease Control and Prevention. (2020). *Overdose Deaths Accelerating During COVID-19*. https://www.cdc.gov/media/releases/2020/p1218-overdose-deaths-covid-19.html

U.S. Census Bureau. (2021). *State Population Totals and Components of Change: 2010–2019*. https://www.census.gov/data/tables/time-series/demo/popest/2010s-state-total.html

Wen, H., & Hockenberry, J. M. (2018). Association of medical and adult-use marijuana laws with opioid prescribing for medicaid enrollees. *JAMA Internal Medicine*, *178*(5), 673–679. https://doi.org/10.1001/jamainternmed.2018.1007

Wen, J., Wen, H., Butler, J. S., & Talbert, J. C. (2021). The impact of medical and recreational marijuana laws on opioid prescribing in employer-sponsored health insurance. *Health Economics*, *30*(5), 989–1000. https://doi.org/10.1002/hec.4237

Wiese, B., & Wilson-Poe, A. R. (2018). Emerging evidence for cannabis' role in opioid use disorder. *Cannabis and Cannabinoid Research*, *3*(1), 179–189. https://doi.org/10.1089/can.2018.0022

How to cite this article: Drake, C., Wen, J., Hinde, J., & Wen, H. (2021). Recreational cannabis laws and opioid-related emergency department visit rates. *Health Economics*, *30*(10), 2595–2605. https://doi.org/10.1002/hec.4377

APPENDIX A

Specification and measures

Specification

Our baseline event study model is

$$\ln\left(EDrate_{st}\right) = \alpha + \sum_{j=-5}^{3} \beta_t RML_{st}\left(t = k + j\right) + \gamma Pol_{st} + \delta Dem_{st} + \theta_s + \tau_t + \epsilon_{st}. \quad \text{(A1)}$$

The outcome, $\ln\left(EDrate_{st}\right)$, is the log opioid-related emergency department (ED) visit rate per 100,000 population in state s in quarter t. We log transform the outcome to normalize its distribution. In the summation term $\sum_{j=-5}^{3} \beta_t RCL_{st}\left(t = k + j\right)$, j indexes the quarter relative to the implementation of a recreational cannabis law (RCL) in a treatment state; k represents the quarter in which a RCL was implemented. We observe three periods after RCL implementation, so the summation ends with 3. We also include "leads" in the model where $j < 0$ to test for differential pre-trends between treatment and comparison states. The reference category is $j = -1$. The furthest lead, $j = -5$, serves as a catch-all term for pre-treatment periods where $j \leq -5$. Pol_{st} is a vector of binary indicators for whether state s implemented the following policies by the start of quarter t: a medical cannabis law (MCL); a mandatory prescription drug monitoring program (PDMP); Medicaid expansion; a good Samaritan law; a Naloxone access law. Dem_{st} is a vector of state-year socioeconomic variables including: the poverty rate; median household income; the unemployment rate; community hospital beds per 1000 population. We also include state and quarter fixed effects θ_s and τ_t, as well as a binary indicator for whether a given state-quarter has a lead with an value greater than four. We cluster the error term, ϵ_{st}, at the state level. We retransform standard errors using the delta method. We estimated all models in Stata 16 using the *reghdfe* command. We calculated standard errors using the delta method with the *nlcom* command. We report results using the *estout* command.

Our identifying assumption is that opioid-related ED visit rates would have trended similarly in states that legalized recreational cannabis in the absence of legalization. We lend support to this assumption by testing whether the lead coefficients are statistically different from zero. We do not find that the lead terms are jointly significant ($F = 0.77$, $p = 0.52$).

Our samples include all states that contributed to AHRQ'|'s Healthcare Cost and Utilization Project (HCUP) State Emergency Department Databases (SEDD) data from 2011 to 2017. During these years, four SEDD states implemented RCLs and 25 did not. The four treatment states, all of which implemented in 2017Q1, were CA, MA, ME, and NV. The 25 states that did not implement RCLs include AZ, CT, FL, GA, IA, IL, IN, KS, KY, MD, MN, MO, NC, ND, NE, NJ, NY, OH, RI, SC, SD, TN, UT, VT, and WI.

