The Impact of Legalized Recreational Marijuana Laws on Obesity

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Abstract

This study investigates the causal effect of recreational marijuana laws (RMLs) on body mass index (BMI) using data sourced from the CDC's Behavioral Risk Factor Surveillance System (BRFSS). While numerous studies have explored the association between marijuana use and appetite, limited studies have delved into the causal mechanism of marijuana use and BMI. Employing staggered adoption of RMLs as a framework, we utilize a Two-Stage Difference-in-Difference model (2SDiD) to estimate the effect of RMLs on BMI. The empirical findings reveal that RMLs significantly decrease BMI by around 0.294 units or 1.08 percent (0.294/27.33). Our research implies that policies allowing RMLs could potentially generate a positive spillover effect by reducing an individual's BMI.

Keywords: Recreational Marijuana Laws (RMLs), Body Mass Index (BMI), Obesity

JEL Codes: I12, I18, K23

1 Introduction

As of 2023, 24 states in the United States have passed recreational marijuana laws (RMLs), leading to a substantial increase in the accessibility of marijuana (Cerda et al., 2017; Clarke et al., 2018; Paschall and Grube, 2020). In response to allowing recreational marijuana consumption, recreational marijuana use is more strongly associated with cigarette and substance use as compared to medical marijuana use (Freisthler et al., 2017; Cerdá et al., 2020; Coley et al., 2021; Chiu et al., 2021). National Center for Drug Abuse Statistics (2023) indicates that 16.9% of American adults are active marijuana users, and 45% have tried marijuana consumption at least once. Given the growing popularity of marijuana use, extensive medical studies have examined the potential health implications (Lotan et al., 2014; Vu et al., 2014; Volkow et al., 2016; National Academies of Sciences et al., 2017).

As obesity is a significant burden on public health and human resources (Cawley et al., 2021; Tzenios, 2023), the increasing prevalence of obesity in the U.S. has been studied extensively. The estimated annual medical cost is higher for obese individuals compared to normal-weight individuals (Cawley and Meyerhoefer, 2012; Cawley et al., 2021). Over the past two decades, obesity has increased from 30.5% to 41.9% in the U.S (Centers for Disease Control and Prevention, 2024). The rising prevalence of obesity induces higher social costs, increasing the rate of preventable diseases and death (Dixon, 2010; Bhaskaran et al., 2014).

Existing literature has documented an association between marijuana use and appetite (Greenberg et al., 1976; Foltin et al., 1988; Rodondi et al., 2006). This implies that a causal link between marijuana use and Body Mass Index (BMI) is possible. Although numerous studies demonstrate that cigarette use reduces an individual's BMI (Amialchuk et al., 2018; Courtemanche et al., 2018), there is limited causal evidence regarding the effect of marijuana use on BMI. Medical studies find that marijuana use stimulates appetite (Foltin et al., 1986; Berry and Mechoulam, 2002; Kirkham, 2009; Soria-Gómez et al., 2014) and influences a consumer's consumption patterns by increasing food expenditures (Baggio et al., 2020; Lu, 2021; Hodge and Hazel, 2022). Furthermore, marijuana use decreases overall physical activity

(Vidot et al., 2017; Ames et al., 2020).

According to the 'calories in, calories out' paradigm (Howell and Kones, 2017), increased appetite and rising food expenditures may lead to higher calorie intake, while reduced physical activity decreases calorie expenditure, potentially resulting in weight gain. However, marijuana use may also lead to a decrease in calorie intake, e.g. substituting alcohol consumption with marijuana use (Mark Anderson et al., 2013; Crost and Guerrero, 2012), which could offset the increase in appetite and reduce overall caloric intake, potentially mitigating weight gain.

The causal mechanism between them remains ambiguous because there could be endogeneity concerns with respect to marijuana use and body weight. The previously mentioned papers might be only documenting an association, rather than a causal link. For example, obese individuals might tend to use marijuana more frequently, or marijuana users may be likely to neglect their health (Gümüş et al., 2013; Dare et al., 2015). Given the possibility of endogeneity for marijuana consumption and obesity (Rodondi et al., 2006; Sansone and Sansone, 2014; Le Strat and Le Foll, 2011), examining the causal link between them is crucial to understanding the benefits and costs of the recent passage of RMLs and minimizing the prevalence of obesity.

To address the empirical issues, Sabia et al. (2017) employed the passage of medical marijuana laws (MMLs) as an exogenous variation, exploring how MMLs affect body weight. They found that implementing MMLs induces a 2% to 6% decline in the probability of obesity. However, given the limited legal accessibility of marijuana in MML states (Mark Anderson et al., 2013; Pacula et al., 2015; Sarvet et al., 2018), it might be more appropriate to examine changes in the obesity rate under RMLs. In contrast, although March et al. (2022) leveraged the enactment of RMLs and found a decrease in the obesity rate, the study only considers data from Washington state. There is a limit to how broadly these findings may be applied. Lu (2021) examined the effect of RMLs on spending on food. Their finding suggests a complementary relationship between RMLs and food expenditure, implying the proxy on the BMI change. The current study contributes to the existing literature regarding the previously described difficulties. First, we focus on the RMLs instead of MMLs, as RMLs expand marijuana use along the extensive and intensive margins. We find that RMLs lead to an increase in marijuana consumption by around 4.03 percentage points. This finding suggests that the RMLs have increased marijuana consumption and imply the necessity for further health research.

The second contribution of this paper is to investigate the spillover effect of RMLs passage on BMI. While previous studies have examined the association between marijuana use and health outcomes such as smoking and drinking (Wen et al., 2015; Choi et al., 2019), limited literature has delved into the BMI. Therefore, to consider the current debate for recreational marijuana allowance, this study provides a new perspective on how the RMLs affect general health using nationally representative data.

Finally, we utilize two statistical methods to estimate the effect of RMLs on BMI. We employ a generalized two-way fixed effect methodology (TWFE) by comparing states with RMLs and those without to estimate the average treatment effect. However, as the staggered adoption of RMLs by states at different times may generate biased estimates (Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021), we employ an alternate method, two-stage difference-in-difference (2SDiD), to account for the staggered adoption of the policy (Gardner, 2022). Using this method, we can determine an unbiased estimate of the treatment effect.

