

The Impact of Recreational Cannabis Markets on Cannabis Use Among Adolescents and Adults: A Synthetic Control Analysis

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ABSTRACT

Objective: To assess the longer-term impacts of recreational cannabis markets on cannabis use among adolescents and adults across five U.S. states. **Method:** Drawing on state-level data from the National Survey on Drug Use and Health, this study uses a novel method of causal inference called the synthetic control method with staggered treatment adoption to estimate the pooled effect of recreational markets on prevalence and initiation of use in Colorado, Washington, Oregon, Alaska, and Nevada. Three separate models were used for those 12-17, 18-25, and 26 and older. Pre-treatment state-level characteristics and trends in cannabis use were used to generate synthetic control weights. Confidence intervals were constructed using a leave-one-out jackknifing method. **Results:** Synthetic controls and treated states were similar in terms of sociodemographic characteristics, prevalence of other drug use, and trends in cannabis use prior to the implementation of recreational markets. The study results revealed moderate increases in prevalence and initiation of use among adolescents aged 12-17 (11% and 13%, respectively), and large increases in prevalence and initiation of use among young adults aged 18-25 (17% and 33%, respectively) and older adults aged 26 and older (33% and 82%, respectively) 2-4 years after dispensaries became operational. **Conclusions:** The findings of this study suggest recreational cannabis markets have increased prevalence and initiation of cannabis use among adolescents and adults. These increases may lead to adverse health outcomes depending on factors such as frequency of use and characteristics of users.

Key words: = cannabis; prevalence of use; initiation of use; recreational legalization; dispensary

Over the past few decades, the cannabis policy landscape has changed rapidly, shifting away from prohibition. While cannabis remains illegal at the federal level, states have legalized cannabis for medical and recreational use. As of January 2024, 23 states have legalized recreational commercial cannabis markets, wherein private firms produce, distribute, and sell cannabis to adults 21 and older at retail locations and cannabis is taxed and regulated similarly to alcohol (National Conference of State Legislatures; Marijuana Policy Project). In contrast, some jurisdictions have legalized recreational use without commercial production and retail sale, allowing consumers to cultivate

small amounts of cannabis for personal use (including states that later legalized recreational markets) (Marijuana Policy Project). In states that legalized recreational markets, it can take years for these markets to be established and for consumers to have access to cannabis products at retail locations, known as dispensaries (e.g., over two years until dispensaries opened in Colorado and over one year in Michigan). In the interim, there may only be legal access through personal, small-scale cultivation. Understanding the impacts of recreational markets on cannabis use is of public interest, as cannabis use, particularly heavy (daily or near daily use) and problem use (meeting the criteria for cannabis use disorder

[CUD] [Patel 2021]), is associated with adverse social and health outcomes (Fergusson & Boden, 2008; Hall et al., 2020; Hudson, 2020; Silins et al., 2014; The National Academies of Sciences, Engineering, and Medicine, 2017), although more research is needed to determine whether these associations are causal. Adolescents are especially at risk for harms associated with cannabis; a substantial body of evidence finds early initiation and frequent use negatively affects brain development in the areas responsible for memory and learning and is associated with CUD, other illicit drug use, mental disorders, school dropout, low life satisfaction, and unemployment (Hall et al., 2020; Fergusson & Boden, 2008; Silins et al., 2014; The National Academies of Sciences, Engineering, and Medicine, 2017). Adults who use cannabis may also be at risk for developing mental disorders, especially with heavy use and use of high-potency cannabis products (i.e., high levels of tetrahydrocannabinol [THC]) (Hudson, 2020; Petrilli et al., 2022). Additionally, preliminary research indicates cannabis use may be associated with cardiovascular diseases such as heart attack and stroke, including among younger, healthier adults (Goyal et al., 2017; Jeffers et al., 2024).

Currently, cannabis is the most commonly used federally illegal drug in the U.S. In 2021, 52.5 million (18.7%) Americans 12 and older reported using cannabis at least once in the past year (Substance Abuse and Mental Health Services Administration, 2022). Of those who used cannabis in the past year, 2.6 million (5%) used cannabis for the first time and 16.3 million (31%) met the criteria for CUD (Substance Abuse and Mental Health Services Administration, 2022). Evidence from studies published since 2000 that used nationally representative data suggests prevalence of use and CUD have increased among adults and decreased or remained the same among adolescents (Hasin et al., 2019).

Legalizing recreational markets could lead to increases in initiation and/or frequency of cannabis use through multiple channels. Five potential mechanisms are (1) increasing availability, (2) reducing costs associated with use, (3) normalizing use, (4) decreasing risk perceptions, and (5) increasing popularity of products that may be more harmful. While policy alternatives, such as legalizing comprehensive access to medical cannabis or legalizing