Measures: Outcomes

We use logarithmic-transformed rates of opioid-related ED visits per 100,000 state population because they improve the skewness and kurtosis of the distributions of the level rates. The logarithmic-transformation is commonly used to transform skewed outcomes to approximately conform to normality; the estimates provided us with the percentage changes of the outcome.

The opioid-related hospital ED visit data were derived from the HCUP SEDD, which contained the universe of the hospital encounter abstracts and ED encounter abstracts from hospital-affiliated EDs in the participating HCUP States and were translated into a uniform format to facilitate multistate comparisons and analyses. Types of hospitals included in the SEDD are community hospitals, defined as short-term, non-Federal, general, and other hospitals, excluding hospital units of other institutions (e.g., prisons); community hospitals include obstetrics and gynecology, otolaryngology, orthopedic,

cancer, pediatric, public, and academic medical hospitals; long-term care facilities such as rehabilitation, psychiatric, and substance abuse treatment hospitals were excluded; however, if a patient received long-term care, rehabilitation, or treatment for a psychiatric or substance abuse condition in a community hospital, the discharge record for that stay was included.

Opioid-related diagnoses, including opioid abuse, dependence, and overdose, were identified by the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) diagnostic codes: 304.00–304.02: Opioid type dependence (unspecified; continuous; episodic); 304.70–304.72: Combinations of opioid type drug with any other drug dependence (unspecified; continuous; episodic); 305.50–305.52: Opioid abuse (unspecified; continuous; episodic); 965.00–965.02; 965.09: Poisoning by opium (alkaloids), unspecified; heroin; methadone; other opiates and related narcotics; 970.1: Poisoning by opiate antagonists; E850.0–E850.2: Accidental poisoning by heroin; methadone; other opiates and related narcotics; E935.0–E935.2: Heroin, methadone, other opiates and related narcotics causing adverse effects in therapeutic use; E940.1: Opiate antagonists causing adverse effects in therapeutic use.

Opioid-related diagnoses were also identified by the International Classification of Diseases, 10th Revision, Clinical Modification (ICD-10-CM) diagnostic codes: F11 series: Opioid-related disorders, excluding F11.21; T40 series: Poisoning by, adverse effect of, and underdosing of narcotics and psychodysleptics, including poisoning accidental, undetermined, and adverse effect, with a seventh digit indicating initial, subsequent encounter, sequela: Opium 0X1, 0X4, 0X5, Heroin 1X1, 1X4, Other opioids 2X1, 2X4, 2X5, Methadone 3X1, 3X4, 3X5, Other synthetic narcotics 4X1, 4X4, 4X5, Unspecified narcotics 601, 604, 605, Other narcotics 691, 694, 695.

More information on the HCUP Fast Stats can be accessed at https://www.hcup-us.ahrq.gov/faststats/OpioidUseServlet.

Measures: Treatment and control variables

Our treatment variables are binary indicators for quarter in which we observe a given treatment state, relative to the implementation of its RCL. We define a state'ı's RCL implementation quarter as the quarter in which it had implemented a RCL by the end of the first month of the quarter. We obtained data on RCL implementation dates from the RAND-USC Schaeffer Opioid Policy Tools and Information Center (OPTIC). Those data are available here at https://www.rand.org/health-care/centers/optic/resources/datasets.html.

We also used the RAND-USC OPTIC data to construct the following binary indicators for whether the following policies were implemented by the first month of each state-quarter: (1) MCLs; (2) PDMP mandates requiring prescribers to consult a PDMP before dispensing prescription opioids; (3) good Samaritan laws; (4) naloxone access laws. Additionally, we included a binary indicator for whether Medicaid expansion was implemented by the first month of each state-quarter. We obtained Medicaid expansion dates from the Kaiser Family Foundation at https://www.kff.org/health-reform/state-indicator/state-activity-around-expanding-medicaid-under-the-affordable-care-act.

