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THE EFFECT OF MEDICAL MARIJUANA LAWS ON BODY WEIGHT

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ABSTRACT

This study is the first to examine the effects of medical marijuana laws (MMLs) on body weight, physical wellness, and exercise. Using data from the 1990 to 2012 Behavioral Risk Factor Surveillance System and a difference-in-difference approach, we find that the enforcement of MMLs is associated with a 2% to 6% decline in the probability of obesity. We find some evidence of age-specific heterogeneity in mechanisms. For older individuals, MML-induced increases in physical mobility may be a relatively important channel, while for younger individuals, a reduction in consumption of alcohol, a substitute for marijuana, appears more important. These findings are consistent with the hypothesis that MMLs may be more likely to induce marijuana use for health-related reasons among older individuals, and cause substitution toward lower-calorie recreational 'highs' among younger individuals. Our estimates suggest that MMLs induce a \$58 to \$115 per-person annual reduction in obesity-related medical costs. Copyright © 2015 John Wiley & Sons, Ltd.

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KEY WORDS: medical marijuana laws; obesity; BMI

1. INTRODUCTION

As of May 2015, 23 states and the District of Columbia had enacted laws legalizing the use of marijuana for medical purposes such as treating neuropathic pain, muscle tension, anxiety, or side effects from chemotherapy.[1] While medical marijuana laws (MMLs) reduce the costs of obtaining marijuana for those suffering from legally specified health ailments, there is also evidence that the effects of MMLs may spillover into the recreational market via supply-side induced reductions in 'street prices' for marijuana (Anderson *et al.*, 2013). Proponents of MMLs often highlight their potential to generate public health benefits (Molina *et al.*, 2011; Penner *et al.*, 2013), but there is little empirical evidence on this claim. Our study is the first in the literature to estimate the impacts of MMLs on body weight, physical mobility, and diet.

The effect of MMLs on body weight is theoretically ambiguous. If MML-induced marijuana use is effective in treating physical or psychological ailments, then MMLs may increase physical activity and reduce body weight. Moreover, if marijuana and alcohol are substitutes (Anderson, Hansen, and Rees 2014; Crost and Guerrero 2012; Kelly and Rasul, 2014; DiNardo and Lemieux, 2001) and MMLs cause individuals to substitute toward marijuana and away from alcohol, a relatively high-calorie beverage, then this reduction in calories could reduce body weight. On the other hand, if marijuana use induces greater lethargy (Pesta *et al.*, 2013) or stimulates appetite (Riggs *et al.*, 2012; Soria-Gómez *et al.*, 2014), or if marijuana and alcohol are complements (Williams *et al.*, 2004; Wen *et al.*, 2014), then MMLs could increase body weight.

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[1]Four additional states (Washington, Colorado, Alaska, and Oregon) and the District of Columbia have legalized the production and consumption of marijuana more broadly, including for recreational use (ProCon.org, 2015)

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A number of empirical studies have examined the relationship between marijuana use and body weight, but almost all have treated marijuana use as exogenous to body weight (for example, Le Strat and Le Foll, 2011; Rodondi *et al*., 2006). This assumption is problematic if difficult-to-measure characteristics—such as personality and personal discount rates—are related to both marijuana consumption and body weight. Moreover, if individuals use marijuana to treat health problems related to obesity (Pagoto *et al*., 2012), reverse causality could also lead to biased estimates.

Our study is the first to examine the effect of MMLs—a plausibly exogenous policy change that has been documented to increase marijuana use among adults (Anderson and Rees 2011; Wen *et al*. 2014)—on body weight, physical well-being, and physical activity. Using data from the 1990 to 2012 Behavioral Risk Factor Surveillance System (BRFSS) and a difference-in-differences approach, we find that the enforcement of MMLs is associated with a 0.4% to 0.7% reduction in body mass index (BMI) and a 2% to 6% reduction in obesity. The estimated magnitudes of these effects are 1.6 to 3.2 times larger in the longer run, consistent with the hypothesis that body weight effects occur with a lag. Our findings are robust to falsification tests on policy leads, the inclusion of controls for state-specific time trends, and the use of a synthetic control state for each state that enacted an MML.

We find some evidence that mechanisms driving the reduction in body weight differ across the age distribution. The MML-induced reduction in BMI we observe for those ages 18–24 years appears largely driven by a reduction in the consumption of alcohol, a relatively high-calorie beverage (Nielsen *et al*., 2012). This suggests that MMLs are reducing younger individuals' body weight via substitution of recreational substances toward a less caloric recreational high. For older individuals, MMLs also appear to increase physical mobility and wellness, suggesting that MML-induced marijuana use may also occur for pain-reducing purposes.

2. BACKGROUND

The legalization of medical marijuana has been the subject of intense political debate for the last two decades. Advocates for MMLs emphasize the effectiveness of marijuana in treating symptoms of illnesses associated with neuropathic pain, muscle tension, anorexia, arthritis, cancer, wasting syndrome, Crohn's disease, diabetes, HIV/AIDS, multiple sclerosis, and Parkinson's disease (Galuppo *et al*., 2014; Lotan *et al*., 2014; Naftali *et al*., 2013; Vu *et al*., 2014).[2] They also cite the potential of MMLs to reduce alcohol-related traffic fatalities (Anderson *et al.*, 2013) and suicides (Anderson *et al*. 2014).