recreational use without legal sales, can impact cannabis use through these channels, characteristics of commercial markets may amplify these effects. First, the proliferation of retailers makes cannabis much more accessible by effectively lowering search costs, or time and effort needed to obtain a product. In some states with developed retail markets, dispensaries are ubiquitous. For example, in Colorado there were more medical and recreational dispensary licenses than Starbucks and McDonalds combined in 2018 (Sabet, 2021). A second mechanism is costs—there is strong evidence that cannabis users are sensitive to prices (Davis et al., 2016; Pacula & Lundberg, 2014). Cannabis prices are expected to decrease in legal markets because suppliers do not need to be compensated for the legal risks of production and can take advantage of efficiencies from economies of scale and innovation in methods of production (Hunt & Pacula, 2017). Indeed, preliminary evidence suggests that prices in recreational markets have declined since their inception (Hunt & Pacula, 2017; Smart et al., 2017). A third potential mechanism is normalization of use. Marketing and advertising from cannabis companies, as well as the presence of retailers at commonplace locations, may normalize use by reducing stigma and raising the social desirability of use (Sabet, 2021; Sznitman & Taubman, 2015). Indeed, studies have shown that exposure to cannabis advertising is associated with use and initiation of use among adolescents (D'Amico et al., 2015; D'Amico et al., 2018; Dai, 2017; Whitehill et al., 2020). A fourth potential mechanism is risk perceptions. Allowing cannabis to be sold for recreational use in a store could signal to the public that cannabis use is safe (Khatapoush & Hallfors, 2004). Risk perceptions are an important mechanism because evidence suggests they are causally related to use (Bachman et al., 1998; Merrill, 2015). Lastly, the implementation of recreational markets may lead to greater consumption of cannabis products that are typically high in THC, such as vape pens and cannabis concentrates (Borodovsky et al., 2017; Daniulaityte et al., 2017; Smart et al., 2017); this finding is important, as use of high-potency products is associated with the development of CUD (Loflin & Earleywine, 2014; Petrilli et al., 2022), more severe CUD (Freeman & Winstock,

2015), and psychosis (Di Forte et al., 2009, 2015; Petrilli et al., 2022).

Numerous studies have evaluated the impacts of recreational cannabis legalization and commercialization on cannabis use. Some studies use the date of policy enactment as the treatment start date (e.g., Anderson et al., 2019; Cerda et al., 2017; Cerda et al., 2020; Coley et al., 2021) while others use the date that recreational dispensaries became operational. Evidence on adolescent use is mixed: studies have found no change (Brooks-Russel et al., 2019; Cerda et al., 2017; Coley et al., 2021; Dilley et al., 2019; Harpin et al., 2018), a decline (Anderson et al., 2019; Dilley et al., 2019), and increase (Bailey et al., 2020; Cerda et al., 2017; Hollingsworth et al., 2022; Paschall & Grube, 2020; Paschall et al., 2021; Rusby et al., 2018) in prevalence of use among different adolescent age groups in the first few years after recreational legalization and/or sales. Additionally, one study has found an increase in CUD (Cerda et al., 2020) and another found an increase in initiation of use among adolescents (Hollingsworth et al., 2022). Studies of younger adults (aged 18-25) and undergraduate students, however, have more consistently found an increase in prevalence of use (Hollingsworth et al., 2022; Kerr et al., 2017; Kerr et al., 2018; Miller et al., 2017) following legalization and sales with the exception of one study (Cerda et al., 2020); among this age group, an increase in initiation has also been found (Hollingsworth et al., 2022). Two studies have also examined the effects on use in older adults (26 and older) and report an increase in prevalence of use (Cerda et al., 2020, Hollingsworth et al., 2022), frequency of use (Cerda et al., 2020), initiation of use (Hollingsworth et al., 2022), and CUD (Cerda et al., 2020).

The purpose of this study is to estimate the effect of recreational markets on prevalence and initiation of cannabis use among adolescents, younger adults, and older adults across five states with established recreational cannabis markets for 2-4 years. This paper builds upon the evidence-base in several ways. First, it uses a novel method for causal inference, called the synthetic control method (SCM) with staggered treatment adoption—an extension of the SCM that estimates an average effect across treated sites that implemented a policy in different time periods (Ben-Michael et al., 2022). Unlike studies that

examined pre-post changes in use without a comparison group (Bailey et al., 2020; Brooks-Russel et al., 2019; Dilley et al., 2019; Harpin et al., 2018; Paschall et al., 2021; Rusby et al., 2018), this empirical strategy can control for secular trends in cannabis use as well as competing interventions that impact use. A potential advantage of this method over study designs that used one or more comparison groups (Anderson et al., 2019; Cerda et al., 2017; Cerda et al., 2020; Coley et al., 2021; Hollingsworth et al., 2022; Kerr et al., 2017; Kerr et al., 2018; Miller et al., 2017; Paschall & Grube, 2020) is that it may generate more ideal controls that are similar to the treated sites in terms of characteristics (e.g., socio-economic status, race/ethnicity) and trends in cannabis use prior to the implementation of recreational markets. Additionally, the SCM with staggered treatment adoption may serve as an alternative to two-way fixed effects difference-in-differences (DID) regression models, which have been employed in studies of cannabis use that exploit variation in timing of cannabis policies (Cerda et al., 2017; Cerda et al., 2020; Hollingsworth et al., 2022). Recent studies have found that these models can be problematic and difficult to interpret (Goodman-Bacon, 2021; Sun & Abraham, 2021). In contrast to most published literature, this paper also focuses on longer-term impacts of commercial markets, when cannabis was more accessible to the general population. Compared to legalizing recreational use alone, the establishment of recreational markets may be more likely to impact use; additionally, it is important to examine the longer-term effects, as it will likely take time for the cannabis industry to develop and for norms and behaviors to shift.