We also controlled for four sociodemographic variables: median income, poverty rates, unemployment rates, and community hospital beds per capita. We obtained the first three variables from the Area Health Resource File, available at https://datawarehouse.hrsa.gov/topics/ahrf.aspx. Community hospital beds include the number of staffed beds for community hospitals, which represent 85% of all hospitals, per 1000 state population, for each state-year. Federal hospitals, long-term care hospitals, psychiatric hospitals, institutions for the intellectually disabled, and alcoholism and other chemical dependency hospitals are not included. We obtained these data from the Kaiser Family Foundation at https://www.kff.org/other/state-indicator/beds-by-ownership/

TABLE A1 Mean opioid-related ED visits per 100,000 population among treatment and comparison states over time

	Mean opioid-related ED visits per 100,000 population		
Time Period	**Treatment states**	**Comparison states**	**All states**
Overall: 2011–2017	286.6	184.3	198.4
Pre-treatment: 2011–2016	277.0	171.5	186.1
Pre-treatment: 2016	368.1	258.1	273.2
Pre-treatment: 2016 Q4	353.6	251.9	265.9
Post-treatment: 2017	343.8	261.1	272.5

Note: Means are calculated from treatment and comparison states as shown in Figure 1. Trends in mean opioid-related ED visits per 100,000 population across the treatment and comparison groups are shown by quarter in Figure 2.

Abbreviation: ED, emergency department.

TABLE A2 Event study estimates of recreational cannabis laws' effects on opioid-related ED visit rates, 2011–2017

Covariate	Percentage change in opioid-related ED visit rate and 95% confidence interval
Quarters prior to RCL implementation	
5+	17.2* [2.8, 31.6]
4	1.0 [−9.3, 11.2]
3	−1.2 [−5.9, 3.5]
2	−0.9 [−4.9, 3.1]
1	-
Quarters after RCL implementation	
0 (implementation)	−7.8** [−13.6, −2.0]
1	−7.7* [−13.8, −1.5]
2	−3.0 [−9.8, 3.7]
3	−2.4 [−9.5, 4.8]
State policies (0/1)	
Medical cannabis law implemented	6.1 [−2.5, 14.8]
Medical cannabis dispensary opened	−7.5** [−12.0, −3.0]
Medicaid expansion	8.9* [1.4, 16.4]
PDMP mandate	0.9 [−4.4, 6.1]
Good Samaritan law	1.2 [−4.2, 6.7]
Naloxone access law	9.5** [3.0, 16.0]
Socioeconomic characteristics	
Poverty (%)	1.2 [−3.6, 5.9]
Median income ($10,000s)	−5.2 [−26.0, 15.6]
Unemployment (%)	−3.4** [−5.6, −1.3]
Hospital beds per 1000 population	−19.9 [−41.0, 1.2]
State fixed effects	X
Quarter fixed effects	X
Mean of outcome (mean [SD])	198.4 (111.1)
States in sample	29
N	812

Note: The model is estimated using log rates. Coefficients are retransformed to represent percentage changes in rates. Retransformed standard errors are calculated using the delta method; standard errors are clustered at the state level. See Figure 1 for a list of sample states and RCL implementation timing. See Appendix A for details on the measurement of the outcome and control variables.

Abbreviations: ED, emergency department; PDMP, prescription drug monitoring program; RCL, recreational cannabis law.

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$.

TABLE A3 Log opioid-related ED visit event study coefficients for recreational cannabis implementation by socioeconomic subgroups

Socioeconomic subgroup	Quarter relative to implementation, coefficient (95% confidence interval)							
	−4	−3	−2	−1	0	1	2	3
Age groups								
1–24	0.9	2.1	0.7	-	−7.9	−1.1	−3.1	−2.8
	[−15.5, 17.3]	[−3.4, 7.6]	[−6.0, 7.4]		[−19.2, 3.3]	[−9.9, 7.7]	[−19.1, 12.9]	[−17.5, 11.9]
25–44	−1.5	−2.2	1.0	-	−10.6**	−8.3*	−0.8	−0.2
	[−11.9, 8.8]	[−7.7, 3.3]	[−4.7, 6.7]		[−17.3, −4.0]	[−15.0, −1.5]	[−8.0, 6.3]	[−9.1, 8.7]
45–64	0.6	−3.7	−6.1**	-	−6.4	−11.1*	−7.8	−8.0
	[−10.7, 11.9]	[−10.3, 2.8]	[−10.7, −1.5]		[−15.8, 3.0]	[−20.4, −1.8]	[−17.9, 2.2]	[−19.7, 3.8]

