From High School to Higher Education: Is recreational marijuana a consumption amenity for US college students? *

Ahmed El Fatmaoui†

August 17, 2023

Abstract

This paper examines how recreational marijuana legalization (RML) affects first-time college enrollment in the US using a unique college-level dataset and various estimation methods such as difference-in-differences, event study, and synthetic controls. I find that RML increases enrollments by 4.6% to 9%, without compromising degree completion, and it boosts college competitiveness in RML states by offering a positive amenity, as evidenced by the rise in non-local enrollments relative to neighboring states. In addition, I find no evidence that RML affects college prices, quality, or local enrollment. This effect is stronger for non-selective public colleges in early-adopting RML states.

Keywords: recreational marijuana legalization, first-time enrollment, difference-in-differences, synthetic control, event study

Acknowledgments: I would like to express my sincere gratitude to Tyler Ransom, Pallab Ghosh, and Josh Kinsler for their invaluable feedback and suggestions, which greatly improved the quality of this paper. I am also grateful for the comments provided by the participants at Midwest Economics Association and Society of Labor Economists conferences, and the University of Oklahoma Brown Bag seminar.

†Department of Economics, University of Oklahoma, Norman, OK 73072. Email:aelfatmaoui@ou.edu.

1 Introduction

Recreational marijuana legalization (RML) is a contentious issue with widespread attention from politicians, researchers, and citizens. Twelve states have legalized recreational marijuana as of 2020 (Carnevale Associates, 2022), and there is a growing trend of high marijuana use among college freshmen. Nearly 35% of high school seniors and 44% of college students reported using marijuana (National Institute on Drug Abuse, 2020, Schulenberg et al., 2021). Marijuana legalization's impact has been extensively studied across disciplines. These include health (Sarvet et al., 2018, Raman and Bradford, 2022), crime or substance abuse (Sabia et al., 2021, Wu et al., 2021), as well as income (Chakraborty et al., 2020, Jiang and Miller, 2022, Dave et al., 2023). Others have shown that students value some college amenities (i.e., student activities and sports) resulting in positive or negative effects on achievements (Webber and Ehrenberg, 2010, Lindo et al., 2012, Jacob et al., 2018). Therefore, the impact of RML on undergraduate enrollment remains an unanswered question.

The intuitive connection between RML and enrollment is based on two theoretical frameworks. The first is the human capital model by Becker (1964), which views education as an investment that depends on costs, earnings, and consumption amenities. The second approach involves the neoclassical model of spatial equilibrium, as proposed by Rosen (1974) and Roback (1982). This model implies that there are no utility gains at equilibrium, given that the rental and wage adjustments driven by amenities counterbalance the utility differentials. These theoretical frameworks imply that RML increases enrollment in states that have legalized recreational marijuana (RM states). However, measuring the value of amenities for location choice is challenging because it involves accounting for various confounding and even dynamic factors. Due to this difficulty, a large literature including Mayer and Trevien (2017), Zambiasi and Stillman (2020), Chen et al. (2022) relies on natural experiments that exploit an exogenous shock to amenities' value.

Related literature focuses on limited geographical locations and uses student-level data or natural experiments to examine how marijuana use affects educational performance, including standardized grades (Marie and Zölitz, 2017, Wright and Krieg, 2020), quantity and quality of applicants (Blake and Betz, 2022), time to graduation, (Arria et al., 2015), school failure (Duarte et al., 2006), and dropout rate or truancy (Roebuck et al., 2004, Suerken et al., 2016).

I contribute to the above literature by examing how RML affects postsecondary education for first-time enrollment in the US and whether the effect is due to the perception of marijuana as a college consumption amenity. To investigate this question, I utilize the state-level and temporal variation in RML and build a unique college-level dataset.[1]. My main empirical strategies are as follows: the standard two-way-fixed effects difference-in-differences (TWFE DID) and the dynamic TWFE DID. These methods compare the mean enrollment differences between RM and non-RM states, controlling for both college-level time-invariant unobserved heterogeneity (college fixed effects) and common time shocks (time fixed effects). I also include time-varying county-level economic variables such as unemployment and per-capita income, as well as various time-varying college-level characteristics, in the regressions. To address potential concerns about the temporal and cohort variation in the treatment effects, I follow the procedures proposed by Sun and Abraham (2021) and Goodman-Bacon (2021) .[2]

The estimates based on TWFE DID show that RML leads to approximately a 4.6% to 9% increase in total first-time undergraduate enrollments. Goodman-Bacon (2021) decompositions indicate that the estimates are driven by early policy adopters and mostly driven by the RM and non-RM states part of the decomposition. These findings are consistent with those of Cheng et al. (2018), Zambiasi and Stillman (2020) and Hodge and Hazel (2022) that respectively indicate RML leads to a 6% increase in Colorado's housing values, approximately a 10% to 20% increase in in-migration to Colorado, and up to a 6% increase in per-capita taxable food sales in Washington.

The potential impact of marijuana use on cognitive abilities also raises concerns about its influence on students' overall performance. Studies show divergent findings on the relationship between marijuana use and cognitive abilities, with some suggesting a negative effect (Scott et al., 2018, Bourque and Potvin, 2021) and others indicating no significant or positive impact on creativity (Hart et al., 2010, Schafer et al., 2012). Hence, these conflicting results imply that the rise in

[1]I construct this panel dataset from Integrated Postsecondary Education Data System (IPEDS) surveys, the Bureau of Economic Analysis, and the Bureau of Labor Statistics

[2]To address spillover effects, I exclude control units near the treated state border and utilize alternative control groups, such as non-treated states that legalized medical marijuana.

enrollment due to RML may have uncertain effects on college completion. My findings reveal that RML has either no statistically significant effect or a weakly significant positive effect on overall performance. Specifically, RML leads to a modest increase of 10% in the number of degrees (i.e., using the leads of the number of associate and bachelor degrees). This result indicates that RML does not have a detrimental effect on degree completion.[3] Next, I attempt to determine the channels leading to this RML-induced enrollment growth.

In line with the neoclassical model of spatial equilibrium (Rosen, 1974; Roback, 1982) and the human capital model (Becker, 1964), it is important to also examine how RML affects first-time enrollments from local and non-local students in RM states. I find that RML increases out-of-state enrollments by at least 15% compared to neighboring non-RM states, but has no effect on in-state enrollments.[4] These findings indicate that RML improves the competitiveness of colleges in RM states compared to neighboring states by providing an additional college amenity, which is consistent with the gravity model of college enrollment (Leppel, 1993).

The second channel investigates two alternative explanations for enrollment growth in RM states: lower costs or higher quality of education.[5] However, I find no evidence that RML affects tuition and fee revenue per student or retention rate. Thus, these factors most likely did not contribute to the enrollment increase in RM states, supporting the hypothesis that RML serves as a consumption amenity. This is in line with the findings of Zambiasi and Stillman (2020) which show that RML-induced migration to Colorado is primarily because potential migrants regard marijuana as a positive amenity.

Next, I explore the heterogeneous effects of RML by institution type and find that RML only affects non-selective colleges with open admission policies, while selective colleges are unaffected. I also show that RML mainly affects public institutions and those offering only associate and

[3]Previous studies (i.e., Marie and Zölitz (2017), Wright and Krieg (2020)) have found a negative effect of marijuana use on student grades. However, this does not imply that marijuana use affects college completion, which is the outcome of interest in my analysis.

[4]This result is distinguished from the main results in that it refers to how RML affects non-local enrollments relative to colleges that are within proximity to those in the treated states.

[5]Besides marijuana use, lower costs or higher quality of education may make RM states more attractive. For instance, RM states may have improved their postsecondary education quality or lowered their tuition fees by using the extra revenue from marijuana sales taxes (Marijuana Policy Project, 2022*a*).

bachelor degrees, rather than doctoral research universities.[6] These effects are stronger for early adopters of RML, suggesting that RML attracts more students to non-selective colleges in early adopting states. However, as RML becomes more widespread and popular among Americans (i.e., 68% support RML (Gallup, 2021)), student sorting or relocation has gradually declined over time and that can explain why the enrollment growth is limited to early adopters.

I test the validity of the TWFE DID estimator using two methods. First, I conduct an event study analysis to determine whether the parallel trends assumption is most likely satisfied and find no significant pre-treatment enrollment differences between treated and control colleges, supporting the assumption. Second, I examine the potential spillover effects from nearby untreated locations. This could happen if students near the border of a treated state move or commute in order to have legal access of marijuana. Following literature that uses the same empirical approach (i.e., Mayer and Trevien (2017), Chen et al. (2022)), I drop control units or colleges within 80 miles of a treated border. The estimate decreases slightly when dropping control units up to 50 miles away, but remains stable for further distances up to 80 miles. This indicates that RML negatively affects control units within a 50-mile radius, supporting the hypothesis that the RML effect is due to student sorting rather than being a net gain. Furthermore, following Roth (2022), I apply the synthetic control method, which does not rely on the parallel trends assumption, to construct a counterfactual outcome for the treated group based on a weighted combination of untreated units.[7] The results from this alternative estimation method are consistent with the main DID estimates and show a significant positive effect of the policy on college enrollment.

The paper is organized as follows. I first provide background on policy definitions and trends in marijuana use and prices. I then describe the data and summary statistics. Next, I explain the empirical methods used. I then present the main results, the underlying mechanisms, and the heterogeneous effects. Finally, I conclude by summarizing the key points and discussing policy implications.

[6]These findings are in line with those of Marie and Zölitz (2017) and Wright and Krieg (2020) suggesting that RML has a greater effect on low-performing students.

[7]Roth (2022) found that conventional pre-trends tests may have low power and recommends supporting DID's findings with other specifications that avoid pretesting altogether.

2 Background

Marijuana legalization in the US is a complicated issue that involves varying degrees of legality. According to the federal law, cannabis is a Schedule I substance under the Controlled Substances Act of 1970, which means it is considered highly addictive and illegal to produce, distribute, or sell. However, some states have legalized marijuana for recreational use since 2012, creating a conflict with the federal law. The Justice Department responded by issuing guidelines that allowed states to regulate and enforce their own marijuana laws, as long as they met certain criteria, such as preventing the access of minors to marijuana (Cole, 2013). Nevertheless, there are ongoing efforts in Congress to decriminalize marijuana at the federal level, as evidenced by several bills that have been introduced (i.e.,*States Reform Act* (2021), *Marijuana Opportunity Reinvestment and Expungement Act* (2022), and *Cannabis Administration and Opportunity Act* (2022)).

Recreational marijuana legalization is a policy trend that has swept across the US states in recent years. Before 2020, only 11 states had legalized cannabis for recreational use, either by ballot measure or by state legislature. The first two states to do so were Colorado and Washington, which passed ballot initiatives to legalize marijuana for adult use in 2012, followed by Alaska and Oregon in 2014, and California, Maine, Massachusetts, and Nevada in 2016. In 2018, Vermont became the first state to legalize cannabis by state legislature, while Michigan passed another ballot measure. The most recent state to join the list was Illinois, which legalized cannabis by state legislature in 2019. Figure 1 illustrates the timing of RML for the states, which are included in the treatment group of this study. To gain a broader understanding of the policy effects, I consider the timing of law passage and the availability of cannabis for retail sale.[8]. However, 10 states joined the legalization trend in the past three years or between 2020 and 2022 (Marijuana Policy Project, 2022*c*).

One key assumption is that RML affects college choices because some students perceive the policy as a positive amenity. A large body of literature found a high prevalence of marijuana use among high school seniors and college students (National Institute on Drug Abuse, 2020,

[8]I omit DC, Alaska, Maine, Michigan, Hawaii, and all US territories from the analysis because they either do not share borders with other states or they lack sufficient post-policy data within the sample periods. The policy became effective in Oregon and Nevada at the end of the year, so I round up to the next year.

Schulenberg et al., 2021), as well as a positive association between marijuana legalization and marijuana use based on survey data (Cerdá et al., 2012, Wen et al., 2015, Martins et al., 2016, Dave et al., 2023). I present additional support for this assumption in Appendix C by using Google Trends and PriceOfWeed.com data to show that RML is correlated with increased marijuana demand and decreased marijuana prices.

3 Data and descriptive statistics

The Integrated Postsecondary Education Data System (IPEDS) is a set of surveys conducted by the National Center for Education Statistics (NCES) that provides data on various aspects of postsecondary education, such as enrollment, degree completion, and institutional characteristics. In the 2019-20 academic year, there were 3982 title IV degree-granting institutions in the US. These institutions are eligible to receive federal student aid funds and are required to report their data to NCES through IPEDS surveys (National Center for Education Statistics, 2022*a*, 2019).

I use several IPEDS surveys, as well as county-level data, to construct a panel dataset of colleges and their characteristics from 2009 to 2019. I use the fall enrollment survey to measure first-time enrollments, the directory survey to obtain the geographical information of each institution, and other surveys (finance, residence and migration of first-time undergraduate students, and admission) to control for potential confounders and explore possible mechanisms. I also use the reviewed or complete versions of these surveys, which are released with a two-year lag and have higher data quality and accuracy. In addition, I control for some county-level variables that affect the enrollment decisions, such as the young population (age 18 to 24), the per-capita income, and the unemployment rate. I obtained these variables from the Bureau of Economic Analysis and the Bureau of Labor Statistics.

I report the summary statistics of all variables in Table 1. The table compares the mean values of the control and treatment groups. The treatment group consists of states that legalized recreational marijuana (RM), while the control group includes states that legalized medical marijuana (MM) only. The use of MM states as a control group may reduce the confounding effects of unobserved factors that affect both marijuana legalization and marijuana use.[9] Nonetheless, I use both MM states and all non-RM states for further robustness checks.

The table shows that institutions in RM states have significantly higher first-time enrollments than institutions in MM states, with a mean difference of about 9%. This suggests a potential positive effect of RML on college enrollment. However, this simple comparison does not account for other factors that may affect enrollment (i.e., local demographics or economic conditions); therefore, I conduct a more rigorous analysis using a difference-in-differences approach, which I discuss in the next section.

4 Empirical strategy

I use two-way fixed effects (TWFE) difference-in-differences to estimate the overall impact of RML and I use the event study (i.e., dynamic TWFE difference-in-differences) to determine the effect over time. I apply other specifications, namely Sun and Abraham (2021), Goodman-Bacon (2021), and synthetic controls by Abadie et al. (2010) for robustness checks.

4.1 Two-way fixed effects difference-in-differences

In order to estimate the effect of marijuana pervasiveness on student enrollment, I use the following TWFE difference-in-differences specification.[10] β_1 is the coefficient of interest measuring the RML effect on enrollments.

$$\log(Y_{ikjt}) = \beta_0 + \beta_1 \text{RM}_{jt} + \delta_1 X_{kt} + \delta_2 Z_{it} + \delta_3 MM_{jt} + \psi_i + \theta_t + \epsilon_{ikjt} \tag{1}$$

[9]This control group is preferable because it is more plausibly comparable to the treatment group in terms of unobserved characteristics, such as social attitudes towards marijuana or political environment. In Appendix Table A1, I present the summary statistics for the alternative control group that includes all non-RM states.

[10]The canonical difference-in-differences does not allow for institution and time fixed effects because of their collinearity respectively with the treatment dummy (Treat) and policy time dummy (Post).