METHODS

The Synthetic Control Method with Staggered Treatment Adoption

This paper uses a generalization of the SCM developed by Ben-Michael, Rothstein, and Feller that allows for staggered adoption of policies across multiple treated sites (Ben-Michael et al., 2022).

The SCM, formalized by Abadie et al. (2010), is an increasingly popular method for estimating the effects of large-scale interventions implemented in a single treated site on aggregate

outcomes. The idea behind the SCM is to construct a counterfactual (i.e., what would have happened in the treated site in the absence of the intervention), called a synthetic control, that is similar to the treated site using a weighted average of control site outcomes. Optimal weights, which are non-negative and sum to one, are chosen by minimizing differences in pre-treatment predictors and outcomes between the treated site and the synthetic control. Control sites with positive weights are selected from a group of potential control sites called a “donor pool”. It is more plausible that the synthetic control is a good counterfactual when there is balance on predictors and the treated site and synthetic control follow similar pre-treatment trends. In the SCM, the impact of the intervention is the difference in the outcome between a treated site and its synthetic control in the post-treatment period.

A limitation of the SCM is that it was designed to evaluate an intervention in a single treated site. Extensions that allow for multiple treated sites and staggered treatment timing have not been formalized with the exception of a recent paper by Ben-Michael et al. (2022). The authors propose a partially pooled SCM that generates weights to simultaneously minimize “unit-specific imbalance” (i.e., pre-treatment differences between each treated site and its synthetic control) and “imbalance for the average of the treated units” (Ben-Michael et al., 2022). This method moves between two extremes: (1) a “separate SCM”, which generates weights by minimizing pre-treatment imbalance for each treated site and (2) a “pooled SCM”, which minimizes imbalance for the average of the treated sites (Ben-Michael et al., 2022). The authors show that both sources of imbalance can lead to bias in the estimate of the average treatment effect (Ben-Michael et al., 2022). A hyperparameter ν , which ranges from 0 to 1, provides the relative weight for each measure of balance; higher values of ν correspond to greater weight given to the pooled fit over the fit for individual treated sites (Ben-Michael et al., 2022). In the application developed by the authors, ν is set to be “the ratio of the pooled fit to the average of the unit-level fit” (Ben-Michael et al., 2022).

In the staggered adoption SCM method, the donor pool consists of never-treated sites and time is indexed on event time, or time since treatment

exposure. The primary estimands of interest are the average treatment effect on the treated (ATT) in each post-treatment period. The ATTs are calculated as simply the average of site-level treatment effects (i.e., difference between each site and its synthetic control). As one method of inference, Ben-Michael et al. (2022) construct confidence intervals for estimates using a leave-one-out jackknifing approach.

Data and Sample

Data on the outcome variables, prevalence of use and initiation of use, were obtained from the National Survey of Drug Use and Health (NSDUH) small area estimate (SAE) files, which provide publicly available state-level estimates that are representative of the population 12 and older. Prevalence of cannabis use was measured as the proportion of the population that used cannabis in the last year. Initiation of cannabis use was measured as average annual rate of cannabis initiation.

Each year, state-level estimates from the NSDUH are published by pooling two years of data for different age groups (12 and older, 18 and older, 12-17, 18-25, and 26 and older for cannabis use outcomes). The age groups used in this analysis were 12-17, 18-25, and 26 and older. A limitation of grouping 18–25-year-olds together is that it includes young adults with and without legal access to cannabis, as states do not allow legal sale to those under 21 years of age. The study period included pooled estimates for the following years: 2002-2003, 2004-2005, 2006-2007, 2008-2009, 2010-2011, 2012-2013, 2014-2015, 2016-2017, and 2018-2019. The treated states consisted of five states that implemented recreational cannabis markets prior to 2018: Colorado, Washington, Oregon, Alaska, and Nevada. One model that included all treated states was used for each age group. The model was limited to two post-treatment periods because Alaska and Nevada had only two post-treatment periods.

For each state, the treatment period began the first pair of years when recreational sales began. The date of first legal sales was determined using the protocol described in Appendix A. Table 1 shows the first month and year of legal sales in each state as well as the years included in the first and second post-treatment periods. During the first post-treatment period, most states received

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partial treatment exposure while the second post-treatment period represents the longer-term effects of commercialization (2-4 years after legal sales).

Table 1. *Recreational Sales Start Date and Post-Treatment Periods*

State	Month and Year of First Recreational Sales	First Post-Treatment Period	Second Post-Treatment Period
Colorado	January 2014	2014-2015	2016-2017
Washington	July 2014	2014-2015	2016-2017
Oregon	October 2015	2014-2015	2016-2017
Alaska	October 2016	2016-2017	2018-2019
Nevada	July 2017	2016-2017	2018-2019

The donor pool consisted of states that did not legalize recreational cannabis during the study period. Additionally, states were excluded if they offered limited or no access to medical cannabis during the entire study period (i.e., Alabama, Georgia, Idaho, Indiana, Iowa, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Nebraska, North Carolina, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, West Virginia, Wisconsin, and Wyoming). Therefore, the donor pool consisted of states that provided comprehensive medical access for at least part of the study period. These states are likely more similar to treatment states in terms of attitudes and beliefs around cannabis use and policies. In fact, some states in the donor pool legalized recreational use/markets right after the study period. States with limited or no medical cannabis access were identified using the National Conference of State Legislators.

