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Exploring the effect of Colorado's recreational marijuana policy on opioid overdose rates

J.J. Alcocer

University of Southern California, Sol Price School of Public Policy, 650 Childs Way, Los Angeles, CA 90089, USA

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ABSTRACT

Objectives: Opioid overdose death rates have continued to spike exponentially from the start of the 21st century, creating what is known to be one of the worst public health crises in the United States. Simultaneously, as more states began passing medical cannabis laws (MCLs), the idea that marijuana was the solution to the opioid crisis began to spread nationwide. As some states have maintained strict medical marijuana policies, others—such as Colorado—have expanded their statutes to allow recreational marijuana sales within their state. Researchers have been able to provide sense of the public health implications resulting from MCLs, but little is known about the effects of this marijuana policy expansion. This preliminary study will focus on exploring the statewide effects of Colorado's recreational marijuana policy on the state's opioid overdose death rates.
Study design: Because Colorado has existing panel data for opioid overdose death rates, we can use statistical software to define and create an optimal control group to adequately resemble Colorado's outcome variable of interest. This process known as the synthetic control method can provide a valid counterfactual for Colorado's opioid overdose outcomes in the absence of this policy—a Colorado that did not expand marijuana policy to the point recreational dispensaries were established.
Methods: Opioid overdose death rate data from the Centers for Disease Control and Prevention's Wide-ranging Online Data for Epidemiologic Research (WONDER) will be used to construct a synthetic control unit composed of a donor pool of states resembling Colorado's regulatory environment pertaining to marijuana before legalization. The synthetic control unit allows for a comparative observation of overdose rate trends in Colorado and its synthetic counterpart for the years 1999–2017, all while including a set of predictor variables for robustness checks. A difference-in-difference estimate will then help us observe the effects of the treatment given to Colorado. Inference tests will be conducted to evaluate the method's predictive power and significance of the results.
Results: The results of the synthetic control model and its outcomes showed that the estimated negative 5% drop in overdose death rates was deemed insignificant on conducting a placebo in-space analysis, meaning there is not enough evidence to prove that opening recreational dispensaries as a result of recreational marijuana legislation was instrumental in reducing Colorado's ongoing opioid crisis depicted through opioid overdose deaths.
Conclusion: Owing to the lack of additional post-treatment data and captured lagged effects, it is too soon to dismiss this policy as inadequate in combating the opioid epidemic. Once additional post-treatment data become available, the study can be reproduced to obtain more robust results and achieve a clearer understanding of the policy implications shown.

Introduction

The consumption of opioid pain relievers (OPRs) in the United States has exponentially increased from the start of the twenty-first century, creating what is known to be one of the worst national crises in the nation. The consumption of hydrocodone has more than doubled, and the consumption of oxycodone has increased by more than 400% from the years 1999 to 2011.[17] The spike in opioid consumption has been observed through numerous studies. One study highlighted that between 2002 and 2007, the non-medical

E-mail address: Alcocer@usc.edu.

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use of prescription OPRs grew from an already 11 million to 12.5 million.[5] On top of that, the National Survey on Drug Use and Health reported that in 2010, 12.2 million people within the country used pain relievers for non-medical reasons 'just' within the year prior.[24] Current data continue to ensure that this opioid crisis is significantly dangerous and a threat to public health, as there was an even bigger increase in overdose deaths due to synthetic opioids after 2013 and heroin after 2016.[6,16]

Simultaneously, as more states began passing medical cannabis laws (MCLs), the idea that marijuana was the solution to the opioid crisis began to spread nationwide.[8] Researchers would begin to study the relationship between analgesic properties of cannabis and opioid usage—as more research hinted it could be used to treat pain.[20] So far, it has been demonstrated that the legalization of medical cannabis is associated with a 21–24.7% reduction of opioid overdose deaths and a 23% reduction of both marijuana- and opioid-related hospitalizations.[4,6,31] On the other hand, cannabis has also been linked with an increased consumption of other drugs—serving as a gateway drug.[12,15,22,30,34]