Overall, we find that the passage of RMLs leads to an increase in marijuana consumption by around 4.03 percentage points and a decrease in BMI by around 0.84 percent (0.230/27.33) in the TWFE model. The staggered adoption estimate, 2SDiD, indicates that there is a reduction in BMI of around 1.08 percent (0.294/27.33) in response to the passage of RMLs. While the staggered model provides a slightly larger estimate, both estimates support that the enactment of RMLs reduces average BMI. The remainder of the paper examines potential heterogeneity in the effect of RMLs across various demographic groups, considering how these groups are differentially affected by RMLs.

2 Background

Table 1 presents the effective dates for Medical Marijuana Laws (MMLs), Recreational Marijuana Laws (RMLs), and for retail recreational sales allowed. In 1996, California enacted the first MML as voters approved the Compassionate Use Act (Reinarman et al., 2011). The act allowed patients to possess and use cannabis for medical purposes with the permission of a physician (Nussbaum et al., 2011; Anderson and Rees, 2023). Since the first MML was passed in California, the use of medical marijuana has been approved in 36 states as well as the District of Columbia as of 2023. However, marijuana for medical use can only be obtained from state-licensed dispensaries, which are limited in number and regulated (Anderson et al., 2014; Pacula et al., 2015).

Following considerable debate by policymakers (Hall and Lynskey, 2009; McGinty et al., 2017), several states that passed MMLs have also legalized recreational marijuana use. At first, Colorado and Washington passed RMLs in 2012 (Cerda et al., 2017; Payan et al., 2021). These are significant initial steps toward the legalization of recreational marijuana consumption. RMLs do not require a prescription or registration with state authorities, and anyone living in the state and at least 21 years old is eligible to purchase recreational marijuana from recreational dispensaries (Dave et al., 2023; Anderson and Rees, 2023). Afterward, in 2023, 24 states passed RMLs to liberalize marijuana consumption.

As shown in Table 1, Column (1) represents the year and month when the MMLs were passed. While 13 states, including Alabama, Georgia, Indiana, Iowa, Kansas, Kentucky, North Carolina, South Carolina, South Dakota, Tennessee, Texas, Wisconsin, and Wyoming, do not pass MMLs, they have legalized the use of Cannabidiol (CBD), extracted ingredients in marijuana (Alharbi, 2020). Columns (2) and (3) specify the year and month of the enactment of RMLs and the opening date of the first dispensary, respectively. The important point is that the dates of RMLs are not aligned with the first recreational dispensary opened. Legalized marijuana laws and the first date dispensaries opened are controversial topics in measuring policy effects (Pacula et al., 2015; Anderson and Rees, 2023). While the opening date of recreational marijuana stores might increase access to marijuana, the expansion rate and number of stores varies by state (Anderson and Rees, 2023); moreover, marijuana consumption may not be aligned with the opening of legal dispensary stores. Thus, we focus on the effective date of RMLs in our analysis.

3 Data

We use the National Survey on Drug Use and Health (NSDUH) to examine the effect of RMLs on marijuana consumption at the state level. The NSDUH is a nationally representative survey administered by the Substance Abuse and Mental Health Services Administration (SAMHSA). The survey is conducted annually to estimate the use of tobacco, alcohol, and drugs. We utilize the NSDUH data for the first-stage regression to support the effect of RMLs on BMI. Our analysis uses the available data collected between 2002 and 2018. The NSDUH provides information for the percentage of marijuana use among individuals aged 12 or older by state. Anderson and Rees (2023) and Wen et al. (2015) utilize the NSDUH data where they find that MMLs increase marijuana use among adults by 16 percent to 19 percent on average.

To examine the effect of RMLs on BMI, we use the Behavioral Risk Factor Surveillance System (BRFSS), a repeated cross-sectional nationally representative survey conducted annually by the Centers for Disease Control and Prevention (CDC), as a primary data source for our study. The survey is conducted every month in all 50 states and DC through telephone via landline prior to 2010, and began to add cellular phones to the sample after 2011 and weighted these respondents accordingly. The BRFSS has health outcomes, health behaviors, and insurance coverage information on a large sample size. For our analysis, we use the BRFSS data years from 1996 to 2022 as California passed its MML in November 1996. Previous studies have also employed the BRFSS to examine the legalized marijuana laws on health behaviors (Mark Anderson et al., 2013; Sabia et al., 2017; Choi et al., 2019).[1]

Our primary outcome variable of interest, BMI, is measured by the respondent's self-reported weight in pounds divided by his or her height in inches squared, multiplied by 703.[2] Table 2 presents weighted means and standard deviations for variables used in the analysis. For the full sample, the average BMI is 27.33, which falls within the overweight range. We further dichotomize the BMI variable into two categories: overweight and obese, based on BMI (Center for Disease Control and Prevention, 2014). The overweight, which is an indicator variable includes individuals with a BMI of 25 or higher. Approximately 62% of the sample falls within the overweight range. Obesity represents those with a BMI of 30 or higher. Around 26% of the sample are classed as obese individuals. For the analysis, we control for indicators of MMLs and the legalization of retail recreational sales.

For one of our subsample analysis, we use above or below 200 percent of the Federal Poverty Level (FPL). Since FPL is defined over the number of people in the household, we use the number of adults and the number of children variables to define how many people are in the respondent's household. For the missing values in the number of children, we treated as no child. For the missing values in the number of adults, we treated either one or two people in the household. Thus, our lower-bound estimation is assuming there are two adults in the household for the missing values in the number of adults variable, while our upper-bound estimation is assuming there are one adult in the household for the missing values on the number of adults variable.

[1] We acknowledge some weaknesses of BRFSS in studying the effect of RMLs on BMI. Although we can estimate the first-stage result using NSDUH, we can not distinguish between medical and recreational users in BRFSS.

[2] Although the BMI used in the study is self-reported, the measurement error should not result in a biased estimate unless the measurement error is associated with the legalized RMLs (Sabia et al., 2017). The formula used in BMI is $(\text{weight(lb)}/[\text{height(in)}]^2) * 703$ and we excluded respondents whose BMI measure was below 10 and above 50 from our analysis sample.