The variable of interest, denoted as Y_{ijkt}, represents the number of first-time fall enrollments in institution i located in county k and state j during the specific time period or year t. To investigate the impact of recreational marijuana legalization, I introduce the binary variable RM_{jt} as an indicator for the adoption of recreational marijuana laws. It is computed as the interaction between two dummy variables, $Post_t$ and $Treat_j$, following the standard difference-in-differences methodology. In this context, RM_{jt} is assigned a value of one if state j legalized marijuana in or after year t, as depicted below.

$$\text{RM}_{jt} = \begin{cases} 1 & \text{if state } j \text{ legalized RM in or after time } t \\ 0 & \text{Otherwise.} \end{cases}$$

X represents the set of baseline county covariates, while Z denotes an extensive set of college-level covariates which are reported in Table 1. The notation ψ_i is the college fixed effects that address any time-invariant heterogeneity within an institution. As shown in equation (1), I use the most robust model specification by incorporating the college fixed effects. However, this choice restricts the ability to simultaneously control for county-fixed effects because most colleges are situated in separate counties. The county covariates are added to control for potential high school graduates within proximity to the college and other important county-level factors that may influence enrollments such as unemployment rate, per-capita income, and net migration. I also control for medical marijuana legalization to account for any potential medical marijuana policy effect on enrollments. MM_{jt} is a control dummy for states that legalized marijuana for medical use. MM_{jt} is a binary variable for the adoption of medical marijuana law. MM and RM are staggered dummies where RM represents a continuation of MM for states that changed the legalization status from medical to recreational.

$$\text{MM}_{jt} = \begin{cases} 1 & \text{if state } j \text{ legalized medical marijuana but not RM in or after time } t \\ 0 & \text{Otherwise.} \end{cases}$$

As shown in Figures 1 and A1, all the RM states have first legalized medical marijuana before proceeding to recreational legalization. This indicates states that legalized medical marijuana are more likely to have similar unobserved characteristics as RM states (i.e., social movements leading to legalization). For the RML definition, I consider both the timing of policy passage and the opening of the first dispensary.[11]

4.2 Event study

I run the following event study or dynamic difference-in-differences model in which I regress the logged first-time enrollments on G leads and M lags and normalized them to the first pre-shock year (reference group). This specification allows for the policy effect to change over time. It is also crucial to examine policy anticipation or trends in RM and non-RM states before the shock event. As a robustness check, I incorporate the event study specification by Sun and Abraham (2021) which assimilates pre-treatment and post-treatment dynamics to resolve the problem of multiple units being treated in different time periods.

$$\log(Y_{ikjt}) = \psi_i + \theta_t + \sum_{m=-G}^{M} \beta_m RM_{i,t+m} + \delta_1 X_{kt} + \delta_2 Z_{it} + \delta_3 MM_{jt} + \epsilon_{ikjt} \tag{2}$$

4.3 Other specifications

I relax the assumption of constant average treatment effect in the TWFE DID by using two alternative methods that account for the heterogeneity in treatment effects due to the staggered policy adoption (De Chaisemartin and d'Haultfoeuille, 2020, Callaway and Sant'Anna, 2021, Goodman-Bacon, 2021). First, I use Sun and Abraham (2021), which extends the TWFE DID to a dynamic setting and allows for varying treatment effects across states and time periods. Second, I use Goodman-Bacon (2021), which decomposes the TWFE DID into a weighted average of all possible pairwise DID

[11] The main analysis shows the results obtained using both MM and all non-RM states as control groups. For the sake of parsimony and to streamline the presentation of results, the medical states control group and the dispensary RML timing will be used in all subsequent analyses. For the mechanism analysis, I show results obtained using the RML law passage timing and the different control groups in the appendix.

estimators. I show that both methods yield similar results to the TWFE DID, suggesting that the estimates are unbiased. I also consider different definitions of RML and control groups, as discussed previously, to enhance the credibility of the estimates.

I test the robustness of the results using the synthetic control method, which does not rely on DID's assumptions. This method matches donor units to the treated ones before the policy intervention, so the parallel trend assumption is not needed. I apply this method to Colorado and Washington, the first states to legalize marijuana, with over two years of data before and after the policy change. I describe this method in detail in Appendix D. The next section presents the main results. I use MM states and the dispensary opening as the preferred control group and RML definition, respectively.[12] However, I also report the results based on all control groups and RML timings.

5 Results

5.1 Main results

The aim of this paper is to examine the effect of RML on academic enrollment.[13] I estimate the RML policy coefficient on first-time enrollment using OLS based on Equation 1.[14] Figure 2 displays the results, which vary by the definition of RML (the timing of dispensary openings or law approval) and the type of control group (MM states or all non-RM states). The figure has two rows and two columns, each showing a different combination of these factors. These main results indicate that RML increases enrollment by 4.6% to 9%.[15]

The results also show that RML has a significant positive effect on both men and women,

[12]MM states refer to the states that legalized marijuana for medical use within the data period (see Figure A7). The other control group is all non-RM states (i.e., non-RML states from 2009 to 2019.

[13]As shown in Figure A4, RML does not significantly affect the enrollment of vocational institutions. This result is consistent with previous studies (e.g., Roebuck et al. (2004), Marie and Zölitz (2017), Wright and Krieg (2020)) that mainly explore the relationship between marijuana use or legalization and academic outcomes.

[14]Tables A3 and A2 provide more details on the estimation. In Table A3, the control group consists of all non-RM states from 2009 to 2019 (see Figure A7 for the list of MM and non-MM states).

[15]When I account for the timing of dispensary openings and use all unaffected states as a control group, I obtain a slightly lower effect of 4.6%, which is significant at the 10% level.

particularly based on the preferred control group. Overall, the effect on men is larger than that on women. Nonetheless, the difference in enrollment growth between estimates based on the timing of legality and the opening of dispensaries is more pronounced for women. Women's law abidance can help explain this heterogeneous gender reaction to RML depending on how the policy is defined (Portillo and DeHart-Davis, 2009).

The above DID analysis results show that on average RML has a positive effect on college enrollment in RM states. To better understand how the effect changes over time, I present the event study analysis results (equation 2). Figure 3 shows that total first-time enrollment increased significantly by 10% to 12% after the third year of policy implementation.[16] In the third year, the effect is positive but not statistically significant.

The results indicate that both women's and men's enrollments rose significantly after the 4th year of the first dispensary opening. However, the significance level for men is 10% in the last two years. This may reflect the overall decline in men's college enrollment. The National Center for Education Statistics (2022*c*) reports that the college enrollment rate for men dropped from 41% in 2010 to 38% in 2021, while the rate for women increased from 42% to 58% in the same period. There are some possible reasons for the delayed response to the policy.

First, there is a slow and gradual development of a marijuana consumption culture or network among college students who use more marijuana (Rinker et al., 2016). Marijuana use among young adults is positively associated with higher perceived rates of marijuana use by peers (Koval et al., 2019), and the internalization of a marijuana use culture within college settings has led to increased consumption of the substance among students (Pearson et al., 2018). Moreover, the college choice and application process usually starts at least a year before the policy adoption year (College Board, 2022). Another explanation could be the slow growth of the marijuana industry after the legalization since most states take two years to start licensing retail stores.

These event study graphs also support the DID's parallel trend assumption. Figure 3 shows that

[16]Figure A5 displays similar results when RML is measured by legal status alone without dispensary availability. These results are also robust to the use of all non-RM states as a control group, as shown in Figure A6. Zero in the x-axis refers to the first year in which the first dispensary opened.

there is no significant difference in enrollment between RM and non-RM states before the policy intervention. There is no major difference in significance level or magnitude between the estimates based on TWFE DID and Sun and Abraham's method.

The above findings indicate that some college students perceive marijuana as a positive amenity through increasing college enrollments. However, I acknowledge that other factors may confound the relationship between RML and enrollments. RM states may use the additional tax revenue from marijuana sales to subsidize their higher education sector. The human capital model of Becker (1964) and related literature (e.g., Cook and Zallocco (1979), Hemelt and Marcotte (2011), Behrman et al. (1996)) suggest that college quality and price are the main determinants of college choice. I present my analysis of these mechanisms in the next section. First, I discuss whether RML also leads to an increase in degree completions.

5.2 RML effect on completion

I test whether RML affects students' overall performance by examining its impact on the number of degrees conferred. I restrict the treatment group to Washington and Colorado, which are the only states that have legalized recreational marijuana for a sufficiently long period.[17] This allows me to use the outcome leads to measure the effect of RML on student cohorts who have different exposure durations (i.e., time needed to complete the degree) to the policy. Table 2 shows that RML has approximately 8% to 10% significant effect on undergraduate degree completions. However, when I use a different control group (see Table A4 in appendix), these results become insignificant but remain positive. Put together, RML is not detrimental to the overall performance of students.

6 Mechanisms

I investigate the mechanisms and causes of the positive effect of RML on first-time enrollment. First, I show that RML increases the number of non-local enrollments compared to neighboring

[17]For example, a student cohort that started in year t finishes bachelor education in t+4, t+5, or t+6. This means the cohort should be exposed to the policy for 4 to 6 years.

states, suggesting that RML provides a competitive advantage for colleges in RM states. Second, I examine whether college prices and quality could have changed due to potential investments from marijuana sales tax revenue in higher education.

6.1 RML effect on out-of-state enrollment, by proximity status

Figure A8 illustrates the states included in the treatment and control groups for contiguous and noncontiguous states. The treatment group includes only the three early policy adopters that have enough observations after the policy implementation.[18] Figure 4 shows that RML improves the total non-local enrollments by more than 30% relative to contiguous states. The effect is not significant relative to noncontiguous states.[19] Based on the most conservative estimate from Figure A9, RML is associated with approximately 15% more non-local total enrollment relative to neighboring states. In addition, Figure A7 shows that the policy has no effect on in-state enrollment. These findings suggest that RML increases enrollment by providing a competitive advantage relative to neighboring states.[20]

Given that RML positively affects non-local enrollment, it is also vital to explore its impact on out-of-state recent high school graduate (RHG) enrollments. Although the results in Figure 4 show that RML has a significant effect on RHG enrollments relative to neighboring states, this effect is not robust to the extensive exercise of using different policy definitions and control groups as shown in Figure A9. The inconclusive significance of the effect on RHG could be due to the legalization policy that permits only individuals aged 21 or above to buy cannabis legally, so perhaps non-RHG have a greater incentive to attend colleges where recreational marijuana is legal. This follows the literature side documenting negative or no association between marijuana laws and the odds of marijuana use among youths (Dilley et al., 2019, Anderson et al., 2019).[21]

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[18]The IPEDS survey on residence and migration of first-time undergraduate students is only available for even-numbered years from 2008 to 2018.

[19]Figure A9 shows these results are robust to the use of a different RML definition (mere legality) and control groups. Contiguous and noncontiguous groups are shown in figures A8, and medical states are shown in figure A7.

[20]Since the control group contains contiguous units, these estimates may overestimate the true RML effect as the spillover analysis and results from Figure A7 indicate.

[21]Cerdá et al. (2017) showed that RML increases marijuana use among younger adolescents by decreasing their

Consistent with the gravity model (Leppel, 1993), these results suggest that distance from the affected states is important and support the hypothesis that improvement in first-time enrollment is driven by the gain of competitive advantage relative to neighboring states. These findings also indicate that the RML effect on enrollment is not a net gain, but rather a redistribution of students across states.

6.2 RML effect on college price and quality

Table 3 shows that RML has no effect on tuition per student and retention rate.[22]This suggests that the growth in enrollments is not due to any price or quality changes but most likely because some students perceive marijuana as a college consumption amenity. Despite the observed improvement in first-time fall enrollment due to RML, column (2) in Table 3 shows that the total tuition revenue grew insignificantly by approximately 6%.[23] This finding raises questions regarding the marginal effect of the policy, suggesting that it may only impact a limited type of colleges. To gain a broader understanding of the policy's effect, the next section examines its heterogeneous effects.

7 Heterogeneous effects

In this section, I analyze the impact of the policy on various types of colleges and the states that implemented it. First, I demonstrate that colleges with admission requirements remain unaffected, indicating that the policy's effect is primarily relevant to colleges without stringent admission criteria. Second, I find that the policy does not influence private colleges and that the effect on enrollment is likely driven by states that adopted the policy earlier.

Table 4 displays the impact of RML on admissions, test score submissions, and standardized ACT and SAT scores for selective colleges (those with admission requirements).[24] While RML does

perception of harm from marijuana use.

[22]Table A5 shows that RML has no impact on tuition per student and the retention rate under different policy definitions and control groups.

[23]This result is significant only when using a different policy definition and control group as shown in A5.

[24]Selective colleges here refer to all institutions with any type of admission policies such as high school rank or GPA, completion of a college preparatory program, or teachers' recommendation.

not significantly affect the number of admissions, it does show a negative impact on the number of test submissions and a positive impact on the SAT Math 75th percentile score.[25] One possible explanation for this result is that RML may have influenced students' preferences, leading some to prioritize open policy institutions. These findings align with Jacob et al.'s (2018) indicating that high-achieving students prioritize academic quality over consumption amenities.

Next, I examine how RML affects first-time enrollments in different types of academic institutions. Figure 6 (panel a) shows that RML has a positive and significant impact only on public colleges that offer undergraduate degrees (associate's or bachelor's). Panel (b) reveals that the effect of RML varies by the timing of policy adoption. Colorado and Washington (the pioneers in RML) experience a large increase in enrollments in institutions that offer bachelor's or associate degrees as their highest level of education by about 21 and 20% respectively. One possible reason for this impact is that they face no competition from neighboring states for at least three years after legalization (see Figure 1).

8 Robustness checks

8.1 Sensitivity to proximity spillover

While the common trend assumption in difference-in-differences (DID) analysis is likely satisfied, as discussed earlier and supported by Figure 3, the stability of the treatment unit assumption requires further investigation. This assumption assumes that the treatment and control groups remain stable over time, with no systematic changes or spillover effects between them.

A major factor that could introduce bias in the main results in Figure 2 is the proximity of students to state borders where recreational marijuana is legal.[26] These students may be attracted to the policy and opt to commute or migrate to the nearest college in the neighboring state where marijuana is legally allowed. For instance, if students from neighboring states start enrolling in

[25]Table A6 shows that these results are robust to different control groups and RML definitions.

[26]A significant spillover effect across borders can potentially violate the stable unit treatment assumption, which is a key assumption of the DID specification.

Colorado colleges, it could lead to an overestimation of the true RML effect.

To investigate this potential bias from extensive commuting or migration within borders' proximity, I exclude colleges located near the border as illustrated in Figure A10. Table 5 presents the results, which demonstrates that the effect remains significant even after removing colleges within 80 miles away from a treated state border. Panel (a) replicates the main results after removing these within-proximity control units. The effect stays at 7.5% or 7.6% when removing units over 40 miles. Panel (c) does the same but based on a sample of public non-research institutions (i.e., those offering undergraduate degrees only) that dominate the effect as discussed in the heterogeneous effects section. The spillover is larger for the latter as the effect goes from 10.6% to 8.7% once the miles removed pass 50. This small spillover, especially for the most affected institutions, indicates that RML attracted some students within proximity. This follows the neoclassical model of spatial equilibrium which suggest students' relocation to maximize their utility from college amenities.

8.2 Alternative estimation methods

The timing effect plays a significant role in the policy analysis context, particularly as different states legalized recreational marijuana at different times. Therefore, it is crucial to comprehend the underlying factors influencing the overall point estimate. In line with Goodman-Bacon (2021), the DID method allows for the decomposition of the point estimate into subcomponents, namely treated versus treated and treated versus untreated. Figure 5 shows the results of this decomposition. Larger weights are assigned to the treated versus untreated subcomponent. This indicates that differences in enrollments between states with and without recreational marijuana legalization are the primary drivers of my estimate. Specifically, the first two early movers, Colorado and Washington, heavily influence the estimate by contributing to a positive 20% improvement in enrollments, with relatively large weights.[27] As expected, the weighted sum of the decomposition is approximately 9%, the estimate from the main results.

[27]The negative coefficient can perhaps be due to already-established student connections in early treated states or ease of marijuana access in these early mover states.

To further support my findings, I utilize an additional empirical strategy (synthetic control) that relaxes the DID's assumptions. Figure 7 shows that first-time enrollment in Colorado increased in comparison to synthetic control counterfactual zones by approximately 11%.[28] Panels (a) and (b) show that although Colorado opened the first dispensary in January 2014, the growth in freshmen enrollments took effect in the fall of the subsequent year (2015). The enrollment gap follows the same trend as the previous event study graphs with a slightly larger point estimate magnitude reaching up to 20%. This is consistent with the heterogeneous results suggesting that the early adopters benefit the most from RML.

The gap growth start to diminish in 2017. This could be due to increased competition as more states within proximity legalize marijuana (i.e., Nevada, and California). In Panel (c), the treatment is randomly assigned to an unaffected zone to show that the observed effect is not due to chance or other unobserved factors. Panel (d) shows the results of the significance permutation method to examine whether falsely treated zones follow a similar effect distribution as the actual affected states. Overall, these panels show that the effect is statistically significant and provide another layer of support to the main results from the difference-in-differences specification.