However, opponents of legalization argue that there may be negative health consequences of MMLs, particularly because of their spillovers into the recreational market. Both Anderson and Rees (2011) and Wen *et al*. (2014) find evidence that MMLs increase marijuana use among young adults, who have relatively low probabilities of suffering from medical ailments. In addition, Wen *et al.* (2014) also find that MMLs increase marijuana use on the extensive margin, increasing the share of daily users of marijuana. Opponents argue that MML-induced recreational marijuana use may serve as a 'gateway' to greater addiction (Hall, 2009a; Miron, 2005). According to the 2011 National Survey on Drug Use and Health, an estimated 4.3 million people struggle with marijuana dependence, a number which exceeds the current number of dependent abusers of pain relievers, cocaine, and heroin combined (Substance Abuse and Mental Health Services Administration, 2013). In addition, skeptics of legalization argue that marijuana use could lead to impaired respiratory function, cardiovascular disease, psychotic symptoms (Hall & Degenhardt, 2009b), and even more crime (Pederson & Skardhamar, 2010).

Could increased marijuana use induced by MMLs affect body weight? If so, these health effects could be important. More than two-thirds of US adults (68.8%) are overweight or obese (Flegal *et al*., 2012). Obesity is associated with a $2741 per person increase in annual medical expenses (Cawley and Meyerhoefer, 2012)

[2]Advocates of legalization also cite potential tax revenues from legalized marijuana appeal to state governments struggling to meet debt obligations (Caputo & Ostrom, 1994; Miron, 2005).

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and has been linked to poorer labor market outcomes (Cawley 2004; Greve, 2008; Tunceli *et al*., 2006), diminished academic performance (Sabia 2007) and reduced educational attainment (Rees and Sabia 2015). Obesity is also linked to a number of health ailments that impede mobility (Vincent *et al*. 2010), including increased physical pain (Heim *et al*., 2008), reduced upper and lower body function (Apovian *et al*., 2002), and increased risk of joint replacement surgery (Harms *et al*., 2007). In the succeeding sections, we discuss a number of theoretical mechanisms through which MMLs could affect body weight.

2.1. Physical health

Pain is debilitating (Heim *et al*., 2008). Medical marijuana is often prescribed to treat chronic neuropathic pain, muscle tension, and arthritis (Galuppo *et al*., 2014; Lotan *et al*., 2014; Naftali *et al*., 2013; Vu *et al*., 2014). There is medical evidence suggesting that marijuana is effective in alleviating pain associated with these ailments (Rog *et al*. 2005, Ware *et al*. 2010). For example, in a randomized control trial, cannabis-based medicine was found to produce a 'significant analgesic effect' for patients suffering from rheumatoid arthritis (Blake *et al*., 2006). Furthermore, marijuana has been shown to relieve pain for patients suffering from fibromyalgia (Fiz *et al*., 2011). Other studies have established the effectiveness in ameliorating the side effects from aggressive treatments for cancer (Hall *et al*., 2005; Doblin and Kleinman, 1991; Vinciguerra *et al*., 1988). If MML-induced marijuana use is effective in alleviating physical pain—particularly pain associated with mobility—then MMLs could decrease obesity by increasing the likelihood and frequency of engaging in regular physical activity. In addition, MMLs may induce individuals suffering from health ailments to substitute marijuana for prescription and over-the-counter pharmaceutical drugs, perhaps both legally and illicitly. To the extent that some pharmaceutical drugs possess obesogenic side effects such as bloating, slowing of digestion and metabolism, and weight gain (Domecq *et al*., 2015; Hasnain *et al*., 2012) that are not present (or are not as severe) in marijuana, MMLs may result in lower body weight through such substitution effects.

Absent chronic pain symptoms, the effect of marijuana use on physical activity is less clear. There is evidence that repeated marijuana use slows the body's resting heart rate (Jones, 2002), reduces athletic performance (Pesta *et al*., 2013), and induces lethargy (Delisle *et al*., 2010; Irons *et al*., 2014; Pate *et al*., 1996). These effects could reduce expenditure of calories and increase the likelihood of obesity.

2.2. Appetite and diet

There is a growing medical evidence to suggest the existence of a number of neurophysiological pathways through which cannabis consumption affects appetite (Soria-Gómez *et al*., 2014). Tetrahydrocannabinol (THC) is the active ingredient in marijuana that is responsible for its psychoactive effects and most likely responsible for its effects on appetite. THC is one of the many cannabinoid-like molecules known as exogenous cannabinoids because they enter the body via external means (i.e., the consumption of marijuana). Endocannabinoids are cannabinoid molecules that exist naturally in the body. They link up to a receptor, called the CB receptor, which influences areas of the body related to appetite including the gastrointestinal system, which moderates food intake; the hypothalamus and hind brain, which regulate food intake; stomach and intestinal tissue, which send signals of satiation to the brain; and the limbic forebrain, which affects the palatability of food. Exogenous cannabinoids work within the body the same way endocannabinoids function by mimicking them and binding to CB receptors (De Fonseca *et al*., 2005). As Kirkham (2005) notes