In addition to MCLs being passed, states began expanding marijuana access by legalizing it for recreational use. Among the pioneers of this development was Colorado as it was the first state to officially pass legislation in December 2012—just two years after having commercialized medical marijuana through their Medical Marijuana Code. Although the passage of Amendment 64 legalized and commercialized recreational marijuana, it was not until 2014 that this policy took effect—when Colorado officially opened licensed retailers on January 1.[29] The literature on MCLs has provided some sense of public health implications, but little is known about the effects of this marijuana policy expansion.[21] This policy change poses the following question: does legalizing marijuana for recreational use further reduce or hinder the ongoing opioid crisis? Knowing the answer to this question can serve as the first step in understanding the implications of expanding marijuana consumption and how it relates to opioid-related outcomes—in this case, statewide opioid overdose deaths within Colorado.

So far, two studies[19,21] have examined the policy implications of legalization on measures of general public health. The first one looked at Colorado's marijuana legalization and its effect on emergency care. Observational data from the Colorado Hospital Association suggested that the number of hospitalizations for patients older than nine years due to marijuana-related emergencies almost doubled from 15 per 100,000 to 28 per 100,000 after 2013.[19] The second study looked at Colorado's marijuana legalization and opioid-related deaths using an interrupted time-series design. Their findings suggested that the policy resulted in a negative effect of 0.68 opioid-related deaths per month—totaling to an estimated 6.5% overall reduction.[21] To build on the findings of the study by Livingston et al,[21] this preliminary study will focus on exploring the statewide effects of Colorado's recreational marijuana policy on the state's opioid overdose death rates. However, instead of using an interrupted time-series design, this analysis will use the more optimal data-driven process of the synthetic control method to create a robust counterfactual to conduct a difference-in-difference estimate.

Methods

Study design

Methods for evaluating policies are generally designed to estimate 'average treatment effects' for populations from which a significant amount of sampled treated and untreated units are available. For the purposes of this study, the 'treatment' will refer to Colorado's policy opening up recreational marijuana dispensaries as a result of its legalization. The opening of dispensaries was essentially unique to Colorado at the time as Washington was the only other state to have passed such legislation. Because of its uniqueness, there is no robust sample of treatment units—or states that have opened recreational dispensaries—to observe and measure. Having a low number of treated units—or states meeting this requirement—can be problematic as our resulting estimates can be ambiguous and standard errors may not reflect the proper levels of uncertainty. However, because Colorado has existing panel data for statewide opioid overdose death rates dating back to 1999, we can use statistical software to define and create an optimal control group to adequately resemble Colorado's outcome variable of interest. This process known as the synthetic control method can provide a valid counterfactual for Colorado's opioid overdose outcomes in the absence of this policy—a Colorado that did not expand marijuana policy to the point recreational dispensaries were established.[1]

Methods

Once a control group is constructed, a difference-in-difference estimation will be conducted to obtain the estimated effect of Colorado's recreational marijuana policy. The synthetic control method can be used to achieve this estimate by having the software calculate the weighted average of all potential 'control states' that closely resemble Colorado's overdose rates and some predictor variables that will be used as robustness checks. Each potential control state taken from a larger state donor pool gets a weight ($\boldsymbol{w_j}$) assigned that will represent the size of that state's role as a part of the synthetic control unit. These calculated weights are non-negative numbers that will collectively sum up to 1 and will provide a solid representation of a control state for Colorado.[1] Weighted average units prevent extrapolation bias, making it more robust than simply running an ordinary least squares regression that is more susceptible to this. Although one of this method's caveats is the concern of interpolation bias, restricting the pool of potential control states to states reasonably similar to Colorado can greatly reduce interpolation while also avoiding the issue of overfitting, as explained by Abadie et al.[3]

While synthetic control weights ($\boldsymbol{w_j}$) minimize the differences between both groups' outcome variable throughout the predispensary period, another form of weights labeled as importance weights ($\boldsymbol{v}$) will be used to measure the predictive power of all the predictor variables that will be used in this study—insuring a better fit for the synthetic control unit. These importance weights will be calculated and chosen in a way that best minimizes the mean squared prediction error, as reflected by Abadie and Gardeazabal[2] and repeated in the study by Abadie et al.[1]

As for the state donor pool that will be used for this study, it will consist of states that have a general form of medical marijuana law—from general cannabis and cannabidiol laws. The objective is to use donor states with somewhat similar regulatory characteristics and opioid death rate trends to Colorado, thereby facilitating the construction of the control unit.