The primary predictor used to generate synthetic control weights is the lagged outcome, i.e., values of the outcome variable in all pre-treatment time periods (i.e., 2002-2003, 2004-2005, 2006-2007, 2008-2009, 2010-2011, and 2012-2013 for all treated states; and the addition of 2014-2015 for Alaska and Nevada). Several auxiliary predictors were also included. The purpose of these predictors was to generate a synthetic control that was similar to the treated states in terms of characteristics that are

correlated with cannabis use: other drug use, education, and race/ethnicity (Gunn et al., 2022; Jeffers et al., 2021; Lemyre et al., 2019; Substance Abuse and Mental Health Services Administration, 2022). Balance on these predictors is important because the treated states and synthetic controls are more likely to react similarly to “global” factors that impact use during the study period (e.g., changes in economic conditions or attitudes towards cannabis use in the U.S.). Three of these predictors were from the NSDUH: proportion of the population (based on age group: 12-17, 18-25, and 26 and older) that (1) used illicit drugs other than cannabis in the past month, (2) binge drank alcohol in the past month, and (3) used a tobacco product in the past month. For these variables, the average from 2002-2003 to 2012-2013 was used (i.e., averaged over the entire baseline period prior to first legal recreational sales in the U.S.). Education and race/ethnicity variables were also collected from the American Community Survey (2009-2013; 5-year estimate prior to legal sales in the U.S.). The education variables included percentage of the population with (1) less than a high school degree, (2) a high school degree, (3) associate’s degree or some college, and (4) bachelor’s degree or more; race/ethnicity variables included percentage of the population that was Black, White, Asian, and Hispanic (any race).

Analyses were conducted in R version 4.1.0 using the multisynth package 0.3.1.

RESULTS

Tables 1B-6B, Appendix B describe average prevalence of use and average rate of cannabis initiation in the pre-treatment and post-treatment periods for the treated states and the synthetic controls (i.e., weighted average of the comparison states) for those 12-17, 18-25, and 26 and older, respectively. Table 2 shows the staggered adoption SCM results for prevalence of use and rate of cannabis initiation, respectively, by age group. The tables include: (1) estimated baseline prevalence of use or rate of cannabis initiation (used to calculate percent change in use), (2) the ATT in the first and second post-treatment periods, i.e., the percentage-point change in prevalence of use or rate of cannabis initiation with 95% confidence intervals (derived from statistical model), and (3) percentage change

from baseline (ATT [percentage-point change in use] divided by baseline use estimate). The ATT is the average of the state-level treatment effects; each state-level treatment effect is the difference in outcome between the treated state and its

synthetic control in the post-treatment period. Baseline values were calculated as the average prevalence of use or initiation of use in the treated states in 2012-2013, the time period prior to first recreational sales in the U.S.

Table 2. *Baseline Prevalence and Initiation Rate, Average Treatment Effect on the Treated, and Percentage Change from Baseline for Prevalence and Initiation of Cannabis Use by Age Group*

Prevalence of Use					
Age Group	Baseline Prevalence (%)	Period 1		Period 2	
		ATT: % Point Change (95% CI)	% Change from Baseline	ATT: % Point Change (95% CI)	% Change from Baseline
12 to 17	16.80%	1.55* (0.72, 2.38)	9.20%	1.87* (0.14, 3.59)	11.10%
18 to 25	36.50%	1.73 (-1.19, 4.65)	4.70%	6.31* (1.75, 10.87)	17.30%
26 and older	14.90%	2.36 (-0.11, 4.82)	15%	5.00* (2.15, 7.85)	32.80%

Rate of Initiation of Use					
Age Group	Baseline Rate (%)	Period 1		Period 2	
		ATT: % Point Change (95% CI)	% Change from Baseline	ATT: % Point Change (95% CI)	% Change from Baseline
12 to 17	6.70%	0.71* (0.01, 1.42)	10.60%	0.88 (-0.03, 1.80)	13.10%
18 to 25	8.60%	1.15 (-0.11, 2.40)	13.20%	2.84* (0.47, 5.22)	33.00%
26 and older	0.40%	0.13 (-0.09, 0.36)	32.50%	0.33* (0.06, 0.60)	82.50%

Note. Baseline values were calculated as the average prevalence of use or initiation of use in the treated states in 2012-2013, the time period prior to first recreational sales in the U.S. In the first post-treatment period, most states received partial treatment and in the second post-treatment period states had active recreational cannabis markets for 2-4 years.