4 Empirical Methodology

We estimate a model of BMI using a difference-in-differences methodology, using RML passage as a binary indicator of treatment. However, in our setting, RMLs are not implemented uniformly in time across treated states, but rather are adopted in staggered fashion across the data set. This can lead to a variety of issues in the estimation of a potential causal effect (Goodman-Bacon, 2021; Roth et al., 2023; Baker et al., 2022). Consequently, we employ two approaches: a standard two-way fixed effects (TWFE) model, and a two-stage difference-in-differences (2SDiD) model designed to account for issues of staggered adoption, following (Gardner, 2022).

4.1 Two-Way Fixed Effects (TWFE)

Following Mark Anderson et al. (2013) and Sabia et al. (2017), we estimate the TWFE model as specified in equation (1):

$$\text{BMI}_{i,s,t} = \alpha + \beta_1 \text{RML}_{s,t} + \beta_2 \boldsymbol{X_{i,s,t}} + \gamma_s + \delta_t + \varepsilon_{i,s,t} \tag{1}$$

Outcomes refer to individual i in state s during year t. γ_s is a state fixed effect, while δ_t is a year fixed effect. The terms γ_s and δ_t account for unobservable, time-invariant characteristics at the state and year levels. $\boldsymbol{X_{s,t}}$ includes education, race, gender, marital status, and age groups. Weights employed are BRFSS sample weights. The key estimate is β_1, which present the relationship between RMLs on BMI. However, the credible identification of β_1 relies on the average treatment effect before and after the implementation of RMLs, assuming no heterogeneous effects in the staggered adoption.

4.2 Two-Stage Difference-in-Difference (2SDiD)

To account for heterogeneous treatment effects over time, we implement the 2SDiD model, as specified in equations (2) and (3):

First Stage:

$$\text{BMI}_{i,s,t} = \gamma_s + \delta_t + \beta_2 \boldsymbol{X_{i,s,t}} + \nu_{i,s,t} \tag{2}$$

Second Stage:

$$\text{BMI}_{i,s,t} - \hat{\gamma}_s - \hat{\delta}_t - \widehat{\beta_2} \boldsymbol{X_{i,s,t}} = \alpha + \beta_1 \text{BMI}_{s,t} + \varepsilon_{i,s,t} \tag{3}$$

The model begins with a first stage on the untreated units, which is designed to impute a regression estimate for comparison with treated units by regressing in the second stage using the residuals from the first. This procedure will provide efficient estimation of the potential effect even in the presence of a staggered policy rollout (Gardner, 2022).

4.3 Threats to identification

The primary threat to identification in a difference-in-differences model is the requirement of parallel trends in the pre-period. We address this concern by examining event studies using both the TWFE and 2SDiD models. As BRFSS is conducted at the year level, we consider five years of lead and lag coefficients in the event study designs.

Another concern is the staggered adoption of RML policies, in two respects. First, MMLs, while qualitatively different from RMLs, are nonetheless present in some states for several years prior to RML adoption. We contend that the actual implications of MML in a state are different enough from RML that their effects may be accounted for in terms of state fixed effects; moreover, many MML states take months or even years to allow for legal dispensaries to open in limited geographic areas (Pacula et al., 2015). Second, RML adoption itself is staggered across multiple years. We know that staggered adoption can yield estimates contaminated by negative weighting in the standard TWFE framework from Goodman-Bacon (2021) and others. We account for this issue by comparing our TWFE estimates with those using the 2SDiD estimator of Gardner (2022). This regression imputation approach allows us greater flexibility in the staggered design, and also gives us a point of comparison for the standard estimator.

Finally, BRFSS is designed to be a representative sample of the adult US population, but this may obscure salient distinctions in treatment effect from RML passage between different ethnic groups, ages, or by socioeconomic status. For example, it may be the case that low socioeconomic status individuals could have borne a disproportionate share of the risk of police action before RML passage, and so subsequently could respond to the lower marginal cost of possession by increasing marijuana use, while this would have a smaller effect on those of higher socioeconomic status. To address the potential for heterogeneous treatment effects, we control by relevant demographic factors in the main model, but we also examine a variety of stratified subsamples, including sex, age, education level, and income.

5 Results

5.1 Main Results

Table 3 presents the effect of RMLs on marijuana consumption. Columns (1) and (2) display the two-way fixed effects (TWFE), and columns (3) and (4) the two-stage differences-in-differences (2SDiD) estimates. Since columns (1) and (2) present TWFE estimates, which are commonly used in previous causal studies but have been found to be biased in some cases, the overall interpretation relies on the 2SDiD estimates. Our findings indicate that RMLs raise marijuana consumption by 3.83 percentage points, which can be interpreted as a 30.83% (3.836/12.44) increase in response to RMLs. Accounting for the staggered adoption time by state, column (4) indicates that RMLs lead to 5.107 percentage points or 41.04%

(5.107/12.44) increase in marijuana consumption.

Figure 1 presents event study estimates of the effect of RMLs on marijuana consumption, using TWFE and 2SDID, respectively. The marker for 'year 0' indicates the normalized year of passage of an RML in treated states. Prior to the enactment of RMLs, Panel (a) in the TWFE model shows a slight upward trend in marijuana consumption, followed by a sharp increase immediately after the policy's implementation, and then a subsequent decline. However, in Panel (b), which employs the 2SDiD accounting for staggered adoption, marijuana consumption demonstrates an increasing trend following the RMLs. Overall, RMLs lead to an increase in average marijuana consumption before and after the policy's implementation.

Table 4 displays the impact of RMLs on BMI. Panel A shows the effect on BMI. Controlling for MMLs and Recreational Sales (Column 3), we find that RMLs are associated with a 1.04 percent (0.285/27.33) decline in BMI. After adding controls for demographics (Column 4), we find that RMLs are associated with a 1.08 percent (0.294/27.33) reduction in BMI, a slightly larger estimate but mostly unchanged by the addition of control variables. Panels B and C show the effects on being overweight and obese, respectively. Without demographic controls (Column 3), we find that RMLs are associated with a 1.62 percent (0.0102/0.629) decline in the overweight population and a 6.53 percent (0.0173/0.265) reduction in the obese population. The magnitude of the association increases slightly when demographic controls are added. All the above results are statistically significant at the 5 percent level. On the other hand, TWFE estimates are consistently smaller in magnitude. The TWFE estimates are 0.84 percent (0.230/27.33) for BMI (Column 2), 1.16 percent (0.0073/0.629) for overweight, and 4.75 percent (0.0126/0.265) for obesity.