There are two caveats that must be acknowledged before moving forward. Because there are differences between medical marijuana laws among states—mainly due to regulatory inconsistencies caused by the federal government's stance on marijuana—using a donor pool of states with MCLs does not guarantee exact similarities to Colorado.[25,28] However, this set of donor states is better suited than using states with no MCLs in the first place. In addition, relying on more strict donor pool characteristics would leave the analysis with a very low number of donor pool states, making it difficult to assess their significance when conducting inference tests.

The second caveat is that some of the states transitioned to MCL states during the predispensary period; when conducting an analysis without those particular states, however, the results and significance testing remained the same—finding no plausible reason to remove them from the analysis. The study's predispensary period will run from 1999 to the end of 2013, and the 'treatment' will take its effect in 2014. As a result, the postdispensary period examined will commence in 2014 and will end in 2017.

Data

Using Livington's analysis in conjunction with the other literature,[4,17,27,28,33] the outcome variable of interest consists of 'opioid overdose mortality rates.' 'Opioid overdose mortality rate *per* 100,000 in population' was obtained from Centers for Disease Control and Prevention's (CDC) Wide-ranging Online Data for Epidemiologic Research (WONDER). The opioid overdose rates were classified using the ICD-10 (International Classification of Diseases, tenth revision) underlying cause codes X40–X44, X60–X64, and Y10–Y14 and contributing cause codes T40.0–40.4 for all opioid poisonings. The data only range from the years 1999 to 2017 as the previous years were classified under ICD-9 codes; as a result, including them would cause a huge discrepancy in the data set. The data on each state's marijuana laws were taken from the triangulation of three studies.[23,25,26]

All of the predictor variables used in this study—opioid prescription rates within each state, percentage of ages 25–54 years, percentages of population without a high school diploma and with a bachelor's degree or higher, per capita income, poverty and unemployment rates—were obtained from the American Community Survey yearly estimates' Selected Population Profile in The United States. The data range from the years 2005 to 2014 and are organized as yearly data per state. Powell[28] makes use of age-groups and unemployment rate—thereby justifying the use of these variables for the nature of this study. Bachuber et al[4] noted that one of their limitations was the lack of individuals' characteristics within states, such as race and socio-economic status–related variables. With this in mind, educational attainment along with *per capita* income and poverty rate was added to the collection of data used for this study. While there is no measurement of availability of unregulated supply of non-medical cannabis in either group owing to data limitations, the predictor variables chosen should be able to assist the statistical software in choosing the donor pool states that best match Colorado's implicit characteristics.

Results

The following section describes the results obtained for this study. Fig. 1 depicts the mean trends in opioid overdose rates from Colorado along with the rest of the donor pool states. As the figure shows, there are some suitable comparison states for Colorado to study the effects of recreational dispensaries. Trends of opioid overdose rates were somewhat similar for both groups, with the exception of the 2001–2004 period, and begin to deviate after 2009. Once Colorado opens their dispensaries in 2014, you can see how the state—already being lower than the average—continues to steadily increase while the average spikes at an even higher pace.

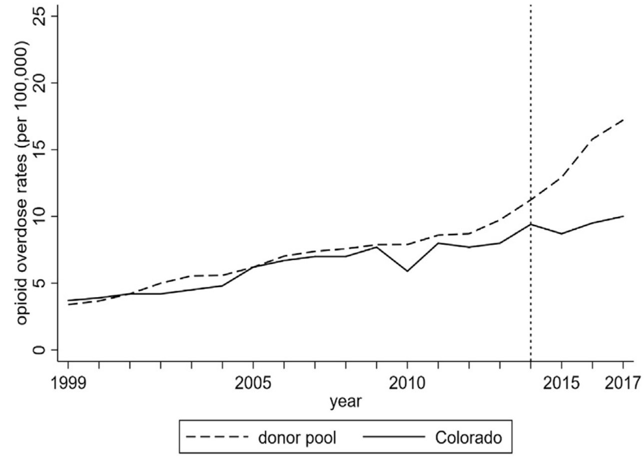

Fig. 1. Trends in overdose rates: Colorado vs. donor pool.