> *It is increasingly apparent that the changes in eating motivation associated with cannabis intoxication, or the administration of THC, reflect a crucial role for these endocannabinoid systems in the normal processes governing appetite, ingestive behavior, energy metabolism, and body weight. (pp. 297)*

Early randomized control trials provide evidence that marijuana use leads to increased appetite and caloric intake (Greenberg *et al*. 1976; Foltin *et al*. 1988; Mattes *et al*., 1994; Berry and Mechoulam, 2002). Consistent with the popular notion of the 'munchies', an experimental study by Foltin *et al*. (1988) finds that increased

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caloric consumption subsequent to active THC consumption was primarily driven by more between-meal snacking, particularly of sweet solid items like candy bars.

Although marijuana and its pharmacological derivatives were initially prescribed to cancer patients to alleviate symptoms of nausea and vomiting, clinical trials soon revealed that it was effective in stimulating the appetite of those undergoing chemotherapy (Gorter, 2004). It has since been used to combat the wasting syndrome that accompanies aggressive medical treatment of cancers and HIV (Musty and Rossi, 2001; Ungerleider and Andrysiak, 1982). Science continues to illuminate the link between the endocannabinoid system and how we experience food. Most recently, Soria-Gómez *et al.* (2014) found that the endocannabinoid and olfactory systems are connected, which could explain why users of marijuana report heighted sense of smell and taste.

A second pathway through which MMLs could affect diet (and therefore body weight) is through their effect on the relative prices of other substances. There is substantial evidence that consumption of marijuana and alcohol are related. Anderson and Rees (2013) find evidence that MMLs are associated with a reduction in alcohol consumption, beer sales, and alcohol-related traffic fatalities, suggesting that marijuana and alcohol are substitutes.[3] A number of other studies come to a similar conclusion using plausibly exogenous variation in the minimum legal drinking age (Crost and Guerrero, 2012; Crost and Rees, 2013).

How large might we expect body weight reductions to be from MML-induced declines in alcohol consumption? The average serving of beer consists of roughly 150 cal, while the average serving of wine and spirits is approximately 120 cal (Nielsen *et al*., 2012). Estimates from Anderson and Rees (2013) and Anderson *et al.* (2014) suggest that MMLs are associated with a 10.6% to 25.2% reduction in the number of drinks consumed per month among 20- to 29-year olds. This would imply, ceteris paribus, an MML-induced reduction of 360 to 570 cal per month, or approximately 2 lbs of body weight for each year an MML is enforced. These effects may be larger if MMLs reduce heavy episodic drinking, including binge drinking, which involves consuming five or more drinks on a single occasion.

Estimated body weight effects may be more pronounced if MMLs affect *where* people are consuming calories. For example, if MMLs induce more *in-home* marijuana consumption and less *at-bar* or *in-restaurant* alcohol consumption, meals and snacks that are often paired with alcohol at bars and restaurants may also be consumed less frequently. If these foods contain more calories than in-home foods, such food substitution could lead to decreased body weight (for example, McCrory *et al*., 1999; Currie *et al*., 2010; Davis and Carpenter, 2009).[4]

In addition to alcohol, consumption of other substances—including cigarettes or illicit drugs—may be affected by MMLs, which, in turn, may affect body weight. Some recent evidence from Choi *et al*. (2015) suggests that MMLs could affect the demand for cigarettes. Because tobacco is known to be an appetite suppressant (Chen *et al*., 2005), MML-induced cigarette consumption could be a pathway through which MMLs affect obesity. Moreover, while there is scant evidence that MML-induced marijuana use acts as a gateway to harder drugs (Wen *et al*. 2014), if MMLs affect consumption of harder drugs such as cocaine or methamphetamine, known appetite suppressants, this could lead to a reduction in body weight.

A final diet-related path through which MMLs could affect body weight is if marijuana consumption takes the form of marijuana-infused ‘edibles’, which could contribute directly to energy intake (Kuddus *et al*., 2013). However, given that even very small amounts of edibles contain potent doses of marijuana with long-lasting psychoactive effects, and overconsumption typically leads to unpleasant side effects (Murphy *et al*., 2015; Armentano, 2005), this channel is likely to be a relatively less important driver of changes in body weight.

[3]Depenalization of marijuana in the UK has also been found to be associated with a decrease in alcohol-related hospital admissions (Kelly and Rasul, 2014).

[4]Existing empirical evidence on the relationship between restaurant food consumption and obesity seems at least somewhat dependent on identification strategy employed. For example, Currie *et al*. (2009) and Davis and Carpenter (2009) find that close proximity to nearby restaurants is associated with increased risk of obesity. On the other hand, Anderson and Matsa (2011) find that increased restaurant food consumption induced by close proximity to restaurants (using plausibly exogenous variation in the historical placement of Interstate highways as an instrument) does not lead to increased obesity.