9 Conclusion

This paper examines the impact of RML on fall freshmen enrollments. The findings indicate that RML leads to a 4.6% to 9% increase in freshmen enrollments in RM states compared to non-RM states. The policy positively affects non-local enrollment and has no effect on local enrollment, college quality or price and the effect is concentrated among early adopters and public non-research colleges. I further find that RML does not negatively impact college completion, suggesting that some students perceive RML as a positive amenity that influences their college choice.

These findings follow at least two conceptual frameworks. They are consistent with the gravity

[28]This estimate is based on the log enrollment gap as a percentage of the mean enrollment in the affected colleges. The summary statistics showing the balance of the variables used are shown in Table A8. Table A9 shows the weights assigned to each buffer zone to construct the synthetic control. Appendix D discusses further details about this methodology. Figure A11 shows similar results for the state of Washington.

model (Leppel, 1993) because the proximity to the treated colleges drives the RML effect. Second, the neoclassical model by Rosen (1974) and Roback (1982) implies that students' relocation due to the rise of new amenities will result in no utility gain at equilibrium.[29] These theoretical frameworks suggest that students relocate to maximize their consumption of college amenities. The findings are in line with the increasing support for marijuana legalization in the US, as indicated by a 68% approval rate according to Gallup (2021). Additionally, the results align with the recent literature which finds that some migrants view marijuana legalization as a favorable amenity (Zambiasi and Stillman, 2020).

Although my findings indicate that RML has no significant effect on overall academic performance (degree completion), it also raises intriguing questions about its impact on other aspects of student behaviors. Additional research is needed to investigate how this policy affects students' choice of majors, including differentiating between STEM and non-STEM disciplines. Understanding this aspect could shed light on potential shifts in educational and career preferences and trajectories. Moreover, it is important to investigate in future studies how RML may contribute to the segregation of low-income or low-performing students (Chetty et al., 2020). This may have further implications for peer effects within educational institutions.

In addition, the current results highlight the dominant impact of early RML adopters and predict null effects for future adopters. As more states legalize marijuana for recreational use and more post-policy data becomes available, future research can explore the long-term consequences of the policy on college enrollment. Another avenue for research may examine all potential externalities and spillovers (Cheng et al., 2018, Dragone et al., 2019, Choi et al., 2019, Sabia et al., 2021, Dave et al., 2023) to conduct a comprehensive cost-benefit analysis of RML from a social welfare perspective. Understanding the broader implications of RML can help policymakers make informed decisions and assess the overall societal impact of marijuana legalization.

[29]The utility gain from consumption amenities will converge to zero as wages and rents on either side of the policy offset each other. For instance, higher enrollment on one side may increase the rent while decreasing it on the other side.

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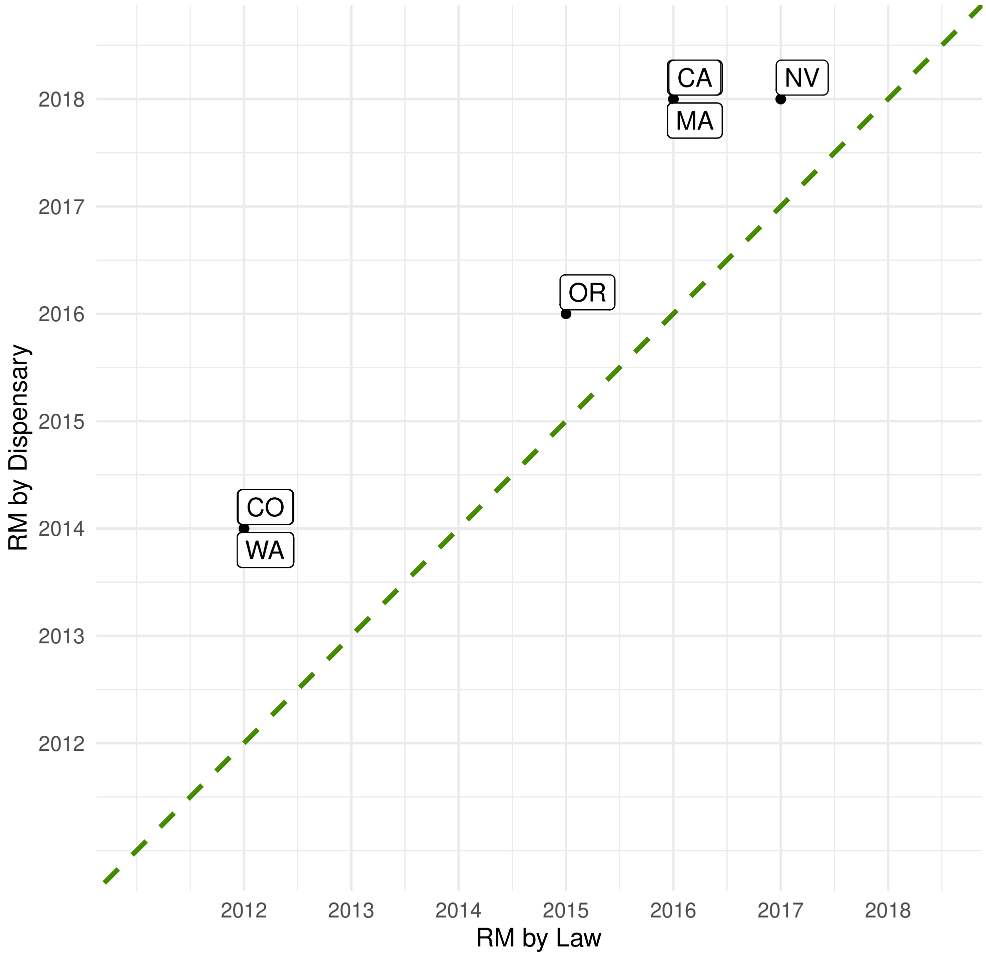
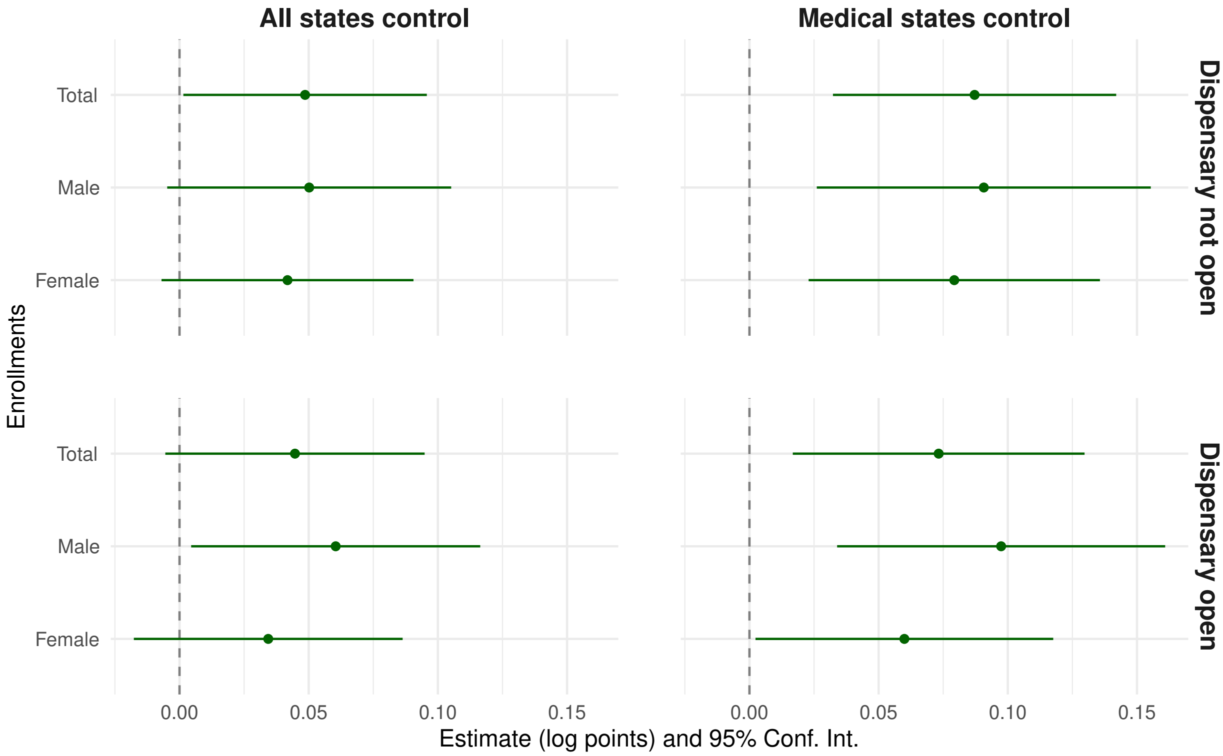
Figure 1: Treated States Legalization Timeline



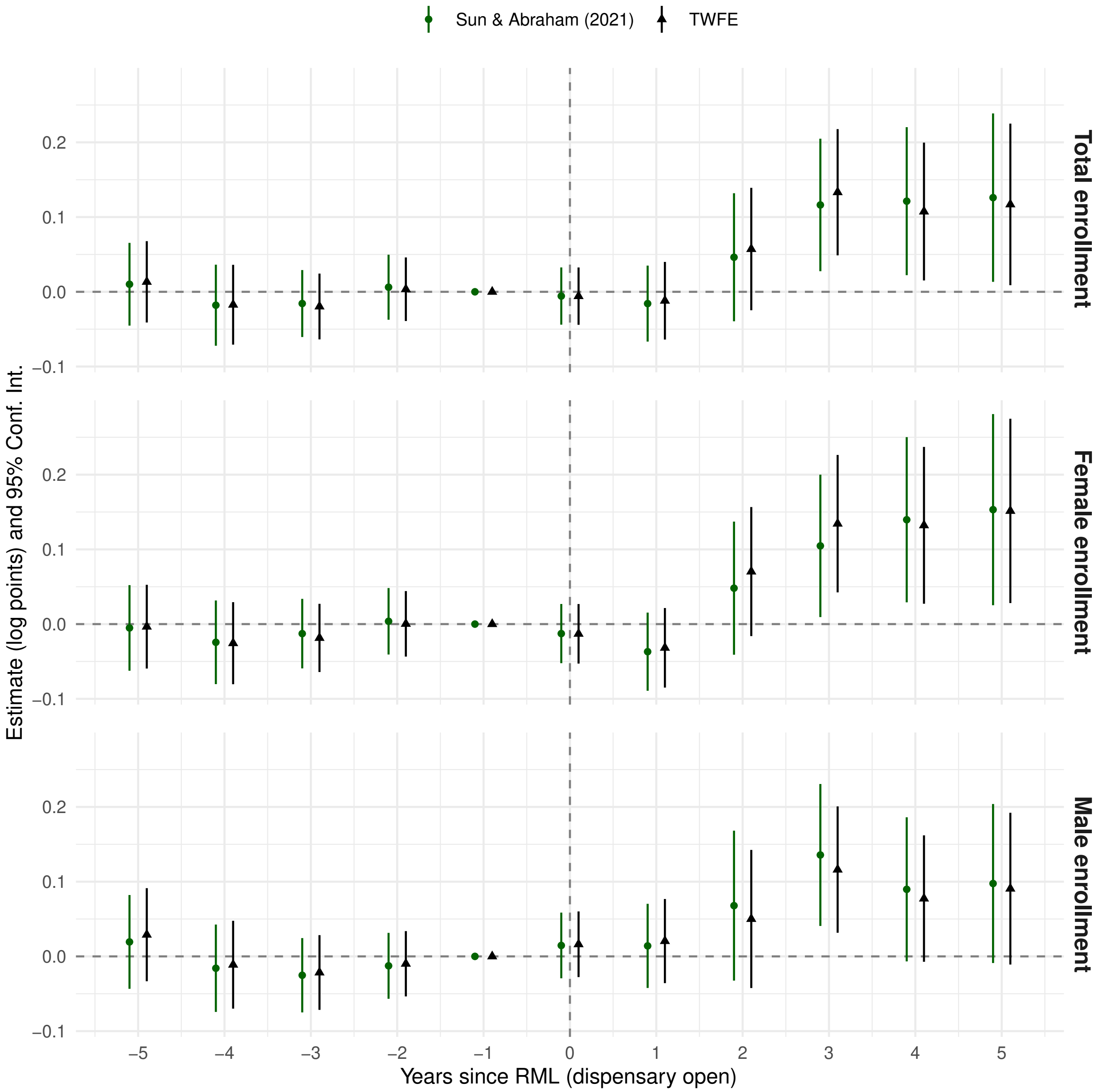
Note: The plot shows when each affected state legalized marijuana for recreational use. RM by Law refers to the year in which the recreational marijuana (RM) policy went into effect; RM by Dispensary refers to the year in which the first dispensary was opened. See appendix figure A1 for more details about the marijuana legalization timeline.

Figure 2: RML Effect on First-Time Enrollment, by Legalization and Control Group Types



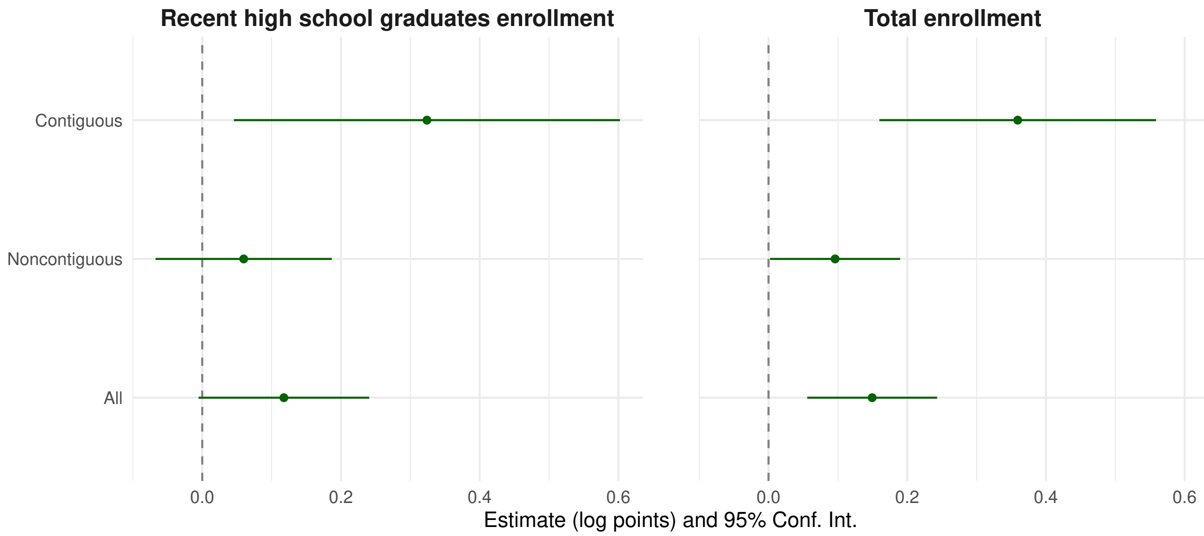
Note: The plots depict the RML effect estimates on log first-time enrollments in academic institutions based on the TWFE difference-in-differences. Each row varies the estimate by how legalization is defined, and each column varies the estimate by how the control group is defined. The legalization status refers to the type of recreational marijuana legalization used for the policy definition as shown in Figure 1. Medical states are those states that legalized marijuana for medical use as of 2019 as illustrated in Figure A7. The models include year and institution fixed effects as well as baseline covariates. The institution-level controls are as follows: medical degree dummy, college size dummy (having over 20k total enrollments), student-to-faculty ratio, distance program dummy, and Reserve Officers' Training Corps (ROTC) program dummy. The county-level controls include the age 18 to 24 population, age 18 to 24 female population share, per-capita income, unemployment rate, and net migration. Standard errors are clustered at the institution level. Further estimation details are shown in tables A3 and A2.