The synthetic control method will be able to construct a counterfactual that takes states closely resembling Colorado in terms of predispensary period values of opioid overdose rate predictors. Table 1 shows these results as it compares the predispensary period characteristics of Colorado with synthetic Colorado along with the average of the 31 states found in the donor pool. On a quick inspection of Table 1, it is evident that synthetic Colorado was able to closely match Colorado's predictor variables more than the average. Unemployment rate was the only exception that already shared the same average value to Colorado, and the opioid prescription rate was the best example of how the average of states did not match Colorado's. In addition, the opioid overdose rate values for the predispensary periods 1999, 2007, and 2013 were not close to Colorado at all, whereas the synthetic counterfactual values moved more toward real Colorado's characteristics.

Table 2 displays the weights $\boldsymbol{w_j}$ of each control state used for synthetic Colorado. The weights depicted in this table are an indicator that opioid overdose rates in Colorado before the establishment of recreational dispensaries are best reproduced by the combination of Alabama, California, Hawaii, Maryland, Massachusetts, Minnesota, Montana, Rhode Island, and Virginia. The rest of the other states with zero weights were not optimal matches for the construction of the control group, and the remaining 18 states were not included in the donor pool because of their regulatory status—either having marijuana as illegal or having it legalized.

Table 1
Overdose rates predictor means.

Predictors	Colorado	Synthetic Colorado	Average of control states
Opioid prescription rate	69.43	69.34	76.79
Percentage, ages 25–54 years	0.43	0.43	0.42
Percentage, no high school	0.11	0.11	0.12
Percentage, bachelor's degree or higher	0.36	0.33	0.29
Poverty rate	0.11	0.11	0.13
Unemployment rate	0.04	0.04	0.04
Overdose rate (1999)	3.70	3.44	3.00
Overdose rate (2007)	7.00	6.74	7.40
Overdose rate (2013)	8.00	8.59	9.80

*All of the variables except overdose rates and percentage of ages are averaged for the 2005–2013 period. Percentage of ages are averaged for the 2009–2013 period. All predictors are at rates per 100,000 population.

Table 2
State weights in synthetic Colorado.

State	Weight	State	Weight
Alabama	0.021	Montana	0.219
Arizona	0	Nevada	0
California	0.022	New Hampshire	0
Connecticut	0	New Jersey	0
Delaware	0	New Mexico	0
Florida	0	New York	0
Georgia	0	Oklahoma	0
Hawaii	0.09	Rhode Island	0.33
Illinois	0	South Carolina	0
Iowa	0	Tennessee	0
Kentucky	0	Texas	0
Maine	0	Utah	0
Maryland	0.122	Vermont	0
Massachusetts	0.169	Virginia	0.129
Michigan	0	Wisconsin	0
Minnesota	0.194	Rest of states[a]	–

[a] Rest of states refers to all other states not included in the donor pool for this analysis. All weights sum up to 1.

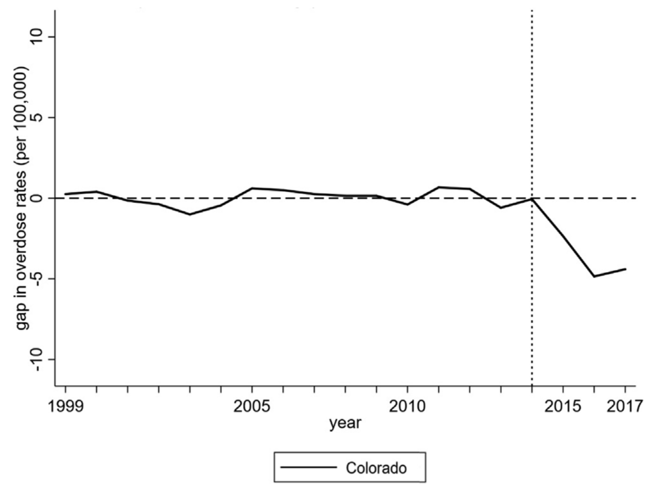

Fig. 3. Opioid overdose rates gap between Colorado and synthetic Colorado.