*p<0.05

ATT—Average treatment effect on the treated; CI—Confidence interval

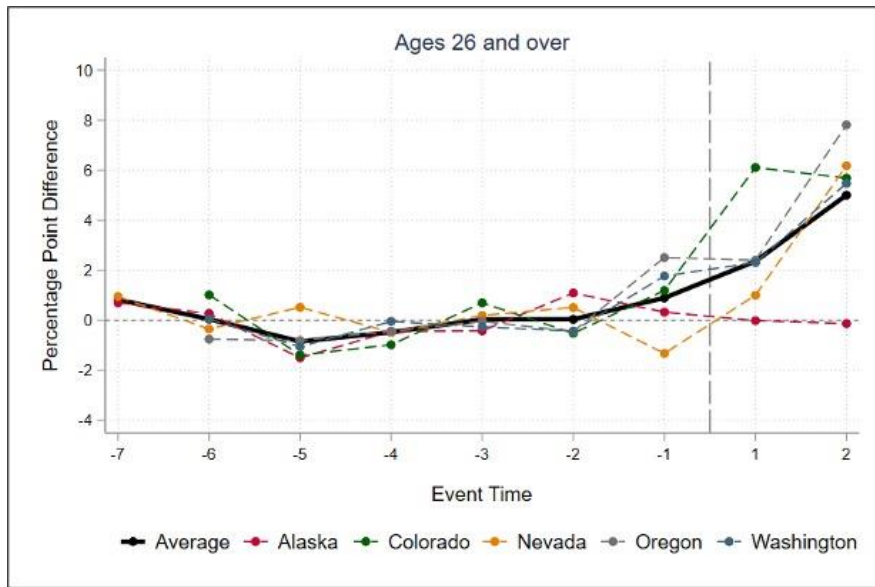
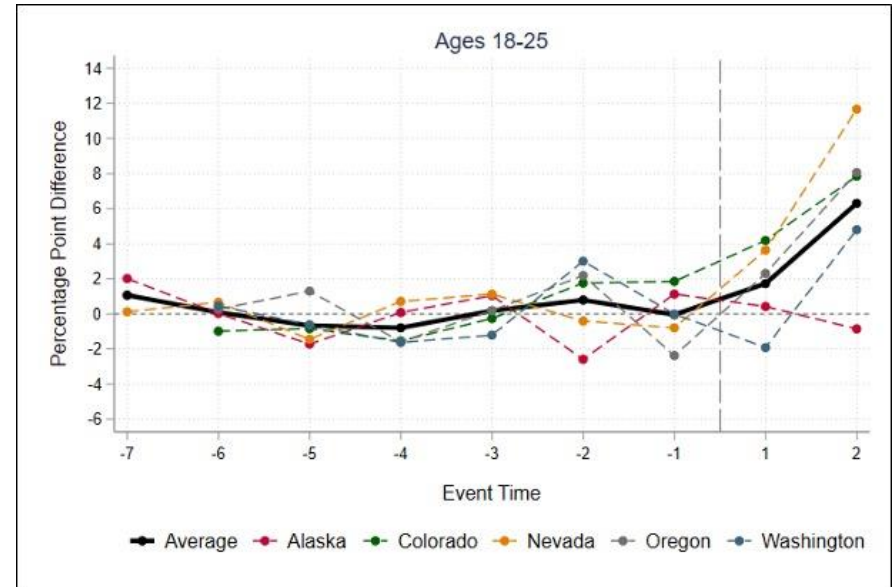
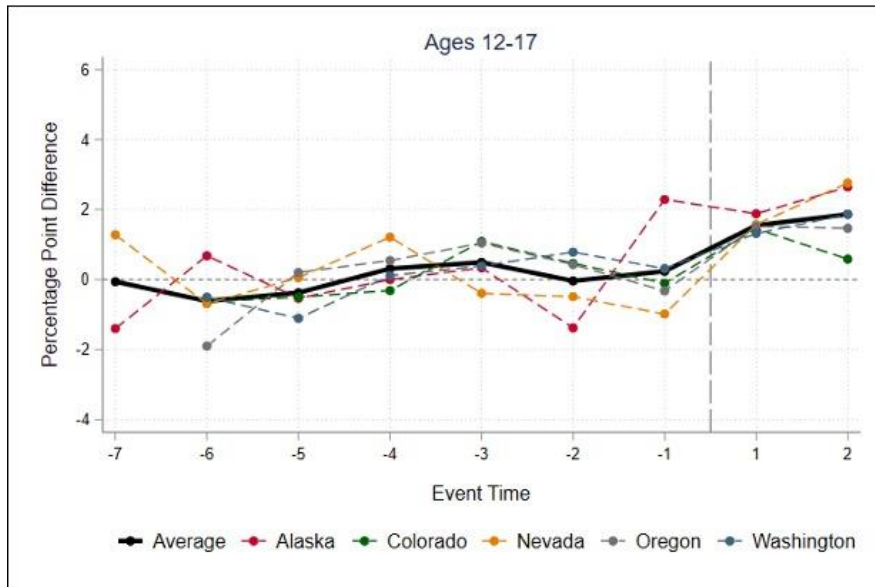
Figures 1 and 2 are graphical representations of the results. Each graph shows the difference in outcome between the treated states and their synthetic controls as well as the average of the treated states (i.e., ATT) during the study period. Period 1 on the x-axis represents the first post-treatment period when legal sales began; period 2 is the second post-treatment period where all states received full treatment. The vertical line separates the pre-treatment period from the post-treatment period.