Figure 3: Event Study Graph of RML Treatment



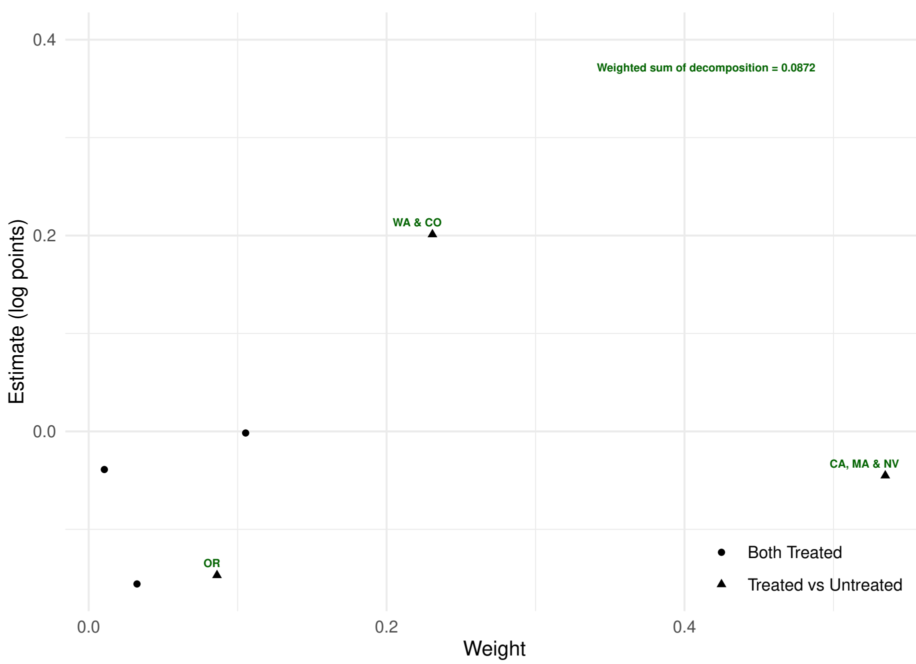
Note: The plots depict the RML effect estimates on log first-time enrollments over time based on both the TWFE difference-in-differences and Sun and Abraham (2021) models. The zero value on the x-axis refers to the first year of legalization. RML policy is defined by the first dispensary opening time as shown in figure 1, and the states which legalized marijuana for medical use are used as a control group. Control variables and fixed effects are as described in Figure 2. Standard errors are clustered at the institution level.

Figure 4: RML Effect on Out-of-State Enrollment, by Contiguity Status



Note: The plots depict the RML effect estimates on log total and recent high school graduates' out-of-state first-time enrollments in academic institutions based on TWFE difference-in-differences. Contiguous refers to states that are contiguous or within close proximity to RM-states as shown in Figure A8. The treatment group includes early movers (Colorado, Washington, and Oregon) because out-of-state data is available only biennially from 2008 to 2018. RML policy is defined by the first dispensary opening time as shown in Figure 1. Control variables and fixed effects are as described in Figure 2. Standard errors are clustered at the institution level.

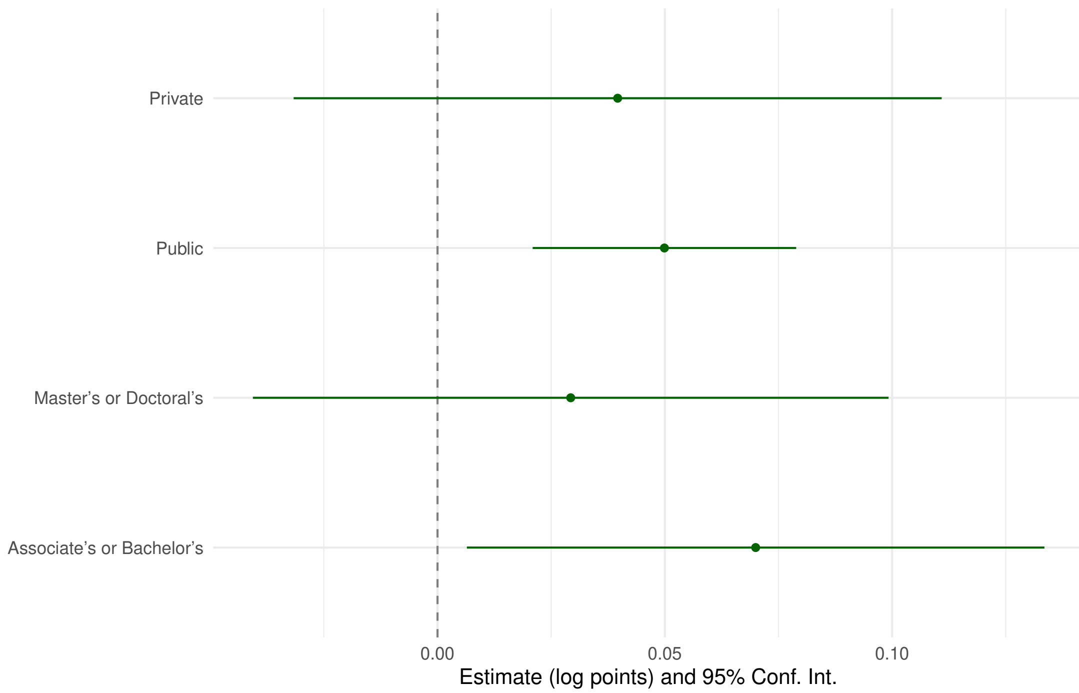
Figure 5: Goodman-Bacon Decomposition



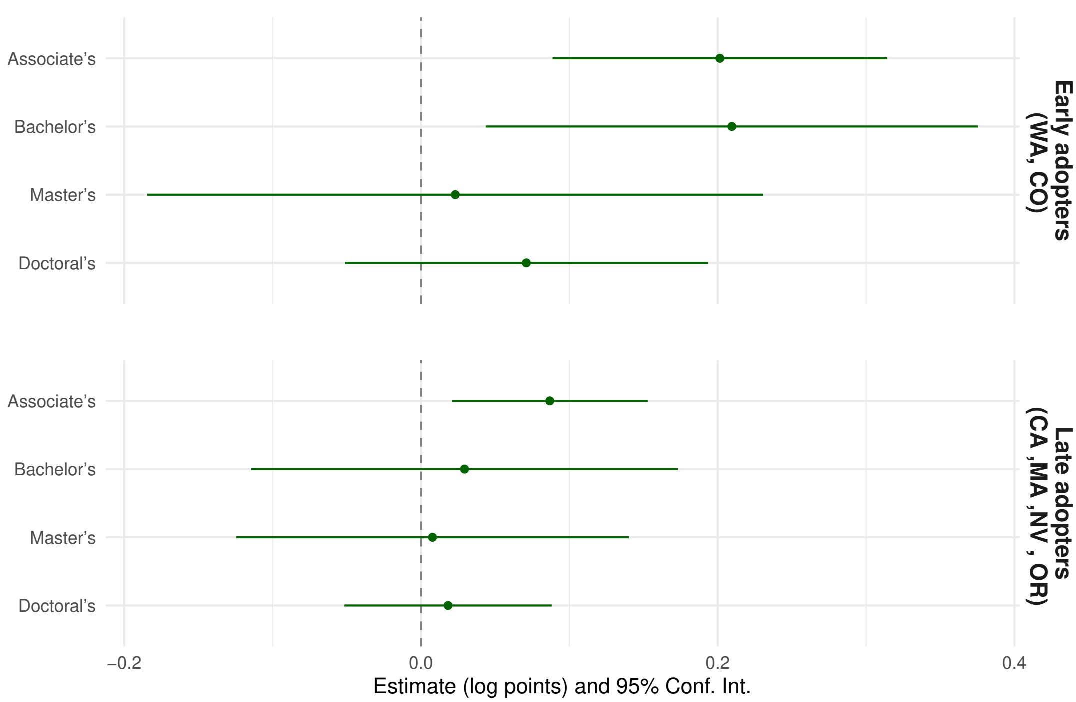
Note: The figures illustrate the point estimate subparts according to Goodman-bacon decomposition. The outcome variable is the logged total first-time enrollments in academic institutions. The decomposition shows that the point estimates are mainly derived from RM and non-RM state pairs–"both treated" pairs have minimal weights. Control variables and fixed effects are as described in Figure 2.

Figure 6: Heterogeneous Effects of Recreational Marijuana Legalization

(a) RML Effect by All Institution Types



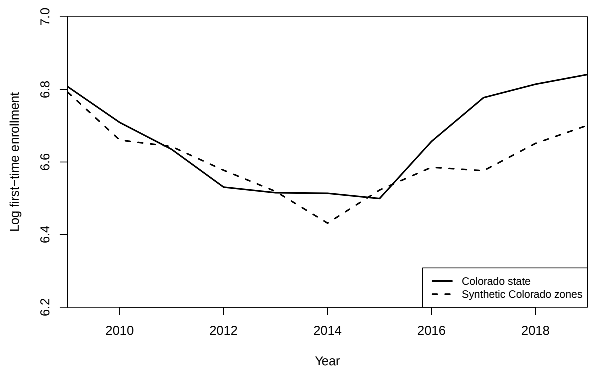
(b) RML Effect by Public Institutions Types and The Timing of Adoption



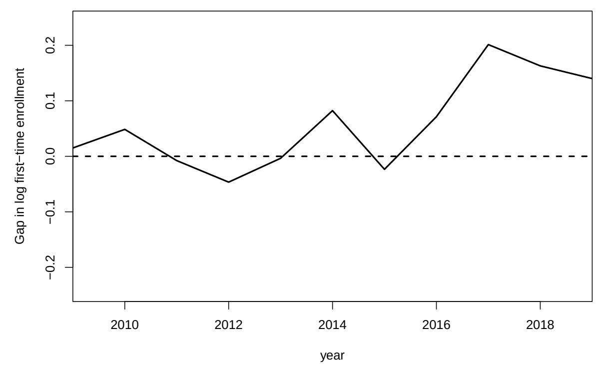
Note: RML policy is defined by the dispensary opening as shown in Figure 1. Degree names refer to the institutions' highest degree conferred. For example, "Associate's" indicates institutions (community colleges) that offer an associate degree as their highest degree, and "Doctoral's" refers to research institutions that offer Ph.D. programs. Panel (a) includes both public and private institutions, and panel (b) is restricted to only public institutions. Control variables and fixed effects are as described in Figure 2. Standard errors are clustered at the institution level.

Figure 7: Synthetic Control Results (Colorado)

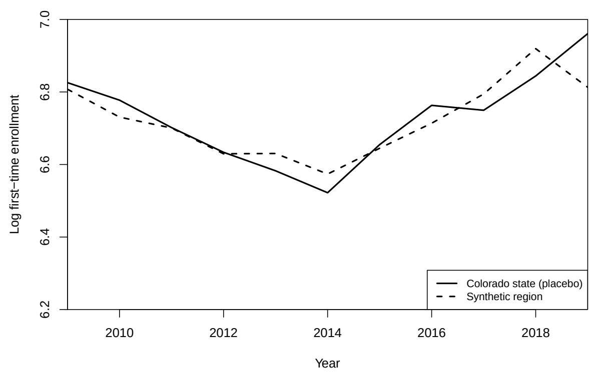
(a) The Effect of RML on Enrollments



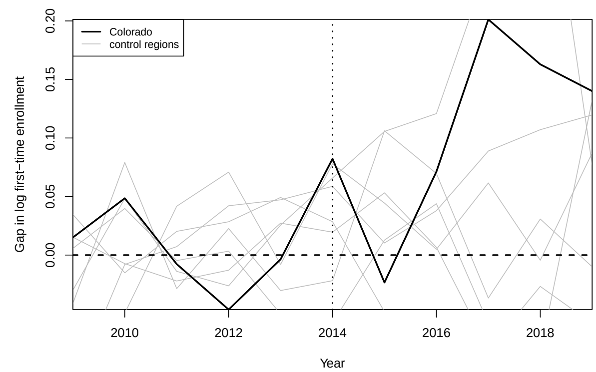
(b) Gap of Enrollments Between Colorado and Synthetic Colorado



(c) Placebo Test



(d) Significance Testing



Note: The synthetic control method is applied on 10 buffer zones around Colorado as shown in A3. I aggregated enrollments and controls over the zones for each year and applied the synthetic control method by Abadie et al. (2010).

Table 1: Summary Statistics, by Recreational Marijuana Legalization Status from 2009 to 2019

	Non-RM States N Observations=16993 N institutions=1814		RM States N Observations=6534 N institutions=733		
	Mean	Std. Dev.	Mean	Std. Dev.	Diff. in Means
Log total first-time enrollment	5.676	1.660	5.765	1.844	0.089***
Log male first-time enrollment	4.717	1.901	4.775	2.110	0.058*
Log female first-time enrollment	5.057	1.697	5.179	1.814	0.122***
Log number of degrees	6.426	1.615	6.518	1.733	0.092
Aggregate enrollment over 20k dummy	0.059	0.236	0.099	0.299	0.040***
Offering medical degree dummy	0.038	0.192	0.029	0.168	-0.009***
Offering ROTC program dummy	0.309	0.462	0.226	0.418	-0.083***
Offering distance programs dummy	0.789	0.408	0.762	0.426	-0.028***
Log age 18 to 24 population	10.281	1.484	11.495	1.464	1.214***
Age 18 to 24 population female share	0.491	0.024	0.487	0.022	-0.005***
Unemployment rate	6.258	2.343	7.267	3.397	1.009***
Log per capita income	10.696	0.271	10.793	0.258	0.097***
Log Net migration	11.287	0.142	11.099	1.284	-0.187***
Log total out-of-state enrollment	6.448	1.685	6.507	1.852	0.058
Log RHG out-of-state enrollment	5.764	2.279	5.652	2.465	-0.112*
Tuition and fees revenue	16.573	1.699	16.586	1.611	0.012
Tuition and fees revenue per student	8.896	1.190	8.497	1.683	-0.399***
Log number of admissionss	7.139	1.612	7.131	1.960	-0.008
Log number of ACT and SAT submissions	6.284	1.215	6.681	1.345	0.397***
Retention rate	67.119	17.120	70.376	16.816	3.257***
ACT 75th Math score	25.314	3.356	26.528	3.863	1.213***
SAT 75th Math score	592.911	71.508	611.573	77.858	18.662***
ACT 75th English score	25.883	3.833	27.042	4.437	1.159***
ACT 75th Crititcal Reading score	587.533	69.224	605.316	72.090	17.783***

Note: Enrollment refers to the number of first-time degree-seeking undergraduate students. RM states refer to Colorado, Washington, Oregon, California, Nevada, and Massachusetts which respectively opened the first dispensary in 2014, 2014, 2016, 2018, 2018, and 2018. Territories, Hawaii, Alaska, Maine, and Michigan are excluded either because they are noncontiguous to other states or because they open their first dispensary in 2019 or after (see Figure 1). The unit of observation is university-year. RHG stands for Recent High School Graduates and ROTC for Reserve Officers' Training Corps. The control group in this table consists of all states that have legalized marijuana for medical use, as shown in Figure A1. Table A1 presents similar summary statistics based on the control group of all states. * p < 0.05, ** p < 0.01, *** p < 0.001

Table 2: Effects of RML on Undergraduate College Completion

	Lead 1	Lead 2	Lead 3	Lead 4	Lead 5	Lead 6
RM	0.017	0.058	0.082*	0.101**	0.079*	0.061
	(0.036)	(0.037)	(0.034)	(0.037)	(0.036)	(0.036)
N Obs.	19,450	17,074	14,766	12,541	10,433	8,416
N colleges	2,482	2,482	2,482	2,482	2,482	2,482
Controls	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
College FE	Y	Y	Y	Y	Y	Y

Note: The outcome variable refers to the logged number of all undergraduate degrees conferred. The policy is defined by law approval timing (see Figure 1) to allow the use of 6 leads. This is in contrast to prior exhibits which are based on the dispensary opening. A lead of "i" (ranging from 1 to 6) indicates that the ith lead of the outcome variable was used in the analysis. Colorado and Washington are the only treated states. Nevada, California, Oregon, and Massachusetts are dropped from this analysis due to the inexistence of observations for leads of the outcome variable. The control group includes states that legalized marijuana for medical use (see figure A7 for more details). Control variables are as described in Figure 2. Standard errors are clustered at the institution level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Effects of RML on Tuition Revenue and Retention Rate

	Tuition revenue		Tuition revenue per student		Retention Rate	
	(1)	(2)	(3)	(4)	(5)	(6)
RM	0.084*	0.059	0.055	0.014	−0.009	−0.019
	(0.036)	(0.038)	(0.030)	(0.031)	(0.022)	(0.023)
N Obs.	17,191	17,191	17,189	17,189	16,642	16,642
N colleges	2,024	2,024	2,024	2,024	2,024	2,024
Controls	Y	Y	Y	Y	Y	Y
College FE	Y	Y	Y	Y	Y	Y
Year FE	N	Y	N	Y	N	Y