Fig. 2 is the synthetic control model depicting overdose rate trends for Colorado and its synthetic counterfactual during the period 1999–2017. Unlike the comparing trends of Colorado and the rest of the donor states (Fig. 1), the opioid overdose rates in synthetic Colorado closely track real Colorado's trajectory from 1999 to 2013. There is a small gap that opens from 2002 to 2004 and from 2011 to 2012, but the overall trajectory is consistent with Colorado's overdose rate values. Visual analysis along with the close similarity between the overdose predictor variables (Table 1) demonstrates that the opioid overdose rates in the synthetic control are able to track overdose deaths that would have occurred if Colorado had not legalized recreational marijuana sales and maintained a medical status. This result leads to an estimated negative effect on opioid overdose rates, reaching a decline of approximately 5% from 2014 to 2017 (see Fig. 3 for effects graph). On observing synthetic Colorado's overdose death rate trend after 2014, it appears as overdose deaths would be estimated to continue rising without expanding access to recreational marijuana dispensaries. As to the number of dispensaries that had been opened since 2014, Colorado's Department of Revenue reported that a total of 505 retail stores had opened by the end of 2017—wherein a total of 306 were opened the first year, a total of 463 the second, 454 the third, and finally, 505 the fourth[10]. Based on these numbers, the estimated decline in overdose death rates would seem to share a negative relationship with the number of dispensaries being opened throughout the postdispensary years.

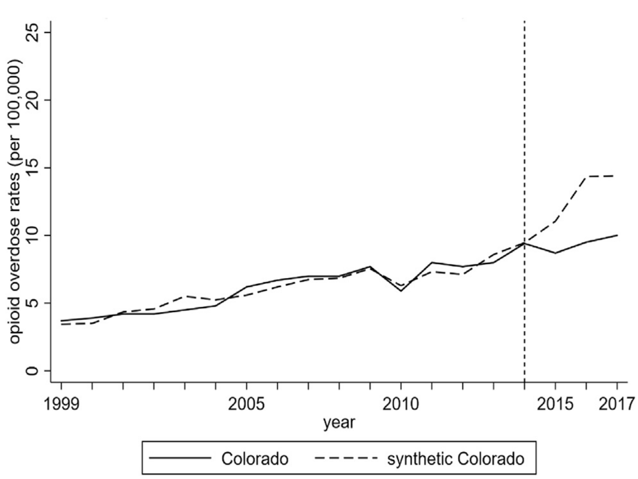

Fig. 2. Trends in overdose rates: Colorado vs. synthetic Colorado.

Significance tests

Although the results display some sort of effect happening owing to Colorado allowing recreational dispensaries, placebo in-time and in-space analysis introduced by Abadie et al.[1,3] will be conducted to evaluate the significance of these results. The placebo in-time test will re-run the model and apply the opening of recreational dispensaries to another time period within 1999–2013—in this case, Stata will construct a synthetic control that opened its dispensaries in the year 2008. From there, we observe if there are any effects associated with this change. If the model was to experience a large placebo effect when it should not be present, it would imply a lack of predictive power in the original synthetic control and therefore would weaken the confidence that Fig. 2 has displayed.

While the placebo in-time test applies the opening of dispensaries to another time period, the placebo in-space test assigns it to all states in the donor pool to compare the estimates of those states that did not receive any treatment. The lines that get produced are read the same way the line from Fig. 3 was read. If Colorado's estimated effect is unusually large and unique relative to the distribution of the placebo estimates, then it would mean the effect of recreational dispensaries on Colorado was significant. If they were to be similar to the point that it would be difficult to choose Colorado out of randomness, then the results would be deemed as insignificant.