(Continues)

TABLE A3 (Continued)

Socioeconomic subgroup	Quarter relative to implementation, coefficient (95% confidence interval)							
	−4	−3	−2	−1	0	1	2	3
65+	14.8	7.1	4.8	-	0.3	−3.3	−5.9	3.3
	[−5.0, 34.5]	[−6.1, 20.4]	[−11.1, 20.8]		[−17.4, 18.1]	[−22.1, 15.6]	[−14.9, 3.1]	[−6.3, 12.9]
Income quartiles								
1	−3.5	−7.0*	−8.8***	-	−11.0	−15.6**	−12.7*	−9.0*
	[−12.0, 5.0]	[−13.5, −0.5]	[−13.9, −3.7]		[−23.3, 1.3]	[−27.1, −4.2]	[−24.0, −1.5]	[−17.3, −0.7]
2	6.5	−0.4	2.7	-	−9.6*	−4.7	−1.7	2.6
	[−7.2, 20.2]	[−8.2, 7.5]	[−3.1, 8.6]		[−17.1, −2.0]	[−12.3, 2.9]	[−13.3, 9.9]	[−6.7, 12.0]
3	1.7	0.9	5.4	-	1.6	3.8	13.5**	6.2
	[−9.4, 12.9]	[−8.5, 10.4]	[−3.4, 14.3]		[−8.4, 11.6]	[−3.3, 10.9]	[4.1, 22.9]	[−2.3, 14.7]
4	0.1	6.5	5.9	-	−6.2	−4.7	1.1	−7.7
	[−15.0, 15.2]	[−7.8, 20.7]	[−13.9, 25.6]		[−15.9, 3.4]	[−13.8, 4.4]	[−7.4, 9.7]	[−21.3, 5.9]
Sex								
Female	−0.5	0.0	−0.0	-	−3.3	−2.2	1.0	0.5
	[−10.4, 9.3]	[−5.5, 5.5]	[−5.3, 5.3]		[−9.1, 2.5]	[−8.2, 3.8]	[−4.4, 6.4]	[−6.8, 7.8]
Male	1.9	−2.3	−1.2	-	−11.5***	−11.8**	−6.1	−4.9
	[−9.0, 12.8]	[−8.1, 3.5]	[−6.1, 3.7]		[−17.9, −5.0]	[−20.0, −3.6]	[−15.3, 3.1]	[−13.2, 3.4]

Note: All models are estimated using the same procedures described in Section 2.3, but with outcomes limited to each of the socioeconomic groups listed above. We caution against a causal interpretation of these results, as we are underpowered to perform a Bonferroni correction (i.e., Bonferroni-adjusted p value = $p / (\text{Parameters} + \text{Models}) = 0.05 / (4 + 10) = 0.0036$). As with our baseline results, these results tend to appear for the first quarter or two after implementation and then dissipate.

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$.

TABLE A4 Event study coefficients iteratively excluding states

Leads and lags	Excluded state, transformed coefficients (SEs)				
	None (1)	California (2)	Maine (3)	Massachusetts (4)	Nevada (5)
−4	1.0	−0.4	−0.8	−0.5	6.3*
	[−9.3, 11.2]	[−12.5, 11.7]	[−12.8, 11.1]	[−12.8, 11.8]	[1.0, 11.5]
−3	−1.2	−0.5	−1.7	−2.5	0.2
	[−5.9, 3.5]	[−5.7, 4.7]	[−7.1, 3.7]	[−6.9, 1.8]	[−4.2, 4.7]
−2	−0.9	0.3	−1.6	−1.6	−0.8
	[−4.9, 3.1]	[−3.1, 3.8]	[−5.8, 2.6]	[−5.8, 2.6]	[−5.2, 3.7]
−1	−7.8**	−8.9**	−9.1**	−5.7	−7.6*
	[−13.6, −2.0]	[−14.9, −2.9]	[−15.2, −3.0]	[−11.6, 0.2]	[−14.8, −0.4]
0	-	-	-	-	-
1	−7.7*	−10.1***	−7.0	−6.4	−7.3*
	[−13.8, −1.5]	[−14.0, −6.3]	[−14.4, 0.5]	[−14.0, 1.2]	[−14.2, −0.3]
2	−3.0	−4.7	−1.7	−4.4	−1.7
	[−9.8, 3.7]	[−11.8, 2.4]	[−8.7, 5.3]	[−12.5, 3.8]	[−8.9, 5.4]
3	−2.4	−4.4	−2.3	−3.0	−0.1
	[−9.5, 4.8]	[−11.7, 3.0]	[−10.8, 6.1]	[−12.2, 6.1]	[−6.3, 6.0]