Note: In Panel (b), the sample control units include the states which legalized marijuana for medical use (see Figure A7). The tuition and fees variables are derived by binding all the IPEDS finance surveys. Since these surveys depend on the institution types (public or private) and the accounting standards (GASP and FASB), I controlled for these types in the tuition models. Tuition refers to all the tuition and fees (logged) collected during a year period. Retention rate (logged) is defined on IPEDS's survey as "the percent of the (fall full-time cohort from the prior year minus exclusions from the fall full-time cohort) that re-enrolled at the institution as either full- or part-time in the current year". The models also include the control variables and fixed effects described in Figure 2. Standard errors are clustered at the institution level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Effects of RML on Admissions and Test Scores for Selective Colleges

	N Admission	N Tests Submissions	ACT Math	SAT Math	ACT English	SAT Reading
	(1)	(2)	(3)	(4)	(5)	(6)
RM	−0.021	−0.092*	0.026	0.150***	0.101	0.007
	(0.047)	(0.040)	(0.099)	(0.043)	(0.113)	(0.049)
N Obs.	8,100	6,486	5,753	5,976	5,754	5,936
N college	1,013	717	679	683	679	683
Controls	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Colleges FE	Y	Y	Y	Y	Y	Y

Note: The dependent variables in columns (1) and (2) refer respectively to the logged number of admitted students and the logged number of SAT and ACT test scores received for admission purposes to an undergraduate program. In columns (3) to (6), the outcome variables are the standardized 75th percentile scores for each test type. The sample control units include the states which legalized marijuana for medical use. The included states are depicted in Figure A7. The policy dummy variable is defined at the dispensary opening time of legalization. Control variables and fixed effects are as described in Figure 2. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

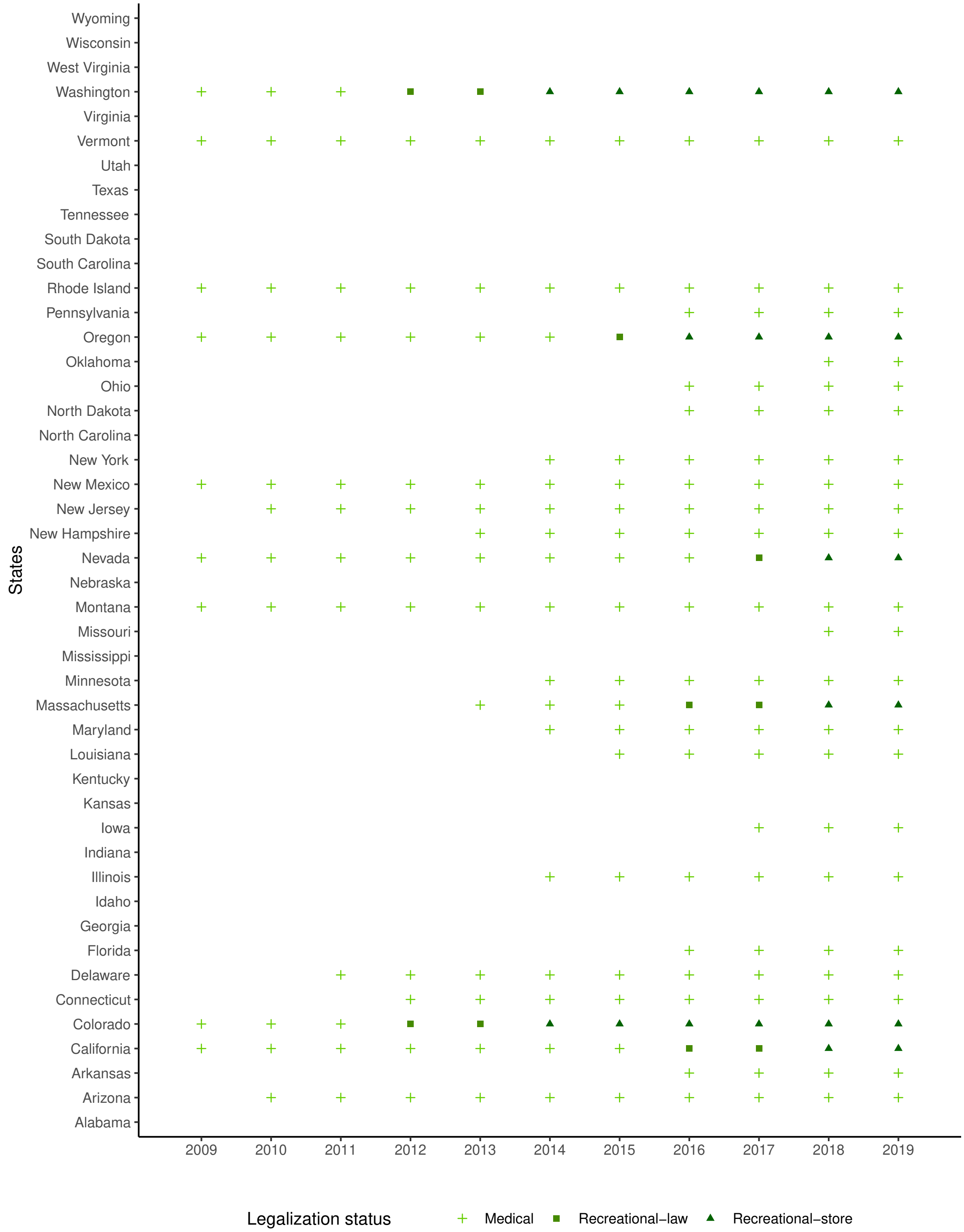
Table 5: Effects of RML on Enrollment Sensitivity to Proximity Spillover

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel (a): All Institutions								
RM	0.078**	0.079**	0.082**	0.078**	0.076*	0.075*	0.076*	0.075*
	(0.029)	(0.029)	(0.029)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)
N Obs.	23,325	23,112	22,919	22,698	22,526	22,409	22,290	22,082
N colleges	2,529	2,507	2,486	2,466	2,451	2,439	2,427	2,409
Panel (b): Public and Non-research Institutions								
RM	0.106***	0.104***	0.106***	0.096**	0.087**	0.086**	0.087**	0.087**
	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.032)	(0.032)
N Obs.	5,635	5,559	5,528	5,418	5,354	5,319	5,257	5,230
N colleges	602	594	591	581	576	572	565	562
N Miles removed	10	20	30	40	50	60	70	80
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
College FE	Y	Y	Y	Y	Y	Y	Y	Y

Note: This table presents the results of the TWFE difference-in-differences analysis. The outcome variable is log first-time enrollments Panel (a) is based on the main results sample, which contains all academic institutions. Panel (b) sample consists of public institutions that do not offer graduate degrees (i.e., offering only bachelor or associate degrees). To assess potential bias in the estimates caused by spillover effects from students commuting or migrating to policy-affected colleges, each column shows the results after excluding control colleges located within a certain distance of the policy-affected border. For instance, Column 8 displays the results obtained after excluding all untreated colleges within 80 miles of the border of the treated states. Figure A10 illustrates the geographical distribution of control and treatment institutions. The policy dummy variable is defined at the dispensary opening time of legalization. Control variables and fixed effects are as described in Figure 2. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A Appendix

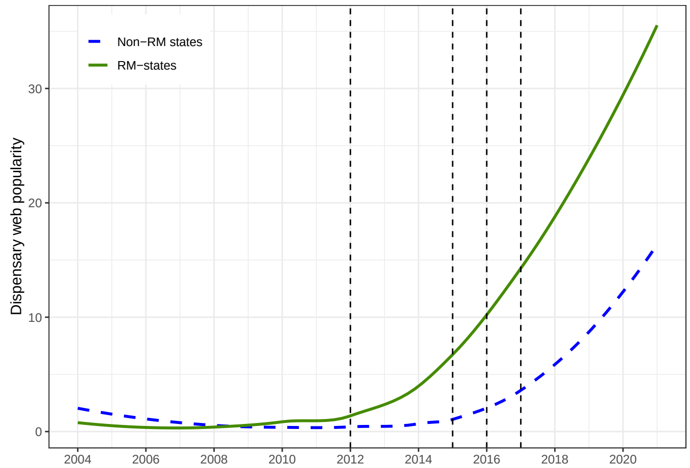
Figure A1: Marijuana Legalization Timeline



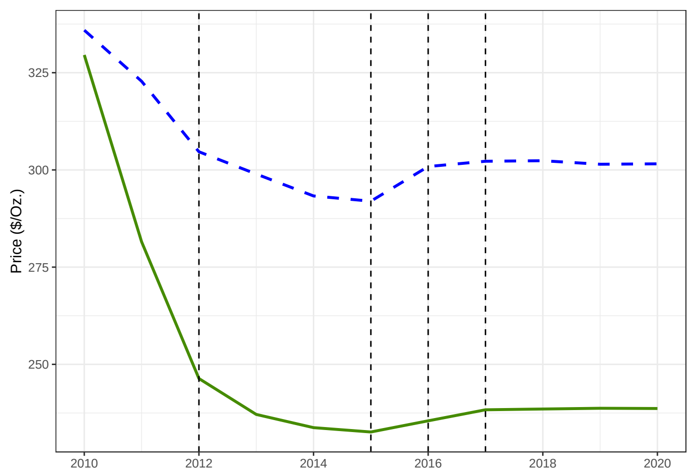
Note: the figure shows the marijuana legalization timeline by state and the type of legalization. Recreational law means that recreational marijuana is legal by means of law passage or approval (i.e., dispensaries not yet open). Recreational store means that recreational marijuana is available for sale by authorized retailers (i.e., dispensaries open). DC, Alaska, Maine, Michigan, and all US territories are excluded due to either being non-contiguous to other states or the unavailability of at least two years of post-policy observations within sample periods.

Figure A2: Marijuana Consumption and Price by Legalization Status

Panel (a): Google Trends for "dispensary"

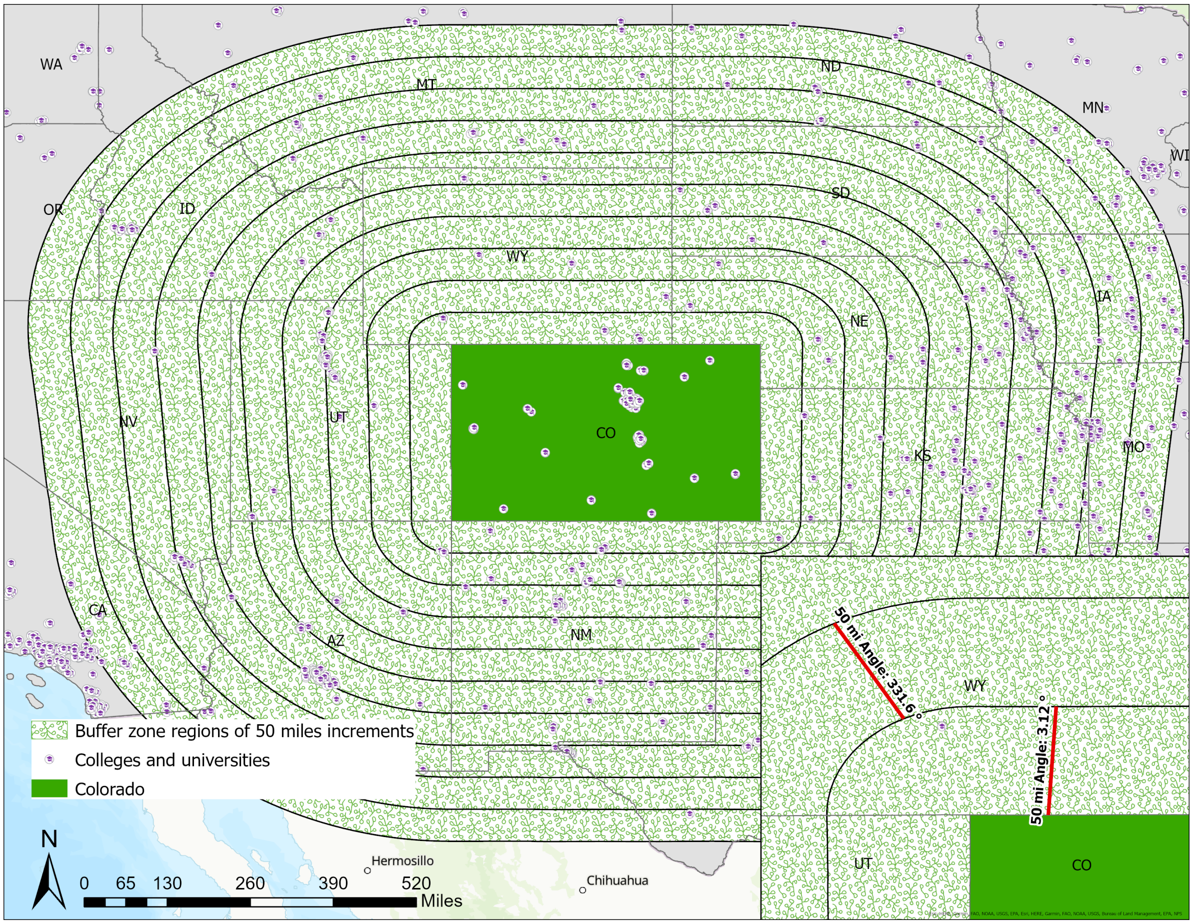


Panel (b): Marijuana Price



Note: Google web popularity (refer to as hits in Google Trends) is a number between 0 and 100 that measures the popularity of Google search terms or words, showing how popular a word is among all other searches in a particular region and time. Panel (a) compares the average popularity of the word "dispensary" between states that legalized recreational marijuana (RM-states) and those that did not legalize it (Non-RM states). Marijuana prices are extracted from PriceOfWeed.com via Wayback Machine. Panel (b) depicts the average of the medium and high-quality marijuana prices (low-quality prices are not available for most years) for each state and year. The figure compares the average yearly cannabis prices between states that legalized marijuana practically for recreational use as of 2019 and those that did not. The vertical lines refer to the year in which different states legalized marijuana–Colorado and Washington in 2012, Oregon in 2015, Massachusetts and California in 2016, and Nevada in 2017.

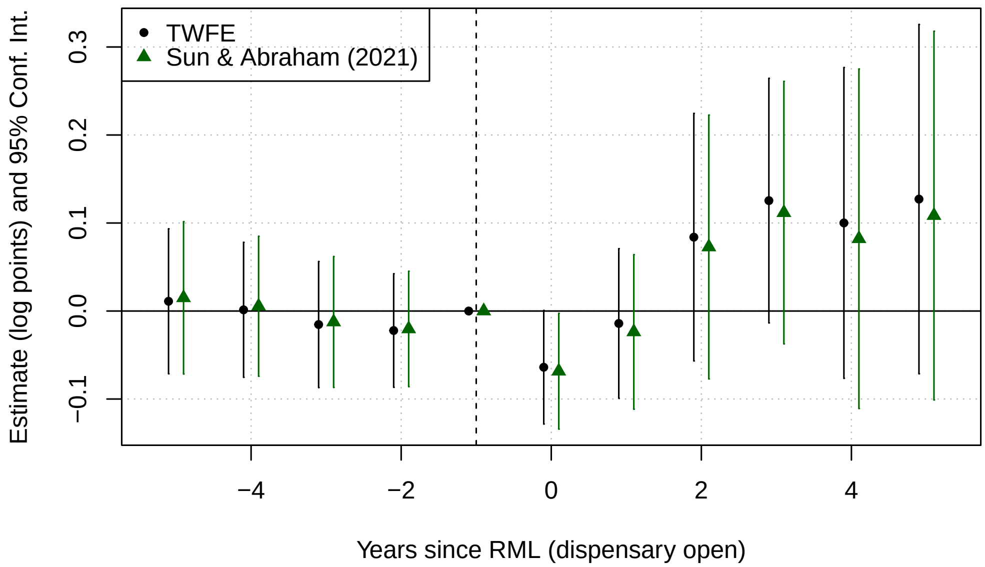
Figure A3: Colorado Buffer Zones



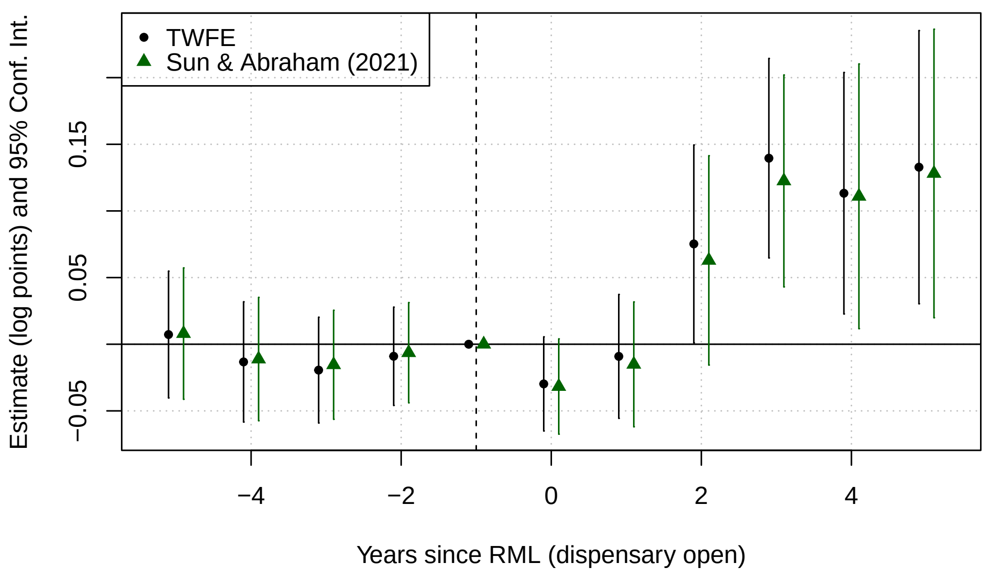
Note: ArcGIS Pro software is used to create buffer zones of 50 miles increments around the Colorado border. Each 50-mile zone serves as a candidate for synthetic control. Note that the dispersion of colleges is not all depicted as some college points coincide due to map zooming.