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2.3. Mental health and healthcare services

Another mechanism through which marijuana use could affect body weight is through its effects on psychological well-being. Cannabinoids have been shown to produce antidepressant-like behavior in animals, suggesting that marijuana use may improve mental and emotional well-being (Bambico *et al*., 2007). While a number of correlational studies have found that marijuana use and depression are positively related (Degenhardt *et al*., 2003; Green and Ritter, 2000), a recent study by Anderson *et al*. (2014) find that this can largely be explained by the endogeneity of marijuana use. In fact, they find that the enactment of MMLs is associated with a nearly 5% reduction in suicides, suggesting potentially important mental health benefits of MMLs. Improved mental health has been found to be associated with greater exercise (Paluska and Schwenk, 2000; Stephens 1988) and better dietary habits (Oddy *et al*., 2009), and could be associated with greater efficiency in the choice of inputs to produce physical health.

Finally, MMLs may lead to greater utilization of healthcare services, which could affect body weight. Specifically, individuals who seek a prescription for medical marijuana may have increased contact with their healthcare providers. Increased contact with healthcare providers could lead to improvements in patients' behavioral and mental health via counseling, information, and provision of medical advice.

2.4. Studies on the effect of marijuana on body weight

A number of studies have examined the relationship between marijuana use and obesity, with the majority finding that marijuana use is negatively correlated with body weight (Le Strat and Le Foll, 2011; Rodondi *et al*., 2006). However, most of these studies assume that marijuana use is econometrically exogenous, which may be problematic given the possibility of both reverse causality and individual unmeasured heterogeneity leading to biased estimates. French and Norton (2010), for example, highlight the empirical challenge in establishing a causal link between substance use and body weight:

> *Estimation of single-equation models will generate consistent coefficient estimates only if no unobservable omitted variables are correlated with [consumption]. Two examples of potentially important omitted variables are dieting practices and chronic eating disorders…Without better measures of eating behaviors and other personality traits, the [substance use] variables in a single-equation model could be picking up the effects of other behaviors and traits, thereby introducing bias into the coefficient estimates. The direction of the omitted variable bias is theoretically indeterminate because it depends not only on the nature of the omitted variables but also on the correlations among the covariates. (p. 5)*

Beulaygue and French (2014) use longitudinal data from the National Longitudinal Study of Adolescent Health and find that the negative relationship between marijuana use and body weight is robust to time-invariant individual unobserved variables. But the use of individual fixed effects models cannot rule out the possibility that these findings are explained, in part or in whole, by reverse causality or time-variant unobserved variables.[5]

We contribute to the above literature by examining the effect of MMLs on body weight. In addition, this study is the first to explore the effect of MMLs on physical well-being, mobility, and diet, all important mechanisms through which marijuana use may affect body weight.

[5]Foltin *et al*. (1988) attempt to overcome the endogeneity of marijuana consumption using a randomized control trial. However, the study lacks generalizability as it only consists of six volunteer subjects.

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3. DATA

Our analysis uses data from the BRFSS, a repeated cross-sectional nationally representative survey conducted annually by the Centers for Disease Control and Prevention (CDC) since 1984. While the BRFSS was administered via landline telephone through 2010, beginning with the 2011 survey, the CDC began adding cellular phones to the BRFSS sample and weighted these respondents accordingly. Respondents, aged 18 to 99 years, are asked detailed questions about their health and health behavior. Our primary analysis sample consists of approximately 5.4 million observations drawn from the years 1990 through 2012.

3.1. Body weight

Our primary outcome variable of interest, *BMI*, is measured in the BRFSS core survey and is calculated using the respondent's self-reported weight in pounds divided by his or her height in inches squared, multiplied by 703. From this continuous BMI measure, we also generate an indicator of obesity status, *Obese*, which is set equal to 1 if the respondent reports a BMI score of 30 or above and 0 otherwise, following the CDC obesity classification (Center for Disease Control and Prevention, 2014).

Table I presents unweighted means for *BMI* and *Obese*, first for the full sample, and then by age. For the full sample, the mean BMI is 27.0, which is considered overweight according to the Center for Disease Control and Prevention (2014). BMI increases with age, rising from an average of 24.6 for 18- to 24-year-olds to 27.4 for individuals 50 years and older. In our sample, 24% of all individuals were obese, with the percentages also rising with age.

3.2. Mechanisms

In addition to body weight, the BRFSS asks respondents a number of questions we use to measure mechanisms through which MMLs may affect body weight. First, as part of the 1993–2012 BRFSS core questionnaires, respondents are asked about the state of their physical health:

> *Now thinking about your physical health, which includes physical illness and injury, for how many days during the past 30 days was your physical health not good?*

We generate a dichotomous variable equal to zero if the respondent reported zero poor physical health days in the last month, and equal to one if the respondent has reported a positive number of poor physical health days in the last month. For the full sample, 35.7% of respondents reported having at least one poor health day in the last 30 days.