Across all age groups, prevalence of use and rate of cannabis initiation increased in the first period (partial treatment) and the second period (full treatment for 2-4 years), with the second period always showing a larger increase than the

first treatment period. In the first post-treatment period, the increase in prevalence and initiation of use were only statistically significant for youth aged 12-17 at the 5% level; the estimated percentage-point changes were 1.6% (9.2% increase from baseline) and 0.7% (10.6% increase from baseline) for prevalence and initiation of use, respectively. In the second post-treatment period, the increase in prevalence of use was significant for all age groups: there was a 1.9% (11.1% increase from baseline), 6.3% (17.3% increase from baseline), and 5.0% (32.8% increase from baseline) percentage-point increase for those aged 12-17, 18-25, and 26 and older, respectively; estimates for initiation of use were significant for those 18-25 and 26 and older: there was a 2.8%

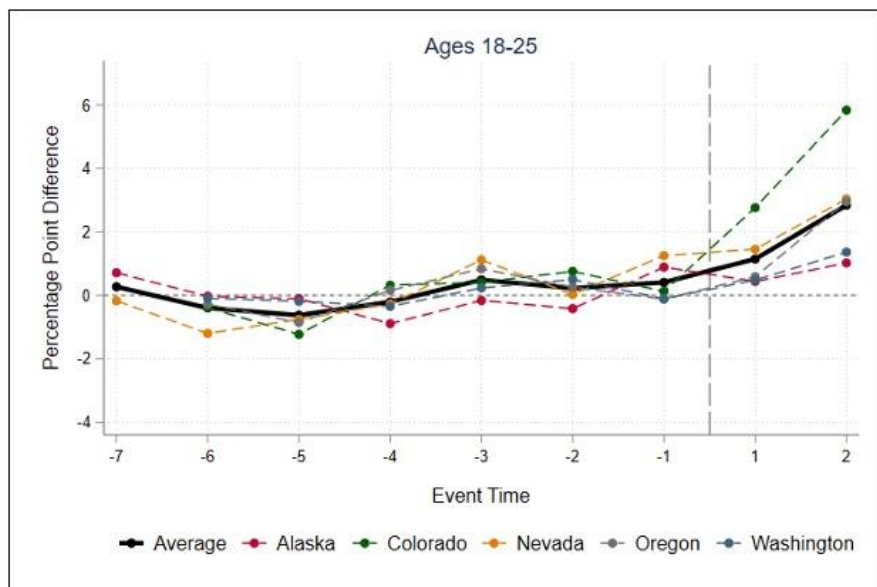
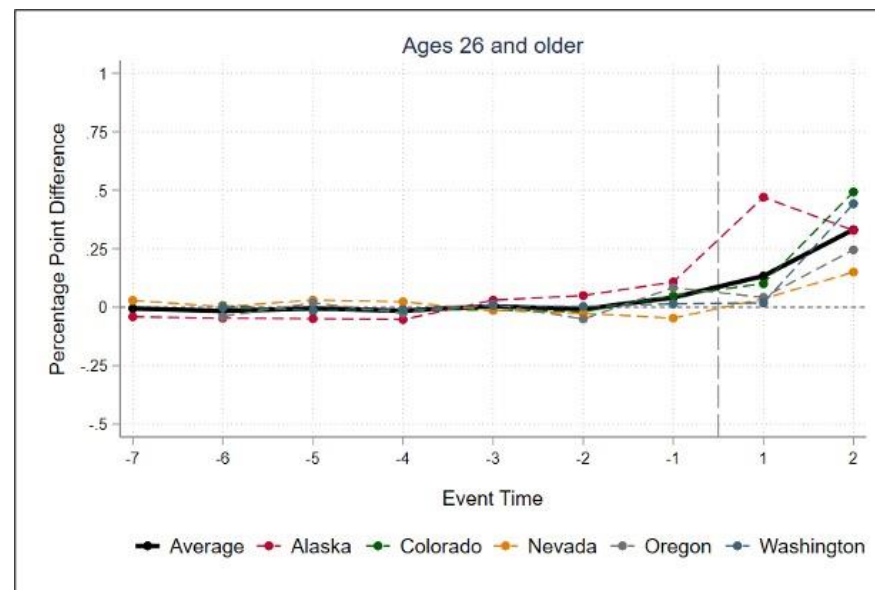
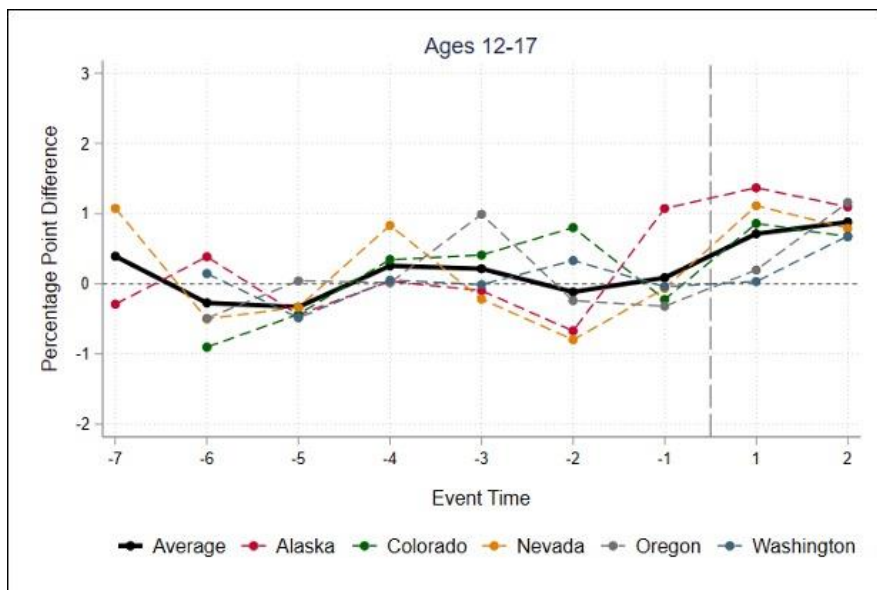
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Figure 1. *Prevalence of Cannabis Use by Age Group: Difference Between Treated States and Synthetic Controls Before and After Recreational Markets Became Operational and the Average Treatment Effect on the Treated*