Fig. 4 displays the results of the placebo in-time analysis that was conducted. Synthetic Colorado closely follows the trends of opioid overdose rates experienced in Colorado for the pseudo predispensary period of 1999–2007, while closely resembling the path followed by synthetic Colorado in Fig. 2. After the pseudo postdispensary period shown in Fig. 4, synthetic Colorado does not diverge considerably before the real treatment occurred as there is only a small difference after the year 2012, just two years before 2014. This suggests that the gap estimated in Fig. 2 does reflect the impact of recreational dispensaries in Colorado as a result of their recreational marijuana legislation and not from a lack of predictive power coming from the synthetic control model itself.

Fig. 5 displays the results of the placebo in-space analysis that was conducted. The gray lines are depicting the gaps associated

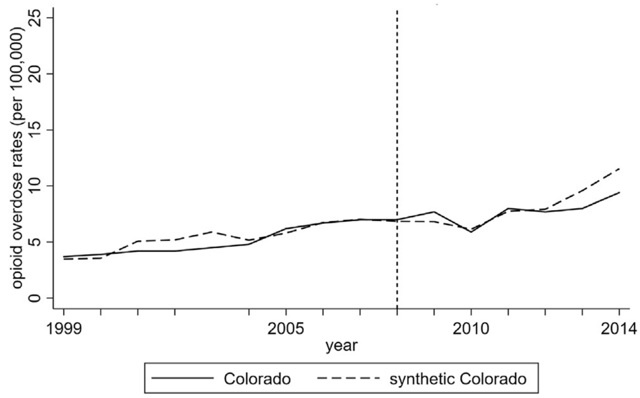

Fig. 4. Placebo legalization 2008—trends in overdose rates: Colorado vs. synthetic Colorado.

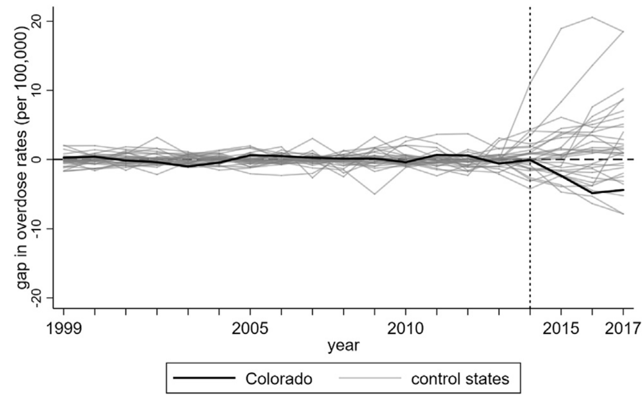

Fig. 6. Placebo in space: overdose rates gap in Colorado gaps in 30 control states.

with all 31 control states, whereas the bold black line represents Colorado's gap. On inspecting the figure, the majority of the control states' predispensary period trajectories are closely fitted to that of Colorado, indicating that their root mean squared prediction errors (RMSPEs) are also approximate to Colorado's. This reinforces the idea that the synthetic control method was able to provide a good fit for opioid overdose rates before the start of recreational marijuana dispensaries for almost all placebo states in the donor pool. Because RMSPE measures the amount of the gap in overdose rates between Colorado and its synthetic counterpart, having a small RMSPE similar to the unit of interest during the predispensary period is necessary to find the analysis credible.

Moreover, analysis of Fig. 5 depicts how the majority—if not all—placebo states with similar estimated predispensary period RMSPE created gaps of similar magnitudes to the estimated gap for Colorado after dispensaries were created in 2014, implying that the analysis conducted 'does not provide significant evidence' of a negative effect of the establishment of recreational marijuana dispensaries on opioid overdose rates in the state.