In Figure 2, we present event study estimates for the effect of RMLs on BMI using TWFE and 2SDiD, respectively. The figures display the TWFE model on the left and the 2SDiD model on the right. The marker for 'year 0' denotes the normalized year of RML passage in treated states. Prior to the enactment of RMLs, trends in BMI were slightly lower compared to the control states but not so different from zero.[3] In 2SDiD estimates, our results suggest that as time passes after RMLs enactment, we observe larger reduction in BMI.[4] Thus, our results suggest that the passage of RMLs leads to a decrease in BMI. Similar trends are observed in the overweight and obesity index.

5.2 Subgroup Analysis: Age

Panel A of Table 5 presents the effect of RMLs on BMI by age cohort. In general, we find evidence across the age distribution that RMLs are associated with a reduction in body weight. Specifically, the passage of RMLs is associated with a 1.11 percent (0.285/25.71) decline in BMI for the 18- to 29-year-old age group, a 1.06 percent (0.289/27.35) decline for the 30- to 39-year-old age group, a 1.63 percent (0.453/27.87) decline for the 40- to 49-year-old age group, a 1.28 percent (0.361/28.26) decline for the 50- to 59-year-old age group, a 0.65 percent (0.182/28.17) decline for the 60- to 69-year-old age group, and a 0.9 percent (0.243/26.86) decline for those over 70 years old. All estimates are statistically significant at the 1 percent level, except for the estimate for those over 70 years old, which is statistically significant at the 10 percent level.

Panel B of Table 5 shows the effect of RMLs on the overweight indicator by age cohort. Generally, the estimates indicates that RMLs are associated with a decrease in overweight population across all ages. For individuals aged 18-29, the passage of RMLs is associated with a 3.45 percent (0.0164/0.476) decrease in the overweight population. Additionally, for individuals aged 40-49 and 50-59, the enactment of RMLs is associated with decreases of 2 percent (0.0135/0.672) and 1.93 percent (0.0136/0.706), respectively. Although statistically indistinguishable from zero, we also observe a negative relationship for individuals aged 30-39, 60-69, and over 70.

Panel C of Table 5 shows the effect of RMLs on the obesity index by age cohort. Over-

[3]The largest estimates occur right before the enactment of RMLs estimated near -0.1 and significant at the 10 percent level.

[4]Sabia et al. (2017) find the similar pattern of reduction on BMI and obesity from the passage of MMLs.

all, the estimates suggest that RMLs are associated with a reduction in the obese population across all ages. Specifically, the enactment of RMLs corresponds to a 8.63 percent (0.0158/0.183) decline in the obese population for the individuals aged 18-29, a 9.2 percent (0.0243/0.264) decline for the individuals aged 30-39, a 12.14 percent (0.0358/0.295) decline for the individuals aged 40-49, a 8.49 percent (0.0270/0.318) decline for the individuals aged 50-59, a 6.12 percent (0.0191/0.312) decline for the individuals aged 60-69, and a 9.47 percent (0.0213/0.225) decline for the individuals aged over 70. All estimates are statistically significant at the 1 percent level, except for the estimate for those over 70 years old, which is statistically significant at the 5 percent level.

Our findings suggest that the largest effects of RMLs on BMI were observed in the 40-49 age group, followed by the 50-59 age group and the 30-39 age group. Specifically, the passage of RMLs was associated with a significant reduction in BMI across all age cohorts, with the 40-49 age group experiencing a 1.63 percent decline, the 50-59 age group a 1.28 percent decline, and the 30-39 age group a 1.06 percent decline. The impact of RMLs on the overweight indicator also indicated a decrease in the overweight population, with the most substantial reductions observed in the 18-29, 40-49, and 50-59 age groups. For the obesity index, the largest effects were observed in the 40-49 age group with a 12.14 percent decline, followed by the 30-39 age group with a 9.2 percent decline, and the over 70 age group with a 9.47 percent decline.

5.3 Subgroup Analysis: Gender

Panel A, B, and C of Table 6 (column 1 and 2) presents the effect of RMLs on BMI, incidence of being overweight, and incidence of obesity by gender, respectively. Generally, we find evidence for both genders that RMLs are associated with a reduction in body weight. Specifically, the passage of RMLs is associated with a 0.83 percent (0.227/27.67) decline in BMI, a 1.35 percent (0.0094/0.696) decline in being overweight, and a 5.9 percent (0.0157/0.266) decline in obesity for male. For female, the passage of RMLs is associated with a 1.38 percent (0.373/26.97) decline in BMI, a 2.25 percent (0.0126/0.559) decline in being overweight, and a 7.79 percent (0.0205/0.263) decline in obesity. All estimates are statistically significant at the 1 percent level, except for the estimates for incidence of being overweight, which are statistically significant at the 5 percent level. Our findings suggest that the effects of RMLs are more pronounced among females than males.

5.4 Subgroup Analysis: Education

Columns (3), (4), (5), and (6) of Table 6 represent the effect of RMLs on BMI according to individuals' education levels. In Panel A, BMI significantly decreased across all groups regardless of education level. The decrease in BMI leads to a reduction in the probability of overweight and obesity. Note that the group with a college education or higher experienced a decrease in the probability of being overweight by approximately 1.14 percentage points or 1.97 percent (0.0114/0.578). Similarly, the higher education group shows a decrease in the likelihood of being obese by 1.88 percentage points or 9.17 percent (0.0188/0.205). Conversely, for individuals with an educational level less than high school, the magnitude of BMI reduction was the least significant, and the decrease in the probability of being overweight or obese was also the lowest.