Note. Figures show the percentage-point differences in prevalence of use between the treated states and their respective synthetic control before and after dispensaries became operational. Additionally, the thick black line represents the average of the treated states, or ATT. The dashed vertical line separates the pre-treatment period (i.e., before recreational sales) from the post-treatment period (i.e., after recreational sales). In the post-treatment period, the percentage-point difference in prevalence of use represents the impact of recreational commercialization on prevalence of use.

Figure 2. Rate of Initiation of Cannabis Use by Age Group: Difference Between Treated States and Synthetic Controls Before and After Recreational Markets Became Operational and the Average Treatment Effect on the Treated



Note. Figures show the percentage-point differences in initiation of cannabis use between the treated states and their respective synthetic control before and after dispensaries became operational. Additionally, the thick black line represents the average of the treated states, or ATT. The dashed vertical line separates the pre-treatment period (i.e., before recreational sales) from the post-treatment period (i.e., after recreational sales). In the post-treatment period, the percentage-point difference in initiation of use represents the impact of recreational commercialization on initiation of use.

(33% increase from baseline) and 0.3% (82.5% increase from baseline) percentage-point increase for those 18-25 and 26 and older respectively.

In terms of model fit, the figures show small differences in outcomes between the treated states and their synthetic controls in the pre-treatment period (i.e., they followed similar pre-treatment trends in use). There is also balance on auxiliary pre-treatment predictors for all models (see Tables 1C and 2C, Appendix C). Together, these results suggest the synthetic controls are valid counterfactuals for the treated states. Tables 1D-6D, Appendix D show weights for donor pool states used to construct the synthetic controls.

DISCUSSION

In the present study, recreational cannabis markets were associated with moderate to large increases in initiation and prevalence of use among adolescents (12-17), young adults (18-25), and older adults (26 and older). In every case, the estimated increases were larger in the second post-treatment period, when states had operational recreational dispensaries for 2-4 years, compared to the first treatment period, which represented a partial treatment (i.e., did not have commercial markets the entire period for some states). The effect in the second period may have been larger because all states had markets for the entire pair of post-treatment years. Another possibility is that it may take time for recreational markets to impact cannabis use through potential mechanisms such as lower costs, greater accessibility, normalization of use, reductions in risk perceptions, and increased popularity of products that may be more harmful. This theory is consistent with a study that found a larger impact of recreational sales on cannabis use compared to recreational use alone (Hollingsworth et al., 2022). Commercialization may be more likely to impact use through these channels; in the open, it may be easier for companies to innovate methods of production to reduce costs, develop new products that may be more appealing and addictive, and engage in marketing and advertising. Some studies have found cannabis marketing increases in intensity over time (Marinello, 2024) and contains content that may be appealing to youth (Cao et al., 2020; Marinello et al., 2024; Shi & Pacula, 2021).

Additionally, newer cannabis products sold at dispensaries may have qualities that could lead to earlier initiation of use, greater frequency of use, and dependency. For example, compared to smoking cannabis bud, vaping cannabis concentrate—which is substantially higher in THC—is perceived as healthier, better tasting, and more efficient (Aston et al., 2019; Budney et al., 2015).

The moderate increase in initiation and prevalence of use among adolescence is of public health importance because adolescents experience the greatest harms from cannabis use (Fergusson & Boden, 2008; Hall et al., 2020; Silins et al., 2014; The National Academies of Sciences, Engineering, and Medicine, 2017). These results for adolescents are not consistent with studies that found no impact or decrease in adolescent use following recreational legalization or the implementation of recreational markets (Anderson et al., 2019; Brooks-Russel et al., 2019; Cerda et al., 2020; Coley et al., 2021; Dilley et al., 2019; Harpin et al., 2018) but are similar to some papers that find a positive impact (Bailey et al., 2020; Cerda et al., 2017; Hollingsworth et al., 2022; Paschall & Grube 2020; Rusby et al., 2018). One potential explanation for why this study found a positive effect, whereas others did not, is that the SCM was able to generate a more ideal control group. Generally, cannabis use among adolescents decreased or remained about the same in the treated states, which is consistent with secular trends in the U.S. (Hasin et al., 2019); however, the synthetic controls saw a greater reduction in use in the post-treatment periods, resulting in a relative increase in the treated states. These findings are similar to those of an evaluation of legal sales in Oregon: adolescent use decreased in counties with and without recreational dispensaries, however, the reduction was steeper in those without dispensaries (Paschall & Grube 2020). The estimates for percentage change in prevalence of use and initiation of use among adolescents in the second post-treatment period were nearly identical to the estimated impacts after legal sales from Hollingsworth et al. (2022) (10% vs. 11% in this study for past-year prevalence of use; 15% vs. 13% in this study for initiation of use), which used the same dataset (NSDUH SAE) but DID regression models. The fact that adolescent use increased suggests some cannabis may have been diverted from the legal

market to underage youth. It is also possible that recreational markets impacted youth cannabis use through other channels, for example, by increasing youth exposure to cannabis marketing, normalizing use, and reducing risk perceptions.