Figure A4: Event Study Graph of RML Treatment by Institution Type

Panel (a): RML Effect on First-Time Enrollment in Vocational Institutions

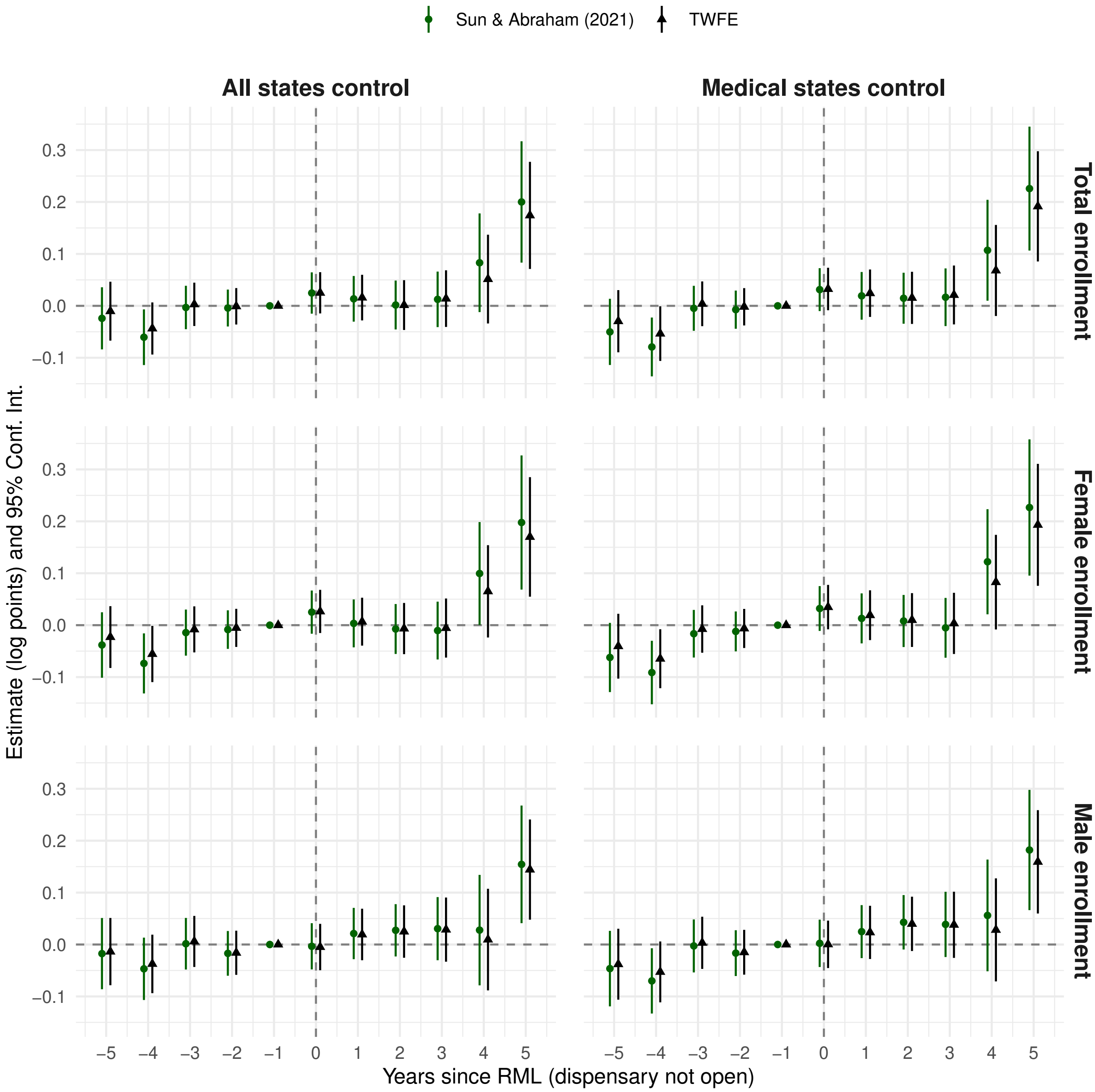


Panel (c): RML Effect on Total First-Time Enrollment in All Institutions



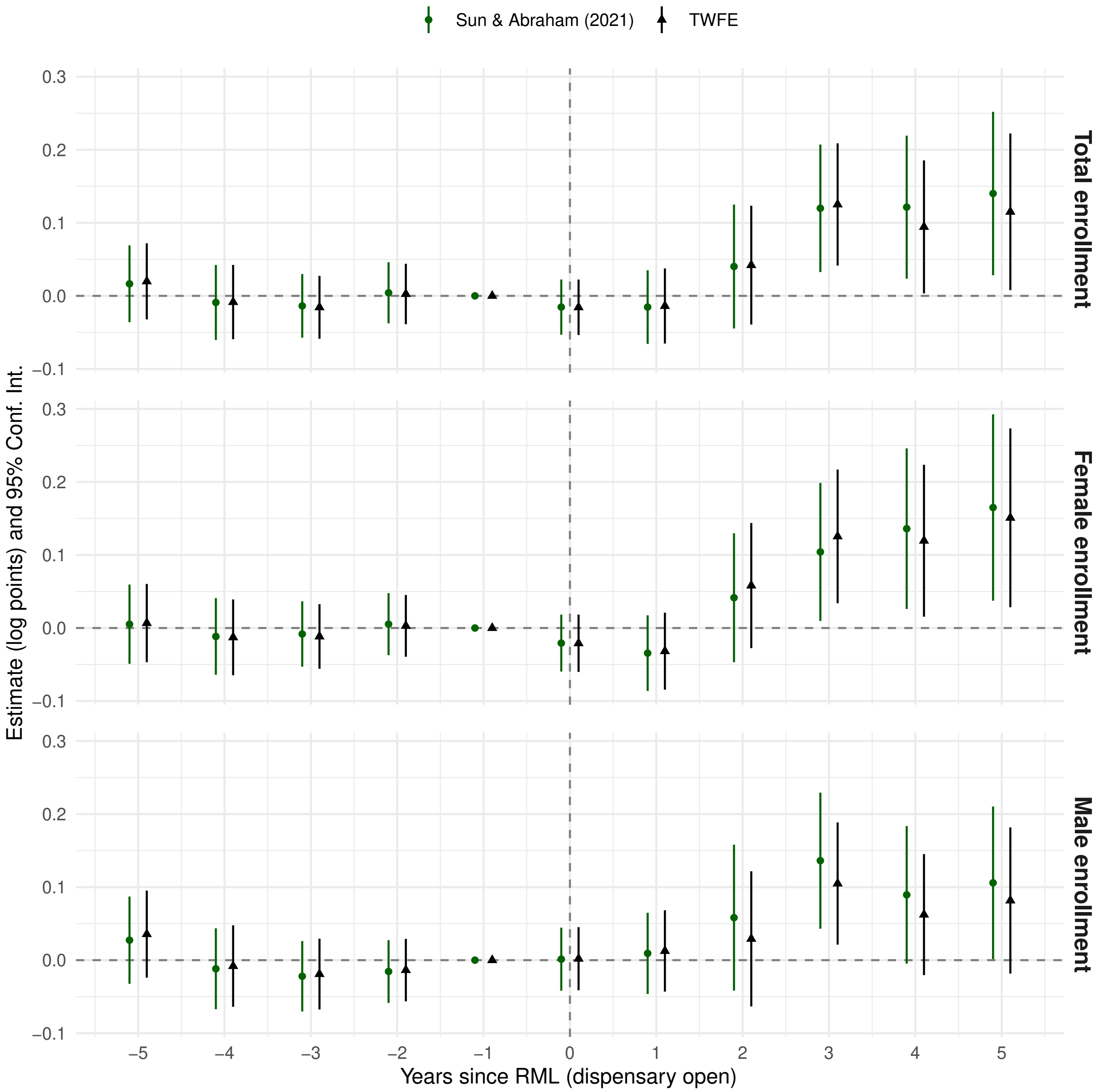
Note: The plots depict the RML effect estimates on first-time enrollments over time based on both the TWFE difference-in-differences and Sun and Abraham (2021) models. All outcome variables are logged to simplify the interpretation of the coefficients. The zero value on the x-axis refers to the first year of legalization. The control group consists of all the states that legalized medical marijauna (see Figure A7). RML is defined by the dispensary opening time. All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level (see Figure 1).

Figure A5: Event Study Graph of RML (Dispensary Not Open) Treatment



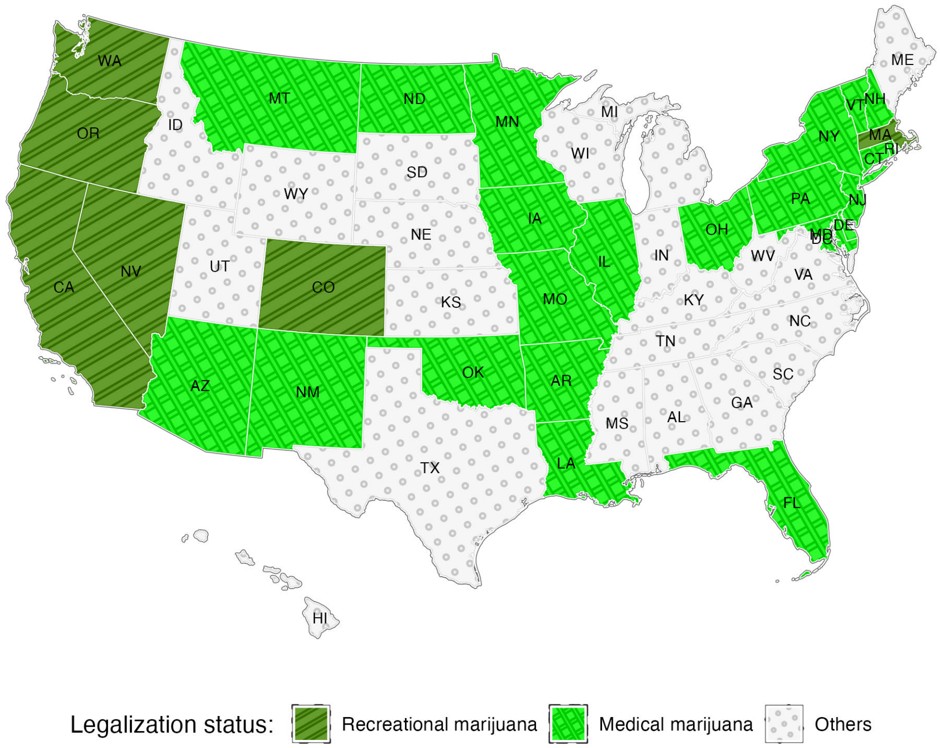
Note: The plots depict the RML effect estimates on first-time enrollments over time using both TWFE difference-in-differences and Sun and Abraham (2021) models. All outcome variables are logged to simplify the interpretation of the coefficients. Medical states control refers to the use of states that legalized marijuana for medical use as a control group (see Figure A7). The zero value on the x-axis refers to the first year of legalization. RML is defined utilizing the law passage timing as shown in Figure 1. All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level.

Figure A6: Event Study Graph of RML (Dispensary Open) Treatment Using All States Control Group



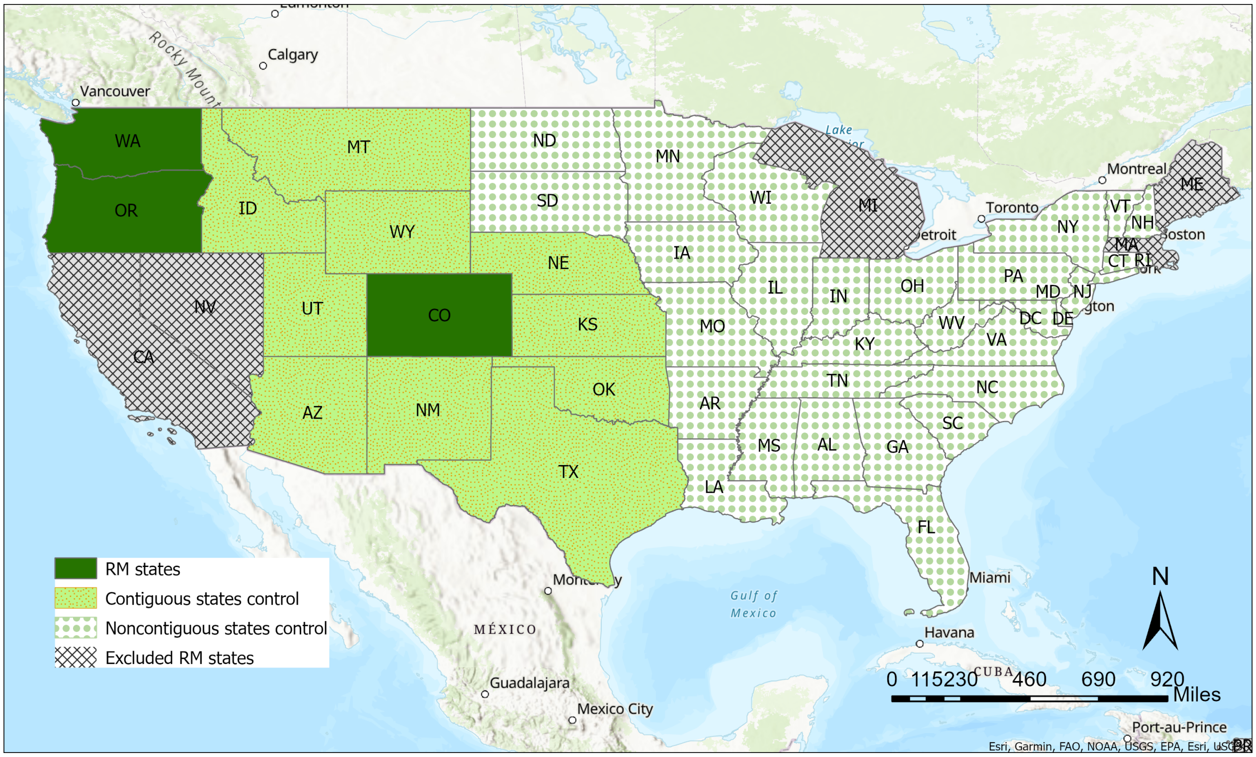
Note: The plots depict the RML effect estimates on first-time enrollments in academic institutions over time based on both the TWFE and Sun and Abraham (2021) models. The zero value on the x-axis refers to the first year of legalization. All Control variables and fixed effects are included as described in Figure 2. RML policy is defined by the first dispensary opening time as shown in figure 1. Standard errors are clustered at the institution level.