5.5 Subgroup Analysis: Income

Panel A, B, and C of Table 6 (column 7 and 8) presents the effect of RMLs on BMI, incidence of being overweight, and incidence of obesity by income groups over and below 200 percent Federal Poverty Line (FPL), respectively. Generally, we find evidence across both groups that RMLs are associated with a reduction in body weight. Specifically, the passage of RMLs is associated with a 1.08 percent (0.293/27.09) decline in BMI, a 3.75 percent (0.0194/0.518) decline in overweight prevalence, and a 7.78 percent (0.0165/0.212) decline in obesity among individuals whose income is over 200 percent FPL. Among individuals whose income is below 200 percent FPL, the passage of RMLs is associated with a 0.93 percent

(0.259/27.78) decline in BMI, a 2.22 percent (0.0125/0.562) decline in overweight prevalence, and a 5.94 percent (0.0161/0.271) decline in obesity. All estimates are statistically significant at the 1 percent level. Overall, our findings indicate that the implementation of RMLs leads to significant reductions in BMI, overweight prevalence, and obesity across both income groups, with more pronounced effects observed among individuals whose income is over 200 percent FPL.

5.6 Robustness

To test the reliability of our estimates, we first perform our regressions with and without the set of policy and demographic controls. For the measure of income as a percentage of the federal poverty level, we tested two specifications of the income bin values, top-coding the category in one case and mid-coding in another. Moreover, we examine our policy variation when excluding the MML and RML recreational sale active status date variables. In all cases, the coefficient estimates remain at the same level of significance with only minor fluctuations in value.

In addition to the standard TWFE and 2SDID regressions, we test the reliability of the results using the Wing et al. (2024) stacked difference-in-difference estimator, which is designed to regularize estimates in cases of staggered adoption. This methodology involves specifying a requisite number of pre- and post-periods (five in our case). This is intended to remove concerns about states with larger numbers of pre- or post-periods that will not yield accurate comparisons versus states with fewer periods available around the treatment. Then, for each year of initial policy treatment, we create a "sub-experiment" consisting of the required number of periods, trimming off the earlier and later observations. Each of these sub-experiment data sets is appended together, and each is assigned a weight relative to the number of sample observations used in its construction. This generates greater weight for sub-experiments that include larger numbers of treated and control units.

Once the data sets are appended and weights assigned, regressions can be conducted using the event time and treatment status as fixed effects, with errors clustered at the state level. Figure 3 presents the stacked DiD results. The results of these regressions can be used to generate both a point estimate of the treatment effect in the post-period (over the specified number of periods) as well as an event study. The results from the Wing et al. (2024) method (see figure 3) match those from TWFE and 2SDID closely; consequently, we believe our main estimates to be reliable.

6 Conclusion

Utilizing RMLs as an exogenous source of variation, this paper presents causal evidence between marijuana use and BMI. Our empirical findings provide answers to several questions related to the RMLs. First, do the RMLs lead to an increase in marijuana consumption, and if so, to what extent? The empirical results indicate that RMLs increase the probability of marijuana consumption by around 5.1 percentage points on average. The second question is, do the RMLs affect body weight? We find that the RMLs significantly decrease BMI, the prevalence of overweight, and the obesity rate in treated states. Finally, what difference might there be based on demographics for the impact of RMLs on BMI? Our findings suggest some heterogeneous effects of RMLs on BMI across different age groups and genders, but an overall decrease across all groups.

More specifically, the RMLs lead to a decrease of around 0.294 units or 1.08 percent (0.294/27.33) in BMI on average. These findings are supported by the previous literature (March et al., 2022). The potential mechanisms might be increased physical wellness and exercise due to reduced pain alleviation from marijuana use (Sabia et al., 2017; Keyhani et al., 2018). The result might also be explained by changes in food consumption patterns (Lu, 2021; Ross et al., 2022). Furthermore, although the substitution effect of marijuana consumption for other foods within a budget constraint may reduce calorie intake, we acknowledge that the mechanism is still ambiguous and requires further research.

Regarding gender difference in the effect of RMLs on BMI, women experience a greater reduction in BMI compared to men. This may be because men are more likely to engage in behaviors such as higher calorie intake through beer and food, complementary to marijuana use (Goncy and Mrug, 2013; Camenga et al., 2014). Notably, after the RMLs, there was a significant decrease in BMI among middle-aged groups (between 40 and 69). Marijuana use might support exercise and physical mobility in those age groups, influencing BMI (Sabia et al., 2017; Minerbi et al., 2019; Nicholas and Maclean, 2019).

While our study examines the effect of RMLs on marijuana consumption, it is important to interpret the estimated impact of RMLs on BMI as an intent-to-treat effect, since the BRFSS does not include data on marijuana use (Sabia et al., 2017). Nevertheless, using nationally representative data, we find that the effectiveness of RMLs increases the prevalence of marijuana consumption. Further, our findings show that RMLs have a significant impact on an individual's BMI. Thus, RMLs may generate an unintended positive spillover effect by reducing BMI. These results appear to be strongest among people in middle age, which could lead to significant welfare gains from better health and ultimately lower health care spending among that age group.

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A Tables

Table 1: As of August 2023, the effective month for medical and recreational marijuana legalization.

	(1) MML effective dates	(2) RML effective dates	(3) Retail recreational sales allowed
Arkansas	Nov. 2016		
Alaska	Mar. 1999	Feb. 2015	Oct. 2016
Arizona	Apr. 2011	Nov. 2020	Jan. 2021
California	Nov. 1996	Nov. 2016	Jan. 2018
Colorado	Jun. 2001	Dec. 2012	Jan. 2014
Connecticut	May. 2012	Jul. 2021	Jan. 2023
Delaware	Jul. 2011	Apr. 2023	
District of Columbia	Jul. 2010	Feb. 2015	Feb. 2015
Florida	Jan. 2017		
Hawaii	Dec. 2000		
Illinois	Jan. 2014	Jan. 2020	Jan. 2020
Louisiana	May. 2016		
Maine	Dec. 1999	Jan. 2017	Oct. 2020
Maryland	Jun. 2014	May. 2023	Jul. 2023
Massachusetts	Jan. 2013	Dec. 2016	Nov. 2018
Michigan	Dec. 2008	Dec. 2018	Dec. 2019
Minnesota	May. 2014	Aug. 2023	
Mississippi	Feb. 2022		
Missouri	Nov. 2018	Dec. 2022	Feb. 2023
Montana	Nov. 2004	Jan. 2021	Jan. 2022
Nevada	Oct. 2001	Jan. 2017	Jul. 2017
New Hampshire	Jul. 2013		
New Jersey	Oct. 2010	Feb. 2021	Apr. 2022
New Mexico	Jul. 2007	Jun. 2021	Apr. 2022
New York	Jul. 2014	Mar. 2021	Dec. 2022
North Dakota	Dec. 2016		
Ohio	Sep. 2016		
Oklahoma	Jun. 2018		
Oregon	Dec. 1998	Jul. 2015	Oct. 2015
Pennsylvania	May. 2016		
Rhode Island	Jan. 2006	May 2022	Dec. 2022
Utah	Dec. 2018		
Vermont	Jul. 2004	Jul. 2018	Oct. 2022
Virginia	Jul. 2020	Jul. 2021	
Washington	Nov. 1998	Dec. 2012	Jul. 2014
West Virginia	Apr. 2017		