In the case of any poor placebos creating noise within Fig. 5, another version of the placebo in-space analysis was conducted in which states beyond a pretreatment RMSPE of 2 were removed.[1] As Fig. 6 demonstrates, the pretreatment RMSPE cutoff of 2 only led to one state dropping, and Colorado's outcome was still indistinguishable from other similar placebo states—solidifying the fact that the results found with the synthetic control were deemed 'insignificant.' Fig. 7, which demonstrates a bar graph of each state's RMSPE ratio, proves just that. Colorado is only the sixth state with the highest RMSPE ratio, with five placebo states showing higher effects, followed by states such as Florida, Montana, and Massachusetts having almost similar RMSPE ratios. In the end, this placebo in-space analysis has been able to regard Colorado's recreational dispensary policy results as insignificant.

Discussion

The discussed significance test demonstrated that there was not enough evidence to prove that expanding marijuana policy to allow the opening of recreational dispensaries was instrumental in reducing the ongoing opioid death rates experienced by the state. However, that does not mean that there is evidence of this policy worsening it either. A strong limitation encountered in this study was the lack of postdispensary data as Colorado's recreational marijuana dispensary program is still developing. Just as how the opening of recreational dispensaries took approximately a year to implement after its passing, it can be expected that there are some lagged effects not captured in the analysis for opioid users switching to marijuana. Moving forward, being able to collect more postdispensary data on opioid overdose deaths for all states can provide more evidence to get a better sense of the results as it is still too early to dismiss this policy tool as inadequate in combating Colorado's opioid epidemic.

One piece of evidence suggesting this is how the results of Colorado's recreational marijuana legislation were not too far off

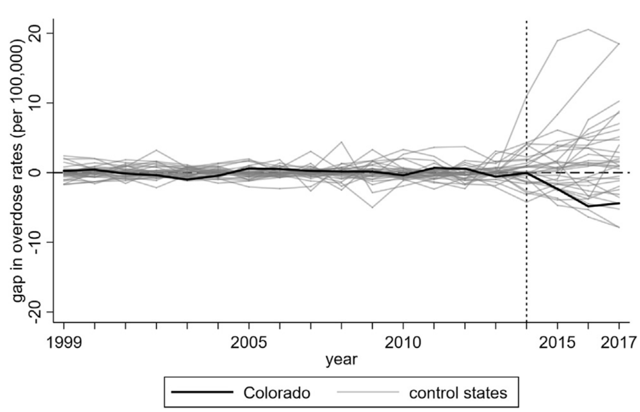

Fig. 5. Placebo in space: overdose rate gaps in Colorado and placebo gaps in all 31 control states.

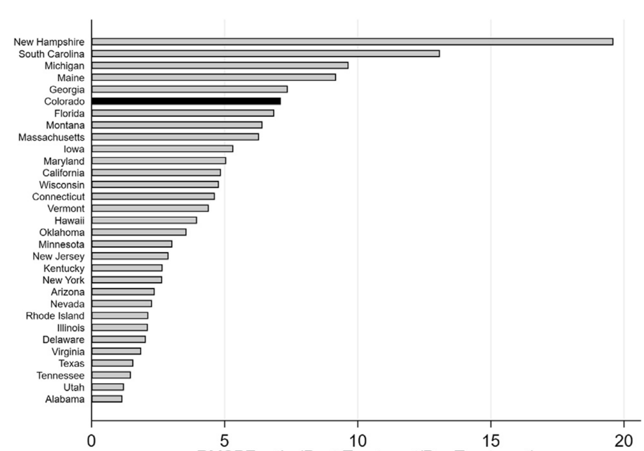

Fig. 7. RMSPE ratios for Colorado and placebo states. RMSPE = root mean squared prediction error.

from the findings of Livingston et al.[21] Like the analysis of Livingston et al.,[21] the synthetic control managed to capture a negative effect as well. Although the findings here were not significant, there is definitely some direction for future research to be conducted as soon as more postdispensary data become available—more suitably, the same amount of longitudinal data equating to the predispensary data that were used for this analysis. As additional data become available, the replication of this study will have to be modified to account for regulatory changes occurring within donor pool states. Because recreational marijuana policies continue to be enacted throughout states (e.g., California 2017), these states will have to be discarded as they are no longer eligible to be part of the donor pool owing to their similarity to Colorado.[1]

Within the placebo in-space analyses, there were two states whose outcomes were outstanding in comparison with Colorado and the other placebo states. On inspecting it with the RMSPE ratio bar graph, it was revealed to be the states of New Hampshire and South Carolina. Because their predispensary RMSPE was visually low in contrast to their high postdispensary RMSPE, it might be of interest to conduct additional research within these states to see if there were any policy changes that might have led to such large gaps.