Note: Model (1) is the baseline model described in Section 2.3 and shown in Appendix Table A1. Subsequent models are the same as this model, but exclude the listed state.

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$.

TABLE A5 Event study estimates of recreational cannabis laws' effects on opioid-related ED visit rates over different study periods, 2006–2017 and 2011–2017

	2006–2017 sample		2011–2017 sample	
Covariates	**(1)**	**(2)**[a]	**(3)**	**(4)**
Quarters before RCL				
4	5.4 [−0.1, 10.9]	5.8* [0.3, 11.4]	1.0 [−9.3, 11.2]	1.5 [−9.0, 11.9]
3	0.0 [−4.8, 4.8]	0.4 [−4.3, 5.1]	−1.2 [−5.9, 3.5]	−0.7 [−5.5, 4.0]
2	−1.5 [−6.0, 3.0]	−1.2 [−5.7, 3.2]	−0.9 [−4.9, 3.1]	−0.6 [−4.4, 3.2]
1	-	-	-	-
Quarters after RCL				
0	−4.5 [−13.9, 4.9]	−7.7* [−14.2, −1.2]	−7.8** [−13.6, −2.0]	−9.6** [−16.8, −2.5]
1	−4.6 [−13.3, 4.2]	−7.8* [−14.3, −1.4]	−7.7* [−13.8, −1.5]	−9.6** [−16.6, −2.7]
2	0.5 [−5.8, 6.8]	−2.5 [−9.8, 4.9]	−3.0 [−9.8, 3.7]	−4.9 [−12.7, 2.8]
3	2.8 [−4.4, 9.9]	−0.1 [−6.8, 6.6]	−2.4 [−9.5, 4.8]	−4.2 [−13.3, 4.8]
Model properties				
State-linear time trends	-	X	-	X
RCL implementing states	3	3	4	4
Number of states	25	25	29	29
State-quarters (*N*)	1200	1200	812	812

Background: We re-estimate our baseline model with HCUP Fast Stats data dating back to 2006 to test whether our findings are sensitive to the chosen study period. This excludes four states that did not participate in the HCUP Fast Stats as of 2006, including one of the treatment states: Nevada. Here, we find that the magnitude of our findings is reduced and their significance is eliminated if we extend the sample period to 2006 (column 1). However, our baseline model was not intended to capture the longer term dynamics of the opioid epidemic (i.e., states transitioning to the second wave of the opioid epidemic and the huge increases in adverse opioid-related events that occurred around the beginning of the previous decade). We estimate models with state-year linear time trends to test whether these dynamics may explain the differences between our results. We find that adding state-year linear time trends to the 2006–2017 model (column 2)—as well as our baseline 2011–2017 model (column 4)—yields estimates that are statistically indistinguishable from our baseline model (column 3). We conclude that our results are robust to the chosen study period, at least after including controls to account for the changing dynamics of the opioid crisis.

Note: The 2006–2017 sample excludes four states present in the 2011–2017 sample. Illinois, Kentucky, Nevada, and North Dakota. These four states were not included in the HCUP Fast Stats data by 2006, though they were by 2011. The model is estimated using log rates. Coefficients are retransformed to represent percentage changes in rates. Retransformed standard errors are calculated using the delta method; standard errors are clustered at the state level. See Figure 1 for a list of sample states and RCL implementation timing.

Abbreviations: ED, emergency department; HCUP, Healthcare Cost and Utilization Project; RCL, recreational cannabis law.

[a]A *F*-test of the joint significance of the lead terms in model (2) does not yield a significant result ($F = 0.05$, $p = 0.45$).

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$.