Notes: There is a difference between the date of medical marijuana legalization by legislation and the date on which the first medical marijuana dispensary (Sabia and Nguyen, 2018; Lu, 2021; Anderson and Rees, 2023).

Table 2: Summary Statistics

Variable	Mean	Standard Deviation
Body Mass Index (BMI)	27.335	5.562
BMI Index		
Overweight	0.629	0.483
Obesity	0.265	0.441
Independent Variable		
Medical Marijuana Laws (MML)	0.350	0.477
Recreational Marijuana Laws (RML)	0.081	0.273
Retail recreational sales allowed	0.060	0.238
Gender		
Male	0.509	0.499
Educational Level		
Less than high school	0.114	0.318
High school graduate	0.285	0.452
Some college	0.292	0.455
College and over	0.308	0.462
Race		
White	0.689	0.463
Black	0.106	0.308
Hispanic	0.118	0.323
Other	0.087	0.281
Marital Status		
Married	0.567	0.496
Unmarried	0.189	0.391
Divorced, etc.	0.245	0.430
Age Group		
18-29	0.197	0.398
30-39	0.196	0.397
40-49	0.190	0.392
50-59	0.172	0.377
60-69	0.128	0.334
70-79	0.081	0.273
80+	0.036	0.185
N of Observation	7,319,977	

Table 3: Effect of RMLs on Marijuana Consumption

	(1) TWFE	(2) TWFE	(3) 2SDiD	(4) 2SDiD
RML	3.860***	3.836***	5.139***	5.107***
	(0.477)	(0.506)	(0.584)	(0.620)
MML/Rec Sale Controls	Yes	Yes	Yes	Yes
Covariate	No	Yes	No	Yes
Observations	867	867	867	867
Mean of Dep. Var	12.44	12.44		

Note: *** p<0.01, ** p<0.05, * p<0.1 and robust standard errors for Column (1) and (2) in parentheses. Columns 1-2, two-way fixed effect difference-in-difference regression; columns 3-4, two-stage difference-in-difference regression. The standard errors in parentheses are clustered at the state level in Columns (1) to (4).

Table 4: Effect of RMLs on BMI and classified BMI index

	(1) TWFE	(2) TWFE	(3) 2SDiD	(4) 2SDiD
Panel A: Body Mass Index (BMI)				
RML	-0.267***	-0.230***	-0.285***	-0.294***
	(0.077)	(0.081)	(0.077)	(0.080)
Mean of Dep. Var	27.33	27.33		
Panel B: Overweight Index				
RML	-0.0096**	-0.0073*	-0.0102**	-0.0106**
	(0.0044)	(0.0041)	(0.0044)	(0.0045)
Mean of Dep. Var	0.629	0.629		
Panel C: Obesity Index				
RML	-0.0164***	-0.0126**	-0.0173***	-0.0178***
	(0.0046)	(0.0053)	(0.0044)	(0.0045)
Mean of Dep. Var	0.265	0.265		
Demographic Controls	No	Yes	No	Yes
MML and Rec Sale Controls	Yes	Yes	Yes	Yes
Observations	7,319,977	7,319,977	7,319,977	7,319,977

Note: *** p<0.01, ** p<0.05, * p<0.1 and robust standard errors for Column (1) and (2) in parentheses. Columns 1-2, two-way fixed effect difference-in-difference regression; columns 3-4, two-stage difference-in-difference regression. Weights used in the regression analysis. The standard errors in parentheses are clustered at the state level in Columns (1) to (4).

Table 5: Effect of RMLs on BMI and classified BMI index by age groups

	(1) 18-29 years	(2) 30-39 years	(3) 40-49 years	(4) 50-59 years	(5) 60-69 years	(6) 70+ years
Panel A: Body Mass Index (BMI)						
TWFE	-0.300**	-0.273*	-0.353***	-0.134***	-0.111*	-0.215
	(0.119)	(0.153)	(0.093)	(0.042)	(0.062)	(0.142)
2SDiD	-0.285***	-0.289***	-0.453***	-0.361***	-0.182***	-0.243*
	(0.095)	(0.095)	(0.086)	(0.099)	(0.058)	(0.127)
Mean of Dep. Var	25.71	27.35	27.87	28.26	28.17	26.86
Panel B: Overweight Index						
TWFE	-0.0165***	-0.0048	-0.017***	0.0008	0.0053	-0.0116
	(0.0056)	(0.0068)	(0.0059)	(0.0023)	(0.0054)	(0.0133)
2SDiD	-0.0164***	-0.0116	-0.0135***	-0.0136**	-0.0025	-0.0042
	(0.0054)	(0.0072)	(0.0049)	(0.0057)	(0.0054)	(0.0062)
Mean of Dep. Var	0.476	0.625	0.672	0.706	0.709	0.621
Panel C: Obesity Index						
TWFE	-0.0121*	-0.0170	-0.0237**	-0.0064	-0.0084	-0.0094
	(0.0070)	(0.0124)	(0.0094)	(0.0046)	(0.0064)	(0.0081)
2SDiD	-0.0158***	-0.0243***	-0.0358***	-0.0270***	-0.0191***	-0.0213**
	(0.0060)	(0.0068)	(0.0057)	(0.0061)	(0.0040)	(0.0094)
Mean of Dep. Var	0.183	0.264	0.295	0.318	0.312	0.225
Demographic Controls	Yes	Yes	Yes	Yes	Yes	Yes
MML and Rec Sale Controls	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	748,469	1,023,447	1,221,810	1,461,104	1,420,287	1,444,860

Note: *** p<0.01, ** p<0.05, * p<0.1 and robust standard errors for TWFE model in parentheses.