Respondents are also asked about the frequency with which they engage in physical activity. In odd years between 2003 and 2011 (and as a module question in 2002), respondents are asked about time spent exercising:

> *Now thinking about the vigorous physical activities you do [fill in "when you are not working" if 'employed' or 'self-employed' in a usual week, [how often] do you do vigorous activities for at least 10 minutes at a time, such as running, aerobics, heavy yard work, or anything else that causes large increases in breathing or heart rate?*

For the full sample, about 40.3% of respondents reported engaging in any minimal exercise, defined as at least 30 min of exercise during an average week over the last month. Conditional on any minimal exercise, the average weekly time spent exercising was 226.1 min per week. Finally, we examine more frequent exercise to further capture the intensive margin. Conditional on having performed any minimal exercise in the last week, we generate a dichotomous variable equal to one if the respondent performed at least 90 min of exercise on average per week, and zero if they performed less than 90 min per week. Approximately 70% of those who reported minimal exercise performed at least 90 min per week.

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Table I. Means of Key Variables

Variable	Mean	Standard Deviation	N
BMI			
Full Sample	27.01	5.73	5428399
18-24	24.64	5.16	316544
25-34	26.29	5.72	722704
35-49	27.22	5.93	1445107
50+	27.37	5.61	2915976
Obese			
Full Sample	0.240	0.4272	5428399
18-24	0.131	0.3378	316544
25-34	0.204	0.4032	722704
35-49	0.250	0.4332	1445107
50+	0.257	0.4369	2915976
Any Poor Physical Health Days in Last 30 Days			
Full Sample	0.357	0.479	5176842
18-24	0.357	0.479	287599
25-34	0.332	0.471	669034
35-49	0.346	0.476	1377555
50+	0.369	0.482	2802428
Drink Any Alcohol in Last 30 Days			
Full Sample	0.501	0.500	5181180
18-24	0.5525	0.4972	286441
25-34	0.59	0.4918	667771
35-49	0.5737	0.4945	1359434
50+	0.4411	0.4965	2828214
Binge Drank in Last 30 Days			
Full Sample	0.1199	0.3249	5127666
18-24	0.2705	0.4442	283118
25-34	0.2169	0.4121	661835
35-49	0.1576	0.3644	1346269
50+	0.0645	0.2456	2798323
Any Minimal Exercise in Last Month (*Extensive Margin*)			
Full Sample	0.403	0.491	1650516
18-24	0.596	0.491	83103
25-34	0.540	0.498	203563
35-49	0.490	0.500	448655
50+	0.312	0.463	902953
Minutes of Exercise in Last Month (*Intensive Margin*)			
Full Sample	226.13	307.62	665592
18-24	265.45	337.40	49504
25-34	214.03	289.30	109943
35-49	213.38	293.66	220050
50+	233.92	318.72	281655
Any Exercise Over 90 Minutes (*Intensive Margin*)			
Full Sample	0.728	0.445	665592
18-24	0.763	0.425	49504
25-34	0.727	0.446	109943
35-49	0.719	0.449	220050
50+	0.729	0.444	281655
Food Consumption			
Full Sample	118.42	67.75	2262538
18-24	108.33	72.79	140954
25-34	110.97	67.37	332665
35-49	113.89	66.56	657606
50+	124.44	67.24	1117259

(*Continues*)

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Table I. (Continued)

Variable	Mean	Standard Deviation	N
Poor Mental Health in Last 30 Days			
Full Sample	0.318	0.466	5191627
18-24	0.462	0.499	287738
25-34	0.403	0.491	667574
35-49	0.379	0.485	1374420
50+	0.255	0.436	2821617
Independent Variables			
MML	0.185	0.385	5428399
Male	0.406	0.491	5428399
Married	0.549	0.498	5414325
Age	51.57	17.81	5426971
White	0.851	0.356	5383327
Black	0.084	0.277	5383327
Hispanic	0.058	0.234	5404882
Some high school	0.069	0.254	5419941
High school graduate	0.309	0.462	5419941
Some College	0.268	0.442	5419941
College +	0.318	0.466	5419941
Unemployment Rate	6.02	2.18	5428399
Prime-Age Male Average Wage Rate	15.64	3.30	5428399

Note: For some independent variables, missing observations are included in each regression, which leads to some differences in the number of actual observations

A third mechanism we measure in the BRFSS is alcohol consumption. Alcohol consumption is measured in two ways. First, we measure whether an individual reported drinking any alcoholic beverages such as beer, wine, malt beverages, or liquor in the prior 30 days. Data on alcohol consumption are available as a core question throughout the entire sample except for even years from 1994 to 2000 when alcohol consumption is a module question. We first generate an alcohol consumption measure equal to 1 if a respondent reported any alcohol consumption in the last 30 days and 0 otherwise. We find that 50.1% of all respondents reported consumption of at least one drink of alcohol in the last 30 days. Second, we measure binge drinking using responses to the following questionnaire item:

Considering all types of alcoholic beverages, how many times during the past 30 days did you have 5 or more drinks on an occasion?