Figure A7: Medical Marijuana Control Group



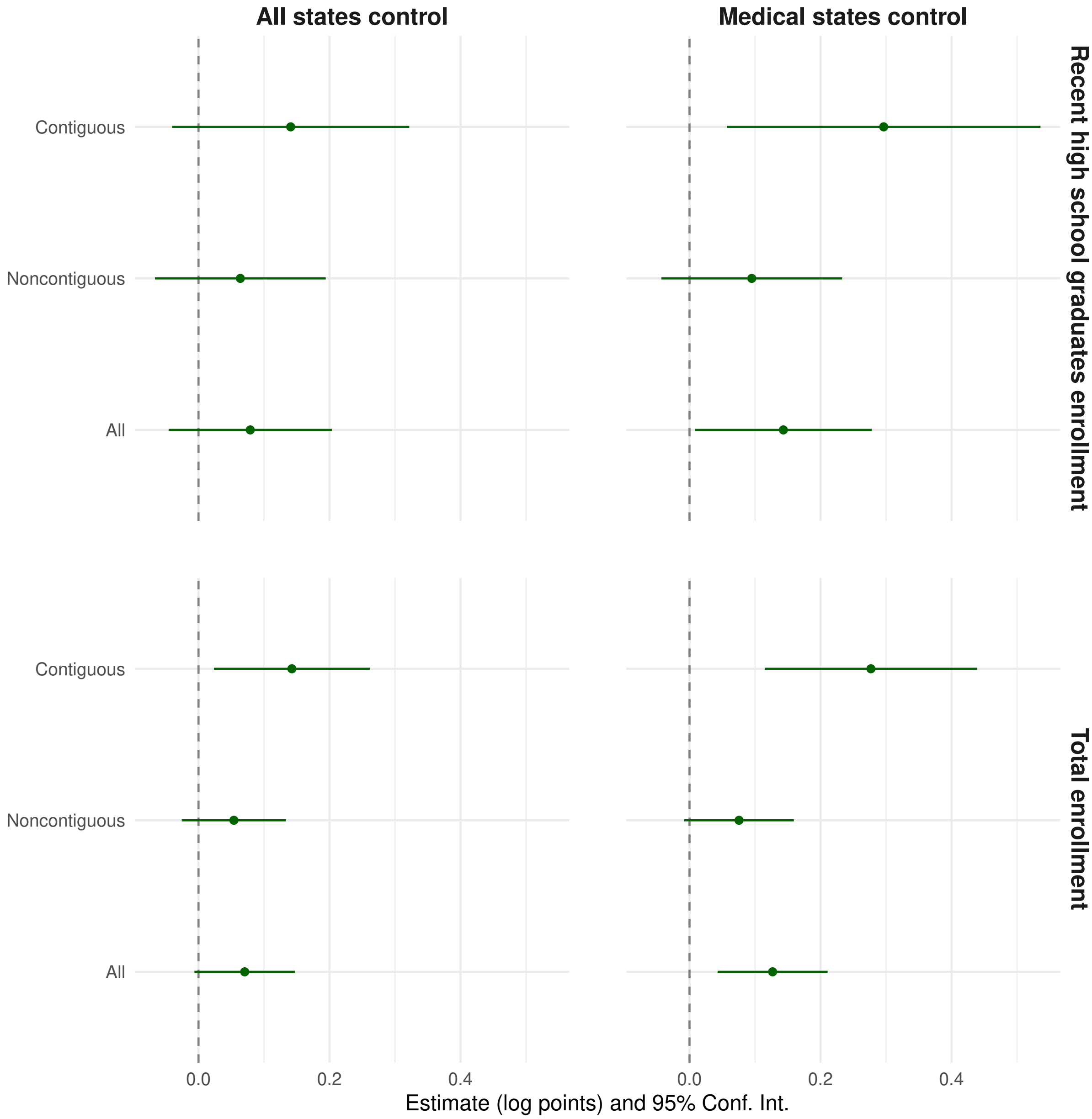
Note: the map shows the states which are included in the medical control group–the states that legalized medical marijuana as of 2019. Others refer to the states which are excluded (Maine, Michigan) because of a lack of post-policy observations or states that have not yet legalized marijuana for medical use.

Figure A8: Contiguous and Noncontiguous Control States



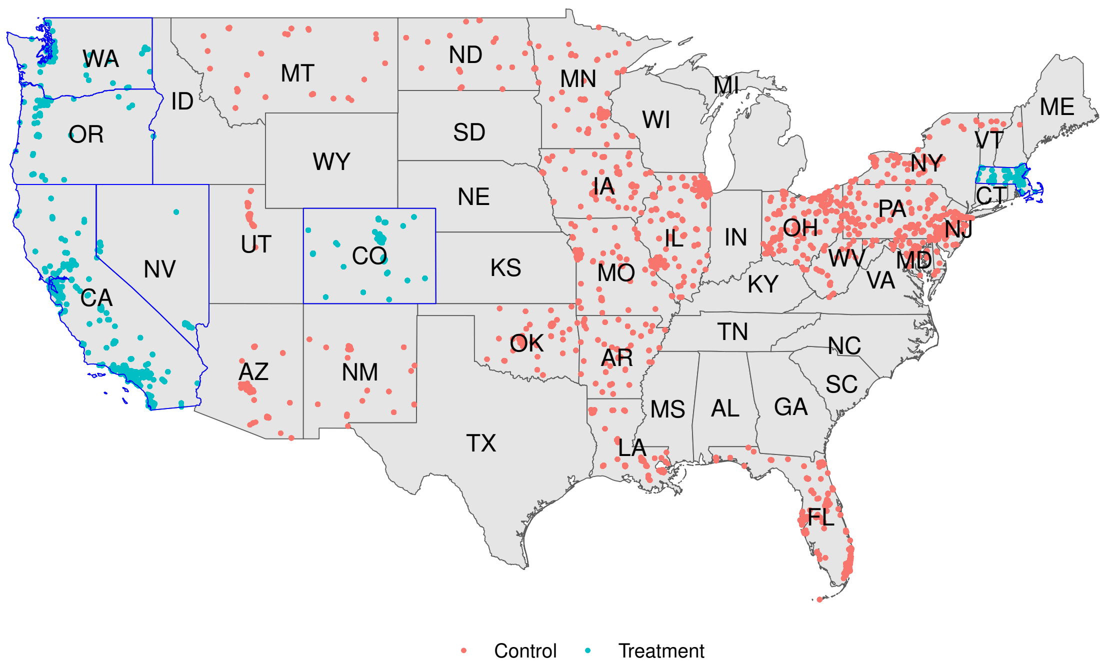
Note: the map shows the states which are included in the contiguous and noncontiguous control groups.

Figure A9: RML (Dispensary Not Open) Effect on Out-of-State Enrollment, by Contiguity Status



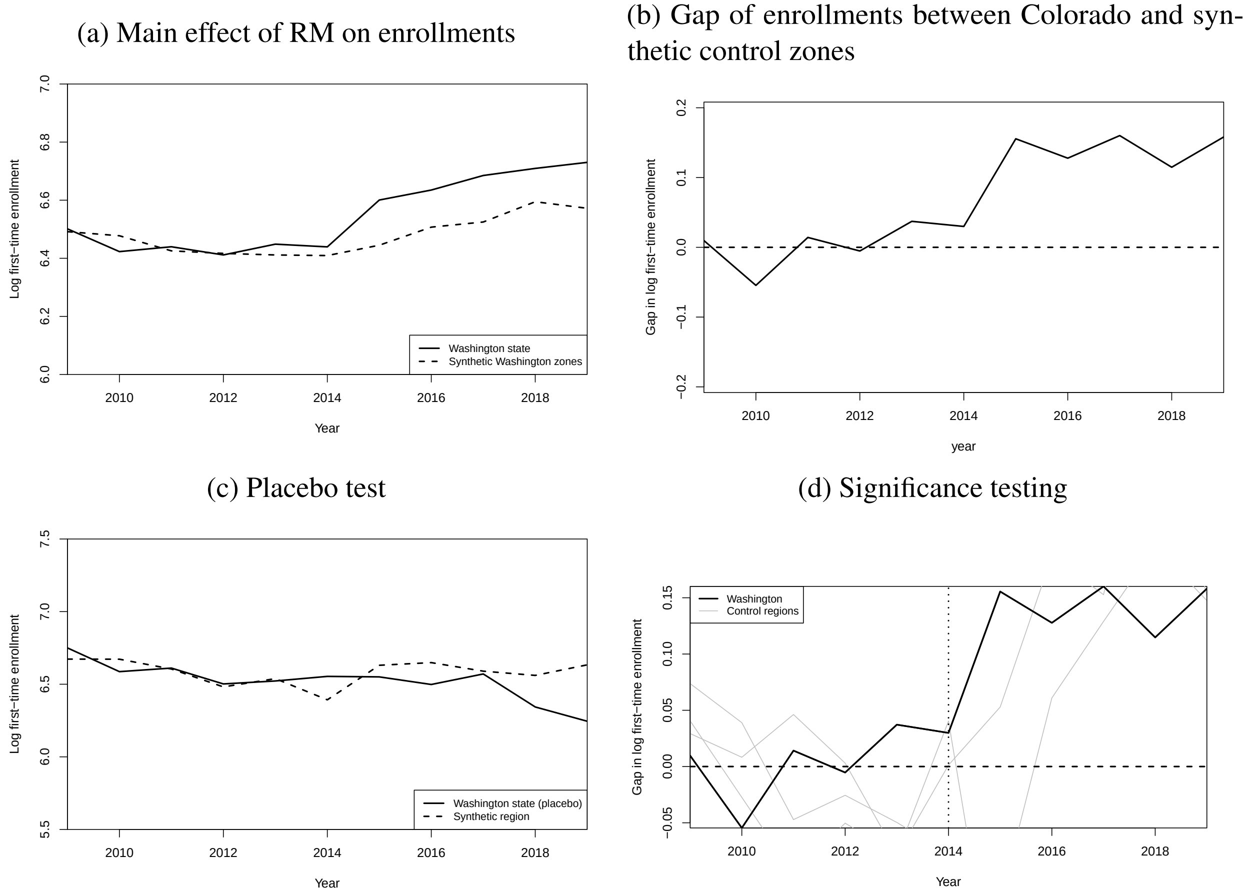
Note: The plots depict the RML effect estimates on total and recent high school graduates' out-of-state first-time enrollments based on TWFE difference-in-differences. Contiguous refers to states that are contiguous or within close proximity to RM-states as shown in figure A8. Medical states refer to the states that legalized marijuana for medical use as shown in A7. The treatment group includes early movers (Colorado, Washington, and Oregon) because out-of-state data is available only biennially from 2008 to 2018. RML is defined utilizing the law passage timing as shown in Figure 1. All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level.

Figure A10: The Exclusion of Control Colleges Within 80 Miles of Treated Borders



Note: The figure depicts colleges in the states that are included in the control and treatment groups for spillover analysis. Colleges within 80 miles are excluded from the control group, which includes all the states that legalized marijuana for medical use.

Figure A11: Synthetic Control Results (Washington)



Note: the synthetic control method is applied on 10 buffer zones around Washington state (i.e., similar to buffers shown in Figure A3). I aggregated enrollments and controls over the zones for each year and applied the synthetic control method by Abadie et al. (2010).

Table A1: Summary Statistics–All States Control Group

	Non-RM States N Observations=28710 N institutions=3114		RM States N Observations=6534 N institutions=733			
	Mean	Std. Dev.	Mean	Std. Dev.	Diff. in Means	p
Log total first-time enrollment	5.672	1.655	5.765	1.844	0.092	<0.001
Log male first-time enrollment	4.693	1.907	4.775	2.110	0.082	0.004
Log female first-time enrollment	5.065	1.684	5.179	1.814	0.114	<0.001
Log number of degrees	6.361	1.632	6.518	1.733	0.157	<0.001
Aggregate enrollment over 20k dummy	0.059	0.236	0.099	0.299	0.040	<0.001
Offering medical degree dummy	0.038	0.192	0.029	0.168	-0.009	<0.001
Offering ROTC program dummy	0.320	0.466	0.226	0.418	-0.094	<0.001
Offering distance programs dummy	0.794	0.405	0.762	0.426	-0.032	<0.001
Log age 18 to 24 population	10.091	1.498	11.495	1.464	1.404	<0.001
Age 18 to 24 population female share	0.492	0.027	0.487	0.022	-0.005	<0.001
Unemployment rate	6.328	2.521	7.267	3.397	0.939	<0.001
Log per capita income	10.657	0.259	10.793	0.258	0.136	<0.001
Log Net migration	11.296	0.119	11.099	1.284	-0.197	<0.001
Log total out-of-state enrollment	6.444	1.677	6.507	1.852	0.063	0.088
Log RHG out-of-state enrollment	5.743	2.305	5.652	2.465	-0.091	0.064
Tuition and fees revenue	16.504	1.741	16.586	1.611	0.082	0.069
Tuition and fees revenue per student	8.842	1.174	8.497	1.683	-0.345	<0.001
Log number of admissionss	7.130	1.597	7.131	1.960	0.001	0.973
Log number of ACT and SAT submissions	6.307	1.249	6.681	1.345	0.374	<0.001
Retention rate	66.252	17.022	70.376	16.816	4.124	<0.001
ACT 75th Math score	24.866	3.362	26.528	3.863	1.662	<0.001
SAT 75th Math score	585.438	70.585	611.573	77.858	26.135	<0.001
ACT 75th English score	25.504	3.913	27.042	4.437	1.538	<0.001
ACT 75th Crititcal Reading score	582.072	68.650	605.316	72.090	23.243	<0.001

Note: enrollment refers to the number of first-time degree-seeking undergraduate students. RM states refer to Colorado, Washington, Oregon, California, Nevada, and Massachusetts which respectively opened the first dispensary in 2014, 2014, 2016, 2018, 2018, and 2018. Territories, Hawaii, Alaska, Maine, and Michigan are excluded either because they are noncontiguous to other states or because they open their first dispensary in 2019 or after (see Figure 1). The unit of observation is university-year. RHG stands for Recent High School Graduates and ROTC for Reserve Officers' Training Corps. The control group in this table consists of all the states that did not legalize marijuana for recreational use (see Figure A1).