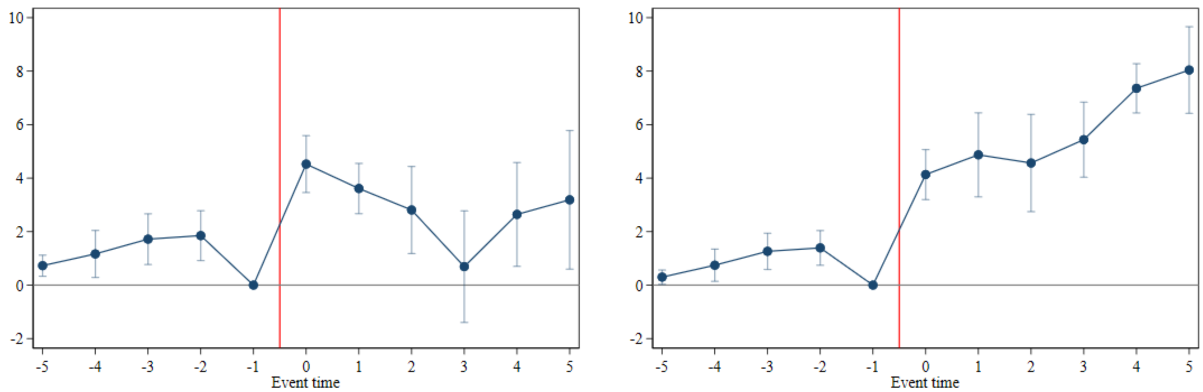
Table 6: Effect of RMLs on BMI and classified BMI index by subsample groups

	(1) Male	(2) Female	(3) < Highschool	(4) High school	(5) Some college	(6) College +	(7) >= 200FPL200	(8) < 200FPL200
Panel A: Body Mass Index (BMI)								
TWFE	-0.214**	-0.255***	-0.228***	-0.254**	-0.205**	-0.207**	-0.221**	-0.204**
	(0.082)	(0.086)	(0.085)	(0.103)	(0.082)	(0.078)	(0.061)	(0.091)
2SDiD	-0.227***	-0.373***	-0.168**	-0.314***	-0.279***	-0.286***	-0.293***	-0.259***
	(0.058)	(0.105)	(0.071)	(0.120)	(0.066)	(0.067)	(0.064)	(0.0643)
Mean of Dep. Var	27.67	26.97	28.06	27.65	27.56	26.54	27.09	27.78
Panel B: Overweight Index								
TWFE	-0.0091	-0.0063*	-0.0166	-0.0012	-0.0061	-0.0089*	-0.0153***	-0.0076**
	(0.0057)	(0.0032)	(0.0106)	(0.0033)	(0.0046)	(0.0048)	(0.0049)	(0.0031)
2SDiD	-0.0094**	-0.0126**	-0.0015	-0.0103	-0.0099**	-0.0114***	-0.0194***	-0.0125***
	(0.0040)	(0.0052)	(0.0051)	(0.0064)	(0.0041)	(0.0029)	(0.0049)	(0.0036)
Mean of Dep. Var	0.696	0.559	0.681	0.653	0.639	0.578	0.518	0.562
Panel C: Obesity Index								
TWFE	-0.0129*	-0.0128***	-0.0117**	-0.0159**	-0.0074	-0.0129**	-0.0129**	-0.0157***
	(0.0071)	(0.0042)	(0.0045)	(0.0070)	(0.0054)	(0.0061)	(0.0061)	(0.0058)
2SDiD	-0.0157***	-0.0205***	-0.0066	-0.0176***	-0.0167***	-0.0188***	-0.0165***	-0.0161***
	(0.0046)	(0.0047)	(0.0043)	(0.0055)	(0.0050)	(0.0045)	(0.0051)	(0.0035)
Mean of Dep. Var	0.266	0.263	0.318	0.289	0.283	0.205	0.212	0.271
Demographic	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MML and Rec Sale	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	3,215,080	4,104,897	565,949	2,066,651	2,014,596	2,672,781	4,713,606	2,655,525

Note: *** p<0.01, ** p<0.05, * p<0.1 and robust standard errors for TWFE model in parentheses.

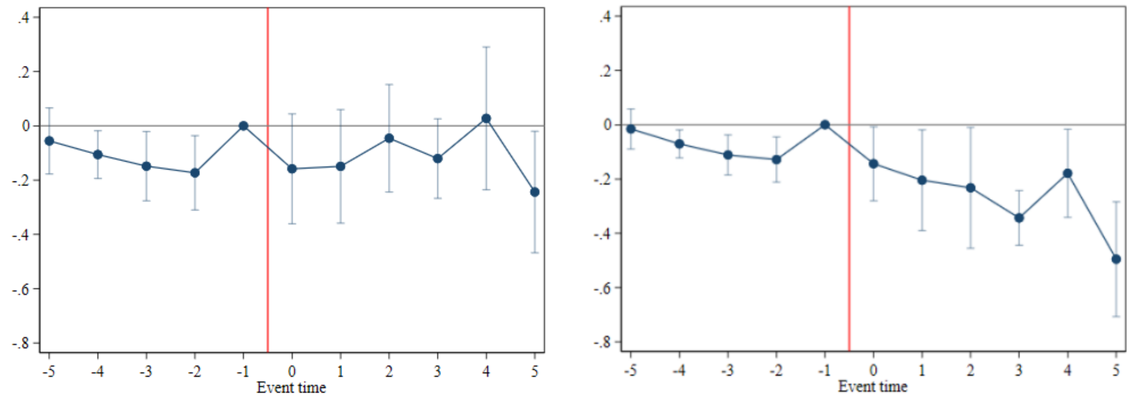
B Figures

Figure 1: Effect of RMLs on Marijuana Consumption.