If a respondent reported being a non-drinker or answered the aforementioned question in the negative, our binge drinking measure is set equal to zero; if the respondent reported binge drinking at least once in the last 30 days, our binge drinking measure is set equal to zero. Approximately 12% of the full sample binge drank at least once in the last 30 days.[6]

The BRFSS also asks questions about food consumption and diet consistently as part of their core questionnaire between 1990 and 1992, and then odd years from 1993 to 2001. Module questions are asked in even years from 1994 to 2002, and then odd years from 2003 to 2009. However, the BRFSS only contains information on *healthy* food consumption during the years when states changed MMLs.[7] To estimate total monthly food consumption, we sum how often respondents eat potatoes, fruit juice, green salad, carrots, and vegetables. The average number of times individuals have eaten any of these foods is about 118 times in the last month.

Finally, respondents are asked about their psychological well-being as part of the core questionnaire from 1993 to 2012 except for 2002 where it is part of the module questionnaire. Respondents are asked

[6]In addition to these drinking measures, we also experimented with measures of number of drinks in the last month. The results are generally qualitatively similar to those presented using our dichotomous measures.

[7]The BRFSS asks about unhealthy food consumption during the years 1990–1994, but no states changed MMLs during this time period.

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Now thinking about your mental health, which includes stress, depression, and problems with emotions, for how many days during the past 30 days was your mental health not good?

We generate a mental health measure set equal to zero if the respondent reported zero days of poor mental health, and equal to one if the respondent reported positive days of poor mental health. For the full sample, about 32% of respondents reported at least one poor mental health day in the last 30 days.

3.3. Strengths and weaknesses of the BRFSS

We use the BRFSS for our analysis because it provides consistent, high-quality nationally representative data on body weight and the mechanisms that affect body weight during the sample period over which states enacted MMLs. But there are a number of limitations worthy of note. Both our BMI and the mechanisms described previously are self-reported, likely introducing measurement error. Alternative measures, such as percent body fat (Burkhauser and Cawley, 2008) and skinfold thickness (Burkhauser, Cawley, and Schmeiser, 2009) might also better capture healthy and unhealthy body weight. But this measurement error in our left-hand side variable should not generate biased estimates of the impact of MMLs on these outcomes unless this measurement error is correlated with the enforcement of MMLs.

A second limitation with the BRFSS is that marijuana use is not measured in these data. Therefore, we cannot obtain 'first-stage' estimates of the effect of MMLs on marijuana consumption so as to evaluate the effect of MMLs on the body weight of those who consume marijuana. Two studies, however, have found that MMLs are associated with an increase in marijuana use among adults. Anderson and Rees (2011) and Wen *et al.* (2014) use data from the National Survey of Drug Use and Health (NSDUH) and find that MMLs increase marijuana use among adults, on average, by 16% to 19%.[8] However, neither the NSDUH nor the BRFSS allow researchers to distinguish between medical users and recreational users; thus, estimated effects of MMLs—in their studies and ours—capture total effects on registered medicinal users, unregistered self-medicating patients, and recreational users.

As of October 2014 there were 1,137,069 registered patients in 19 out of 23 states that have MMLs and report numbers of patients (ProCon.org, 2015). This comprises approximately 1.0% of the adult populations of U.S. Census Bureau (2014) and 15.3% of all marijuana users (SAMHSA, 2013) in these states.[9] Thus, the magnitude of the effects observed by Anderson and Rees (2011) and Wen *et al*. (2014)—as well as our own estimates—are likely not driven entirely by medical marijuana users.

A third limitation of the BRFSS is that it does not provide a measure of total caloric intake nor of consumption of unhealthy foods during the period MMLs were enacted. Therefore, our analysis of the effect of MMLs on diet will be limited and may capture inter-diet substitution effects toward or away from healthy foods. The BRFSS also lacks information on where food consumption takes place (e.g., at home or at bars or restaurants), which do not allow us to explore the extent to which MMLs might affect meal and snack consumption at restaurants or bars.

A final limitation concerns our mechanism measures as a whole. Because these variables are measured concurrently with body weight (rather than prior to body weight changes), it is possible that they may capture consequences rather than causes of MML-induced changes in body weight. For instance, MML-induced improvements in physical mobility may be a result rather than a cause of reduced body weight. Therefore, we are careful in our interpretation of findings on these mechanisms.

3.4. Medical marijuana law

Our key independent variable of interest is an indicator for the share of the year that a state had enacted a medical marijuana law. We follow the coding of effective dates provided by Anderson and Rees (2013)

[8]Anderson, Hansen, and Rees (forthcoming) finds no evidence that marijuana use affects minor teenage marijuana consumption using data from the Youth Risk Behavior Survey.
[9]The latter estimate is obtained using prior 30-day marijuana use as reported in the most recent wave of the National Survey of Drug Use and Health (SAMHSA, 2013).