Table A2: RML Effect on First-Time Enrollment Using Medical States Control Group

	Total enrollment			Female enrollment			Male enrollment		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel (a): RM policy by the law approval									
RM	0.140	0.087**	0.090**	0.170*	0.079**	0.082**	0.185	0.091**	0.096**
	(0.083)	(0.028)	(0.028)	(0.083)	(0.029)	(0.029)	(0.098)	(0.033)	(0.033)
Panel (b): RM policy by the retailer stores opening									
RM	0.118	0.073*	0.074**	0.147	0.060*	0.061*	0.177	0.097**	0.101**
	(0.092)	(0.029)	(0.029)	(0.093)	(0.029)	(0.029)	(0.107)	(0.032)	(0.032)
N Obs.	23 526	23 526	23 526	23 526	23 526	23 526	23 526	23 526	23 526
N college	2549	2549	2549	2549	2549	2549	2549	2549	2549
Pre-RML mean enrollment	1002	1002	1002	531	531	531	471	471	471
Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
College FE	N	Y	Y	N	Y	Y	N	Y	Y
State FE	N	N	Y	N	N	Y	N	N	Y

Note: the table displays the results of the TWFE difference-in-differences. The outcome variables refer to the logged first-time enrollments. The sample control units include the states which legalized marijuana for medical use. The included states are depicted in figure A7. All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A3: RML Effect on First-Time Enrollment Using All States Control Group

	Total enrollment			Female enrollment			Male enrollment		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel (a): RM policy by the law approval									
RM	0.168*	0.049*	0.054*	0.172*	0.042	0.048	0.253**	0.050	0.056*
	(0.069)	(0.024)	(0.024)	(0.070)	(0.025)	(0.025)	(0.081)	(0.028)	(0.028)
Panel (b): RM policy by the retailer stores opening									
RM	0.147	0.045	0.049	0.153	0.034	0.039	0.239**	0.060*	0.065*
	(0.078)	(0.026)	(0.026)	(0.079)	(0.027)	(0.026)	(0.089)	(0.029)	(0.028)
N Obs.	34 749	34 749	34 749	34 749	34 749	34 749	34 749	34 749	34 749
N college	3851	3851	3851	3851	3851	3851	3851	3851	3851
Pre-RML mean enrollment	1002	1002	1002	531	531	531	471	471	471
Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
College FE	N	Y	Y	N	Y	Y	N	Y	Y
State FE	N	N	Y	N	N	Y	N	N	Y

Note: the table displays the results of the TWFE difference-in-differences. The outcome variables refer to the logged first-time enrollments. All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A4: RML Effect on Completion Using All States Contol Group

	Lead 1	Lead 2	Lead 3	Lead 4	Lead 5	Lead 6
RM	−0.030	0.001	0.029	0.050	0.033	0.025
	(0.035)	(0.035)	(0.033)	(0.037)	(0.036)	(0.035)
N Obs.	30 880	27 073	23 375	19 829	16 470	13 283
N college	4008	4008	4008	4008	4008	4008
Controls	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
College FE	Y	Y	Y	Y	Y	Y

Note: the table displays the results of the TWFE difference-in-differences. The outcome variable refers to the logged number of all undergraduate degrees conferred. The policy is defined by the passage of a law to allow the use of 6 leads. A lead of "i" (ranging from 1 to 6) indicates that the ith lead of the outcome variable was used in the analysis. Colorado and Washington are the only treated states. Nevada, California, Oregon, and Massachusetts are dropped from this analysis due to the inexistence of observations for leads of the outcome variable. The control group includes all the states regardless of whether or not they legalized medical marijuana. All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A5: RML Effect on Tuition Revenue and Retention Rate–RML by Dispensaries Not Open

	Tuition revenue		Tuition revenue per student		Retention Rate	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): All state control group						
RM	0.070**	0.061*	0.057***	0.024	−0.006	−0.013
	(0.023)	(0.024)	(0.017)	(0.018)	(0.016)	(0.016)
N Obs.	33 587	33 587	33 584	33 584	32 729	32 729
N college	3851	3851	3851	3851	3851	3851
Panel (b): medical states control group						
RM	0.083*	0.051	0.055	0.004	−0.016	−0.025
	(0.034)	(0.037)	(0.029)	(0.030)	(0.021)	(0.021)
N Obs.	17 191	17 191	17 189	17 189	16 642	16 642
N college	2024	2024	2024	2024	2024	2024
Controls	Y	Y	Y	Y	Y	Y
College FE	Y	Y	Y	Y	Y	Y
Year FE	N	Y	N	Y	N	Y

Note: In Panel (b), the sample control units include the states which legalized marijuana for medical use. The included states are depicted in figure A7. The tuition and fees variables are derived by binding all the IPEDS finance surveys. Since these surveys depend on the institution types (public or private) and on the type of accounting standards used (GASP and FASB), I controlled for these types in the tuition models. Tuition refers to all the tuition and fees (logged) collected during a year period. Retention rate (logged) is defined on IPEDS's survey as "the percent of the (fall full-time cohort from the prior year minus exclusions from the fall full-time cohort) that re-enrolled at the institution as either full- or part-time in the current year". All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A6: RML Effect on Admissions and Test Scores

	N Admissions	N Tests Submissions	ACT Math	SAT Math	ACT English	SAT Reading
	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): All state controls						
RM	−0.031	−0.036	0.039	0.067**	0.127***	−0.006
	(0.028)	(0.025)	(0.035)	(0.026)	(0.040)	(0.031)
N Obs.	16 749	13 111	11 217	12 152	11 217	12 056
N college	2007	1458	1345	1400	1345	1400
Panel (b): Medical state controls						
RM	−0.032	−0.090**	0.009	0.145***	0.106	0.041
	(0.041)	(0.041)	(0.102)	(0.040)	(0.112)	(0.044)
N Obs.	8100	6486	5753	5976	5754	5936
N college	1013	717	679	683	679	683
Controls	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
College FE	Y	Y	Y	Y	Y	Y

Note: The dependent variables in columns (1) and (2) refer respectively to the logged number of admitted students and the logged number of SAT and ACT test scores received for admission purposes to an undergraduate program. In columns (3) to (6), the outcome variables are the standardized 75th average scores for each test type. In Panel (b), the sample control units include the states which legalized marijuana for medical use. The included states are depicted in Figure A7. All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A7: RML Effect on Local Enrollment

	Total in-state				Recent in-state high school graduates			
RM	0.063	0.023	0.025	−0.003	0.099*	0.077	0.029	0.020
	(0.035)	(0.038)	(0.030)	(0.034)	(0.045)	(0.052)	(0.038)	(0.048)
N Obs.	10 683	8898	15 765	12 436	10 683	8898	15 765	12 436
N college	2503	2088	3786	3004	2503	2088	3786	3004
Control group	MM	MM	All	All	MM	MM	All	All
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
College FE	Y	Y	Y	Y	Y	Y	Y	Y
Contiguous states excluded	N	Y	N	Y	N	Y	N	Y

Note: Total in-state refers to the logged number of local first-time undergraduate students. Recent in-state high school graduates refer to logged local first-time undergraduate students who graduated from high school in the past 12 months. MM refers to the control group consisting of states that legalized marijuana for medical use (see Figure A7) and All to all non-RM states. The included states are depicted in Figures A8. All Control variables and fixed effects are included as described in Figure 2. Standard errors are clustered at the institution level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A8: Pre-Policy Characteristics Summary Statistics (2009 to 2013)

	Colorado			Washington		
	Treated	Synthetic	Sample Mean	Treated	Synthetic	Sample Mean
Per-capita income	43886.232	38655.409	39140.885	45511.047	38240.373	36880.677
Net migration	83633.171	83342.180	81913.374	86390.635	81906.090	80697.701
Age 18 t0 24 population	42679.280	66707.004	48223.470	79661.684	31902.160	29076.415
Age 18 to 24 female share	0.478	0.480	0.485	0.482	0.484	0.485
Number of distinct colleges	73.000	56.000	67.000	70.000	31.000	20.000
Unemployment rate	8.304	6.895	6.655	7.991	8.481	8.911
Share of colleges offering distance programs	0.778	0.887	0.847	0.767	0.679	0.799
Share of colleges with total enrollments from 10K to 20K	0.101	0.092	0.071	0.083	0.076	0.099
Share of colleges with total enrollments more than 20K	0.089	0.073	0.064	0.032	0.071	0.078

Note: all variables are averaged for Colorado and each buffer zone. Unemployment, population, and per-capita income refer to the averages over the counties of colleges.

Table A9: Weights in the synthetic zones

Weights		Buffer zone
Colorado	Washington	
0.403	0.656	0 to 50 mi
0.000	0.000	50 to 100 mi
0.273	0.000	100 to 150 mi
0.000	0.000	150 to 200 mi
0.002	0.000	200 to 250 mi
0.312	0.000	250 to 300 mi
0.000	0.000	300 to 350 mi
0.004	0.344	350 to 400 mi
0.001	0.000	400 to 450 mi
0.006	0.000	450 to 500 mi

Note: The table shows the weights assigned to each zone to construct synthetic Colorado and Washington.

B Description of IPEDS surveys

legally required to file IPEDS surveys. All higher education institutions that participate in any federal student financial assistance program must file the surveys (National Center for Education Statistics, 2019).

To restrict the sample to only colleges, community colleges, and universities, I use string filtration based on the name of the institutions after looking up the mission of each. For instance, I filtered out beauty, barber, welding academies, and other entities whose primary mission is to provide training programs. Students that target vocational entities for their postsecondary education are less likely to relocate to other states perhaps due to their socioeconomic status or to the transiency of the vocational education and training (VET) programs (i.e, the low cost of vocational entities is most likely a major factor influencing VET program choice). Each survey is joined by year and institution identification number with a directory survey which provides important geographical information such as location coordinates, whether the institution offers medical degrees, and, importantly the latitude and longitude coordinates where each entity is located. The latter coordinates were available on IPEDS as of 2009 and are necessary for detailed geographical analysis.

For the main outcome of interest, I use enrollment by race/ethnicity, gender, attendance status, and level of student IPEDS survey,[B1] but I focus only on gender and overall fall first-time enrollment.[B2] One advantage of using a fall-enrollment survey is that it also includes other important measures such as retention rate.

To study possible channels driving improvements in first-time enrollments due to RML, I use other IPEDS surveys. The admissions survey is limited to colleges that have admission requirements such as submission of ACT or SAT scores. The variables of interest are the number of admissions, the 75th percentile scores of SAT and ACT, and the number of these test score submissions. It should be noted that admission may include other requirements besides test scores, such as a high

[B1]This survey is a subpart of multiple surveys under Fall Enrollments.

[B2]Race enrollments most likely suffer from sample selection due to the existence of so-called historical colleges for particular races (National Center for Education Statistics, 2022*b*). Also, many colleges do not report the race enrollments in each period.

school GPA or completion of a preparatory program.

Another useful IPEDS survey is that of residence and migration of first-time undergraduate students; the latter allows me to study the effect of RML on out-of-state enrollments. The survey provides state residency data on first-time undergraduate students who graduated from high school in the past 12 months (referred to as RHS later) and the total. This survey, though, does not provide information on the gender of students and is available on a biennial basis only. Further, the finance survey includes financial information for each academic institution. Since the survey is filed separately by public and private colleges that follow different accounting systems (GASP and FASP), I use all tuition and fees observations and control for the filing type.

Finally, the completion survey provides information about the number of awards or degrees by program type and level of the degree. Similar to other surveys, I restrict the sample to undergraduate academic institutions and calculate the total number of degrees granted by each institution for each academic year, from July 1st to June 30th. This survey is critical in determining whether the effect on enrollment also translates to a similar effect on the number of degrees conferred.

C Marijuana legalization, use, and prices

This section provides an overview of recreational marijuana legalization policy and investigates the trends in marijuana use and prices across states that have adopted this policy and those that have not. The timing of legalization varies because it depends on the time gap between passing the law and the actual availability of cannabis in retail stores. Furthermore, this section explores the significant disparities in marijuana use and prices among states according to their legalization status.

Policy definition

I use different sources to establish the time upon which each state legalized RM. I also take into account the year that the law is implemented, which refers to the opening year of the first dispensary stores. Based on Carnevale Associates (2022), Marijuana Policy Project (2022*c*), Kim et al. (2020), and online searches, Figure A1 depicts the timeline of marijuana legalization for each state. I distinguish between the year when the legalization became legal (law) and the year in which the law went into effect by the local government distributing retail licenses (first store or dispensary evidence). States that legalized marijuana by law but did not implement the law are excluded from the data.[C3] Hence, this study focuses on states that legalized marijuana not just legally but also practically by opening dispensaries. Among all the states that legalized marijuana within our data period (2009-2019), six states satisfy the practical legalization condition: Colorado, Washington, Oregon, California, Massachusetts, and Nevada. Figure 1 shows that it takes these treated states one to two years after legalization to open the first retail store.

Marijuana use and prices, by legalization status

The upswing in marijuana use in RM jurisdictions is not surprising as it is already well documented based on survey data that marijuana legalization results in higher levels of consumption and addiction (Cerdá et al., 2012, Wen et al., 2015, Martins et al., 2016, Cerdá et al., 2017, Dave et al., 2023). To

[C3] Maine and Michigan are excluded from the analysis due to the timing of their marijuana retail store openings, which occurred in or close to the year 2020 (Marijuana Policy Project, 2019, 2022*b*).

further support this literature, I utilize Google Trends data to depict differences in online searches for the word "dispensary" between RM and non-RM states. Google Trends refers to a normalized number (hits) that is between zero and one hundred, depicting the popularity of a search term among other searches at each state and time.[C4] Google Trends measures are based on unbiased samples of all Google searches. I use the Google Trends measure related to the word "dispensary" as a proxy to gauge the demand for marijuana because people usually look up the location of marijuana stores by searching the word "dispensary". Figure A2 (a) shows that the search for the word "dispensary" is most popular in RM states as opposed to non-RM states.

The price of marijuana in Figure A2 (b), on the other hand, is less expensive in RM states. The prices are lower in RM states most likely due to the transition of the industry toward a more competitive market structure. Some of the mechanisms deriving this price decrease in RM states include the reduction of the risk premium and increased supply (Hall and Lynskey, 2016). Hence, colleges located in RM states could gain a competitive advantage if students view marijuana as another consumption amenity, especially due to its availability and low prices.

One valid argument against the RM policy effects is that it may not be binding if people can still purchase cannabis in states that deem marijuana illegal. In response, non-RM states have harsh punishments for small possession of marijuana. Further, possession of marijuana is still considered a federal offense with punishment on the first conviction that goes up to one-year imprisonment with a fine (Norml, 2020). Another inhibitor of seeking cannabis illegally is related to its high price in non-RM states. Figure A2 panel (b) shows that the price of marijuana is about two times higher in non-RM states than in RM states.

[C4]Rogers, Simon (2022) discusses details about Google Trends measurement.

D Synthetic control method (SCM)

This section discusses how I created the synthetic control counterfactuals which serve as Synthetic Colorado and Washington. Next, I give a brief description of the methodology from Abadie et al. (2010).

Buffer zones as counterfactuals

To show that the findings are robust to alternative estimation methods, I apply the synthetic (SCM) control method of Abadie et al. (2010) to the first states that legalized marijuana for recreational use (Colorado and Washington). The fact that Colorado and Washington legalized RM earlier provides an ample number of before and after policy shock observations (at least two years before and after RM shock for both states). To further take into account the importance of the distance between policy-affected and unaffected colleges, I construct buffer zones of 50 miles around each affected state as shown in Figure A3. These buffer zones classify untreated colleges based on their distance from the border of the treated state. For instance, colleges within 50 miles of Colorado's border belong to the 0 to 50 miles zone, whereas colleges that are 450 to 500 miles away from Colorado are assigned to the 450 to 500 miles zone.

A total of 10 distinct and mutually exclusive zones serving as controls for SCM are as follow in terms of their distance from the affected state's border: 0 to 50 miles, 50 to 100 miles,..., and 450 to 500 miles. I limit the distance to 500 miles in order to exclude colleges from the other affected state as both Colorado and Washington opened dispensaries in the same year, 2014. Further, I choose the buffer increment of 50 miles because it encloses areas with sufficient numbers of colleges.[D5] Each of these buffer zones crosses multiple states around Colorado which increases the chances of matching the characteristics of Colorado colleges. This is important because Colorado colleges could be for instance small or large in size, offer or do not offer medical degrees, and other characteristics.

[D5] Using ArcGIS Pro and attempting various increments, I found that increments smaller than 50 miles enclose areas with fewer numbers of colleges than the affected states, and larger increments yielded areas with numbers of colleges exceeding those of the treated states.

SCM description

I provide an overview of the formal definition of synthetic control method (SCM) as described by Abadie et al. (2010). Let $1, 2, ..., J+1$ be the index for treated and control units, so a total of $J+1$ units is given. Suppose also that the first indexed unit is affected (i.e, Colorado) and the other $2, 2, .., J+1$ units are unaffected (the 10 buffer zones). There is a total of T periods and a policy shock occurs in T_0 where $t \in (1, T)$ and T_0[D6] should not be greater than T and preferably greater than one. Let X_1 be a $(k \times 1)$ vector of pre-shock variables for the affected unit. The pre-shock variables are used to match the treated unit with the control units. In my case, I use both college and county-level covariates such as the share of colleges with a total enrollment exceeding 20K and average per-capita income (see table A8 for the complete list of used matching variables). Similarly, let X_0 be a $(k \times J)$ vector of pre-shock variables for the control units.

$$W^* = \arg\min_{w} (X_1 - X_0W)' V (X_1 - X_0W)$$
$$\text{Such that } \sum_{j=2}^{J+1} w_j = 1 \text{ and } w_j \geq 0$$

The objective as shown in the equation above is to choose the weights W^* along with the relative importance of each characteristic V such that the euclidean distance between X_1 and X_0W is minimized. This minimization can be achieved by minimizing the mean-squared prediction error (MSPE) during the pre-shock periods.

[D6]Colorado and Washington's states opened their first dispensaries in 2014, so $T_0 = 2014$