Aside from the lack of postdispensary overdose death rate data, the study suffers from a few more limitations that must be discussed. From a methodological perspective, the synthetic control method uses aggregate-level data to focus on the general outcomes of a policy. In this case, the observed outcome was the state's overall opioid overdose death rates. Because this can also be considered a local average effect as it focused on Colorado's state of opioid and cannabis usage, it would be very difficult to apply this policy and expect similar results in other regions that do not share the similar characteristics in demographics, marijuana and opioid usage, and levels of intervention, among other things. Because of the vast differences in which other regions can tackle the opioid crisis along with the differences in which they may develop their marijuana policies, the probabilities of obtaining similar results to those of Colorado would be unlikely. It is important to acknowledge this form of limitation so that future research can be geared toward exploring the effects of marijuana policies in other regions to find how different they may vary from this study.

Another major limitation to this study is that the synthetic control model cannot take into account other factors that may very well affect the opioid overdose death rate trend for Colorado. In 2015, the state expanded the access to naloxone by providing immunity from civil and criminal liability and professional misconduct to medical practitioners who often prescribed them to individuals at risk or to those close to them.[14] Because this policy was enacted at the same time recreational marijuana dispensaries opened up, it is difficult to quantify how much of the observed effects can be attributed solely to the opening of dispensaries—suggesting that these effects can be overestimated. It also suggests that the observed changes are a result of not only the opening of recreational dispensaries but also a combination of this and an expanded access to opioid alternatives not considered within this study.

A third and final limitation of this study can be explained through the plethora of research discussing the existence of ecological fallacy when studying marijuana legislation. The literature highlights the mixed results found at the individual level as some studies show there is an opposite relationship between marijuana and opioid usage.[7,13] Because of this, it is important to make the distinction that these population-level findings should be solely considered as preliminary and are not to be extrapolated to the individual level in an attempt to bridge a relationship between marijuana and opioid consumption that is still unknown.

Conclusion

The goal of this preliminary study was to observe the beginning effects of Colorado's statewide recreational marijuana policy on opioid overdose deaths. The hopes of the study were to set the grounds for future analyses that can explain whether adopting this policy can serve as an effective tool in dealing with the opioid abuse epidemic that is experienced throughout states with similar characteristics to Colorado. The use of synthetic control has allowed the opportunity to closely construct a counterfactual with the ability to observe these effects robustly. The ability to systematically select comparison units through quantitative processes greatly increases the precision of the counterfactual in comparison with standard statistical methods.[3] Qualitative analysis through the interpretation of this method's significance tests led to the conclusion that although the findings were insignificant, it is too early to clearly define whether recreational marijuana policies improve or exacerbate the opioid crisis. This limitation can be overcome as more overdose death rate data become available throughout the following years—opening an opportunity to replicate this study in the future. Policymakers should contemplate about these implications when considering to pass this form of legislation, and only time will allow the opportunity to keep examining this policy's effects—so long as there is still a considerable amount of states that remain stationary with their medical marijuana policies.

Author statements

Ethical approval

The nature of this research study relied heavily on secondary source data. The data for overdose death rates along with all predictor variables were collected from government agencies—the Centers for Disease Control and Prevention (CDC) and the United States Census Bureau. None of the data extracted from these databases included any personal information detailing of any individuals and are all publicly accessible for everyone. Owing to this particular reason, this research study did not require any ethics approval prior and was approved by a faculty advisor from the beginning of the study period.

Funding

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Competing interests

This study has no competing interests.

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