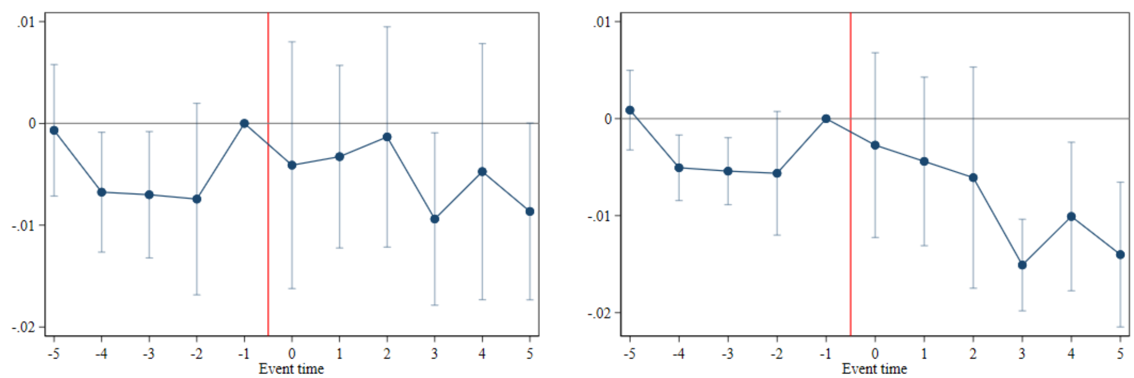


Notes: These figures plot event study, percent of the population using marijuana, NSDUH data, 2002-2018. The plot on the left presents the TWFE model, while the plot on the right shows the 2SDiD model. We include the recreational sale treatment indicator and medical marijuana law indicator. Control also includes state cigarette and alcohol tax, unemployment rate, and minimum wage by state.

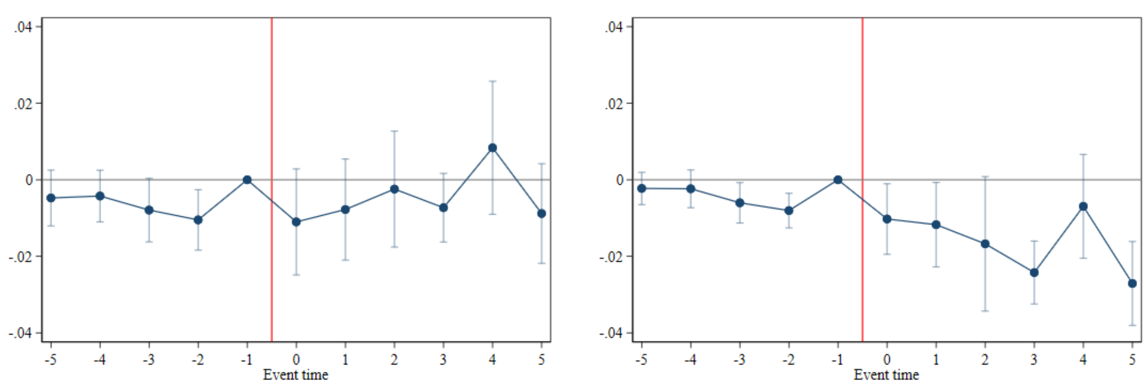
Figure 2: Effect of RML on BMI and classified BMI index.



(a) Effect of RMLs on BMI



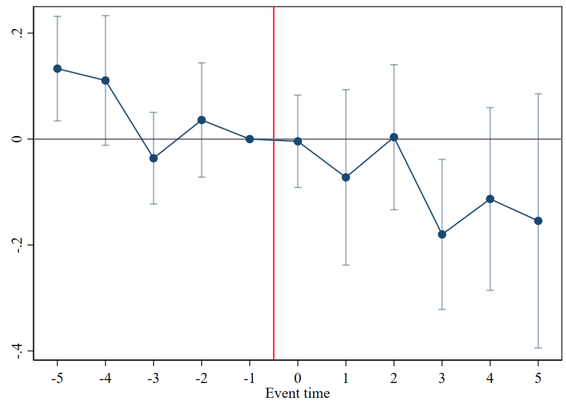
(b) Effect of RMLs on Overweight



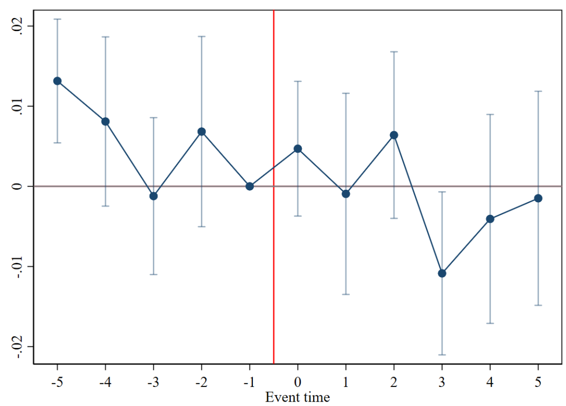
(c) Effect of RMLs on Obesity

Notes: These figures plot event study, BRFSS data, 1996-2022. Figures present the TWFE model on the left and the 2SDiD model on the right. Control variables include a recreational sale treatment indicator, a medical marijuana law indicator, and demographic characteristics.

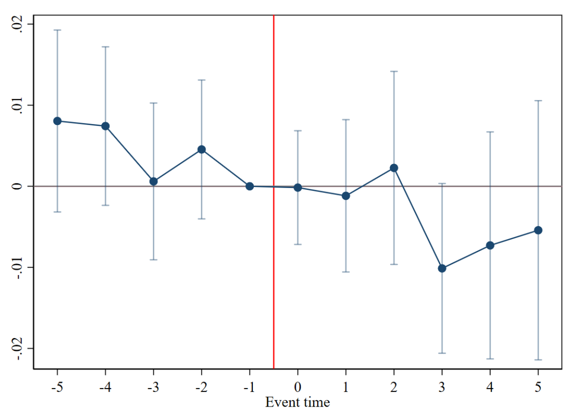
Figure 3: Effect of RMLs on BMI and classified BMI index (Stacked DiD).



(a) Effect of RMLs on BMI



(b) Effect of RMLs on Overweight



(c) Effect of RMLs on Obesity

Notes: These figures plot stacked DiD, BRFSS data, 1996-2022. Control variables include a recreational sale treatment indicator, a medical marijuana law indicator, and demographic characteristics.