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Table II. States enacting and enforcing medical marijuana laws, 1990–2013

State	Effective date
Alaska	March 4, 1999
Arizona	April 14, 2011
California	November 6, 1996
Colorado	June 1, 2001
Connecticut	October 1, 2012
Delaware	May 13, 2011
District of Columbia	June 27, 2010
Hawaii	December 28, 2000
Illinois	January 1, 2014
Maine	December 22, 1999
Massachusetts	January 1, 2013
Michigan	December 4, 2008
Montana	November 2, 2004
Nevada	October 1, 2001
New Hampshire	July 23, 2013
New Jersey	October 1, 2010
New Mexico	July 1, 2007
Oregon	December 3, 1998
Rhode Island	January 3, 2006
Vermont	July 1, 2004
Washington	November 3, 1998

These dates are effective dates for state-level medical marijuana laws and are gathered from the National Conference of State Legislatures (2014), Anderson *et al.* (2013), and Eddy (2010).

and updated by Wen *et al.* (2014), which we show in Table II. There is a broad agreement in the literature that MMLs are not homogeneous across states (Anderson and Rees, 2013; Anderson and Rees 2014; Pacula *et al*., 2015). Therefore, we also explore whether our results are driven by particular types of MML, such as those that allow for home or collective cultivation of marijuana or do not strictly regulate dispensaries.

3.5. Event studies

In Figures 1 and 2, we present trends in BMI and obesity, respectively, for states that implemented MMLs and states that did not implement MMLs during the 1990 to 2012 period. The marker for 'year zero' indicates the year of passage of an MML in a treated state, and a randomly assigned treatment date for the control states. Prior to the enactment of MMLs, the trend in body weight in treatment and control states was relatively similar. However, after year 0, the rate of increase in body weight in the treatment states slows relative to the control states. This event study provides some descriptive evidence that MMLs are associated with declines in body weight. We explore this possibility further with difference-in-difference and synthetic control models.

4. METHODS

Following Anderson *et al.* (2013), we begin with a difference-in-difference model of the following form:

$$Y_{\text{ist}} = \beta_0 + \beta_1 \text{MML}_{\text{st}} + X_{\text{st}}\beta_2 + Z_{\text{ist}}\beta_3 + \nu_{\text{s}} + \omega_{\text{t}} + \varepsilon_{\text{ist}} \tag{1}$$

where Y_{ist} measures body weight of individual i residing in state s in year t, MML is an indicator for whether state s is enforcing a medical marijuana law in year t, X_{st} is a vector of state-level time-varying controls, Z_{ist} is a vector of individual-level time-varying controls. The remaining terms, ν_s and ω_{t}, represent state fixed effects and year fixed effects, respectively. Included in the vector X_{st} are the state unemployment rate, prime-age (ages

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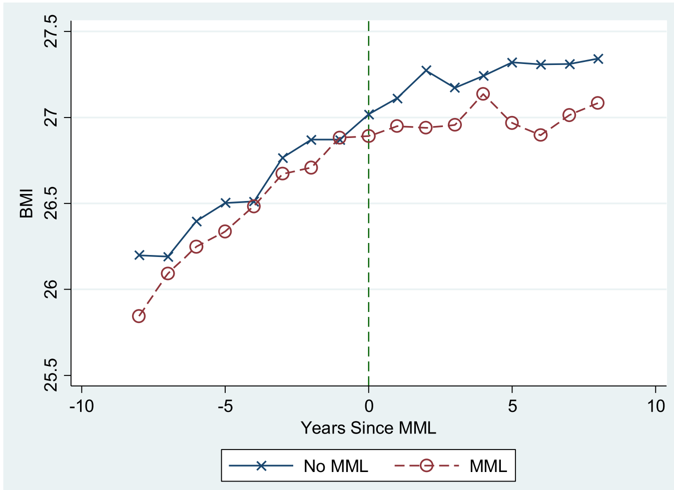

Figure 1. Event study of BMI before and after MML implementation

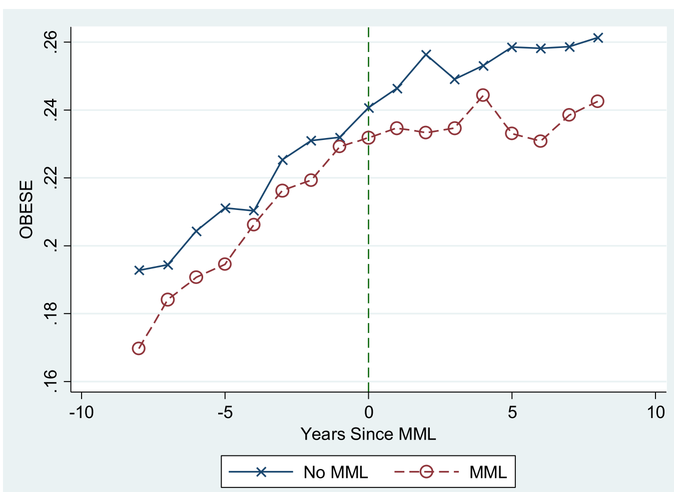

Figure 2. Event study of obesity before and after MML implementation

25 to 54 years) average wage rate, beer taxes, cigarette taxes, marijuana decriminalization law, and food prices.[10] Included in the vector Z_{ist} are age, gender, race/ethnicity, marital status, and indicators for educational attainment. We also experiment with up to 5-year lags of the medical marijuana measure given that the impact on body weight may take time to materialize.