Results for young adults aged 18-25 revealed large increases in prevalence and initiation of use in the second post-treatment period, which represents the longer-term impacts. The finding for prevalence of use is consistent with two studies conducted on undergraduate students in Oregon (23% increase in past-month use) and Washington (DID estimates: 8.6-9.6 percentage-point increases in past-month use) that found increases after recreational legalization (Kerr, et al., 2018; Miller et al., 2017). While the study of Washington did not find an additional impact after legal sales, the study period only goes through 2015, or 1.5 years after dispensaries opened. A limitation of those studies is that they may not be generalizable to all young adults of that age. Additionally, estimates from this study are similar to those in Hollingsworth et al. (2022) (15% vs. 17% in this study for past-year prevalence of use; 24% vs. 33% in this study for past-year initiation of use). These results stand in contrast to those from Cerda et al. (2020), which used individual-level data from the NSDUH and found no significant changes in prevalence of use among this age group after recreational use became legal. One explanation for the discrepancy is that Cerda et al. (2020) had a shorter analytic period and began their treatment start date at policy enactment (i.e., legal recreational use without sales) instead of when dispensaries became operational. In terms of older adults aged 26 and older, there were even larger increases in use in the second post-treatment period. These findings are consistent with Cerda et al. (2020), which also found a 20% increase in past-month prevalence of use in this age group, and Hollingsworth et al. (2022), which found substantial increases in both past-year prevalence and initiation of use (25% vs. 33% in this study for prevalence of use; 31% vs. 82% in this study for initiation of use).

Overall, the impacts of recreational markets on use may have been larger for adults compared to adolescents because adults 21 and older have legal access to cannabis and are more likely able to afford products sold at dispensaries, which are more expensive than cannabis purchased from the

illicit market (Fataar et al., 2021; Goodman et al., 2022). Increases in prevalence and initiation of cannabis use among adolescents and adults may have adverse health and social impacts depending on a number of factors such as frequency of use, timing and setting of use, potency of products, and user characteristics. While there is a substantial amount of evidence that early and heavy cannabis use is harmful for adolescents (Hall et al., 2020; Fergusson & Boden, 2008; The National Academies of Sciences, Engineering, and Medicine, 2017; Silins et al., 2014), emerging evidence indicates that use among adults may be associated with the development or worsening of mental disorders and cardiovascular diseases (Goyal et al., 2017; Hudson, 2020; Jeffers et al., 2024; Petrilli et al., 2022). States may mitigate the impact of commercialization on use and associated health harms through policies and programs; for example, mass media campaigns to educate the public on health harms of cannabis use, restrictions on cannabis company advertising that would prohibit youth-oriented content and require health warnings, restrictions on potency levels of cannabis products, and tax increases to ensure prices remain high over time.

Strengths and Limitations

Strengths of this study include the use of data that is representative at the state level and the use of the SCM with staggered treatment adoption, a novel method for causal inference that may serve as an alternative to DID models with differential treatment timing. This method generated counterfactuals that had similar trends in cannabis use prior to the implementation of recreational markets and were similar in terms of racial/ethnic composition, educational attainment, and use of other drugs. Compared to most of the literature, this study focuses on longer-term effects of commercial recreational markets, which is important because these markets provide greater access to cannabis and may be more likely to impact use over time.

This study has several limitations. First, this study does not examine the impact of recreational markets on frequency of use or CUD because of restrictions to the public use dataset. These dimensions of cannabis use are important for predicting potential health harms. If prevalence of use increased because of increases in casual use,

then cannabis markets are less likely to have negative effects on health. Second, this study did not assess whether there were heterogeneous effects by demographic characteristics. Third, findings may not be generalizable to other regions of the U.S., as all treated states were located in the West. Fourth, there may have been time-varying factors that influenced cannabis use that differed by treatment status. Fifth, treatment exposure was binary when it likely varied in terms of characteristics and intensity across treated states; for example, the number of dispensaries per capita and prices likely varied depending on state and local policies. Lastly, a potential limitation is that cannabis use was self-reported and survey respondents may have been more likely to report cannabis use once it was legal.

Conclusions

Overall, this study finds moderate to large increases in prevalence and initiation of cannabis use among adolescents and adults 2-4 years after dispensaries became operational in five U.S. states. Findings suggest that characteristics of recreational commercial cannabis markets may drive up demand for cannabis and that there may be adverse health and social consequences of legalizing a for-profit cannabis industry. The results for adolescents are especially important, as this population experiences greater health harms from use; a possible explanation for why these results differ from many previous studies is that the SCM with staggered treatment adoption was able to create more ideal counterfactuals that controlled for secular trends in adolescent use. It is important that future work investigates the impacts of markets in other states as more data becomes available and on other aspects of use, such as frequency of use, CUD, methods of consumption, and potency of products. Additionally, more evidence is needed to understand the health effects of cannabis use, especially among adults.

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