The key coefficient of interest, β_1, is the estimated relationship between medical marijuana laws and body weight. Identifying variation in Equation (1) comes from the 17 states and the District of Columbia

[10]Unemployment rate data are collected at the state level from the Bureau of Labor Statistics Local Area Unemployment Statistics, average state level wages from the Current Population Survey for 1990–2012, beer taxes from the Brewers Almanac 2012 (Beer Institute, 2012), cigarette taxes from the *Tax Burden on Tobacco* (Tobacco Institute, 2014), and food prices from The Council for Community and Economic Research. Food prices included are based on coding conventions used in Beydoun *et al*. (2008) and consist of potatoes, bananas, lettuce, sweet peas, tomatoes, peaches, frozen corn, hamburgers, pizza, and fried chicken.

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that changed their MMLs during the 1990 to 2012 period. In all models, standard errors are clustered by state.

Credible identification of β_1 relies on the assumption that body weight trends in states that did not implement MMLs are a reasonable counterfactual for trends in MML states had they not implemented MMLs. Inasmuch as differential trends and policy endogeneity remain a concern, we take a number of tacks to address this issue. First, we add state-specific quadratic time trends as additional controls in Equation (1).[11] Second, we test whether there are differential body weight trends prior to the implementation of an MML by including leads of the MML on the right-hand side of Equation (1).

Finally, we pursue a synthetic control design approach following Abadie *et al*. (2010) to ensure that pre-treatment health trends are common between treatment and control states. The counterfactual synthetic control for each treatment state (defined as a state that implemented an MML between 1990 and 2012) is generated as a linear combination of donor states, where donor states include all states that do not have MMLs enforced at any time between 1990 and 2012. The weight that each donor state contributes to the synthetic control state is determined by an algorithm pioneered by Abadie *et al*. (2010) that assigns synthetic weights to each donor state to minimize pre-treatment differences in body weight and state-level covariates between each treatment and synthetic state. Each treatment state and its synthetic control state are then pooled, and Equation (1) is re-estimated, with clustered bootstrapped standard errors.

There are a few important advantages to a synthetic approach. Forcing counterfactuals to have more similar pre-treatment trends may increase the probability of satisfying the common trends assumption (Sabia *et al*., 2012; forthcoming). Moreover, because we construct a counterfactual to each MML state, this approach more flexibly allows for heterogeneity in the impacts of MMLs across different states.

5. RESULTS

5.1. Difference-in-differences estimates

Table III presents difference-in-differences estimates of the effect of MMLs on BMI.[12] Panel I shows the contemporaneous effects. Controlling for only economic and demographic characteristics (column 1), we find that MMLs are associated with a 0.6% (0.162/27.00) decline in BMI.[13] After adding controls for alcohol policies, cigarette taxes, and marijuana decriminalization laws (column 2), and food prices (column 3), the magnitude of the association falls only slightly.[14] Finally, when we control for state-specific quadratic time trends (column 4), we find MMLs are associated with a 0.31% (0.084/27.00) reduction in BMI. Because changes in BMI in response to MMLs may take time to occur, we next include 5 years of lags of MMLs (panel II). Our results suggest that the impact of MMLs on BMI is substantially larger in the longer run as compared with the short run, as estimated effects become larger (in absolute magnitude) the longer the MML is enforced.[15]

[11] We also experimented with linear time trends and state-specific trends of higher-order polynomial (e.g., cubic trends) and find that difference-in-difference estimates from Equation (1) as well as models that include quadratic or cubic time trends all show a similar pattern of results: a negative effect of MMLs on body weight. Models with linear time trends show smaller effects. The results from each of these specifications are available upon request.

[12] The estimates presented in our main tables are unweighted. Weighted difference-in-difference estimates of MMLs on BMI and obesity are available upon request of the authors and suggest a similar pattern of results.

[13] We estimate the percent change by dividing the estimated marginal effect of the MML by the mean of the outcome for states and years in which there is no MML, following Anderson and Rees (2013).

[14] The results are also robust to controls for state-specific time-varying anti-marijuana legalization sentiment, which was generated using data from the General Social Survey. This suggests that our estimate of β_1 is not driven by within-state over time changes in attitudes toward marijuana legalization.

[15] If we exclude individuals from the sample who were younger than 21 years or younger than 23 years—to ensure that those who lived in an MML state were affected for at least 3 or 5 years, respectively, after the age of 18 years—results are quantitatively and qualitatively similar. These results are available upon request of the authors.

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Table III. Difference-in-difference estimates of the relationship between MMLs and BMI

	(1)	(2)	(3)	(4)
Panel I: contemporaneous effects				
MML	−0.162*** (0.046)	−0.134*** (0.044)	−0.112*** (0.038)	−0.084** (0.034)
Panel II: lagged effects				
Year of law change	−0.117*** (0.036)	−0.100*** (0.035)	−0.105*** (0.037)	−0.088** (0.033)
1 year after MML	−0.078** (0.036)	−0.069** (0.032)	−0.067* (0.037)	−0.058 (0.043)
2 years after MML	−0.160*** (0.050)	−0.148*** (0.047)	−0.164*** (0.046)	−0.159*** (0.050)
3 years after MML	−0.159*** (0.053)	−0.137** (0.052)	−0.132** (0.051)	−0.134** (0.058)
4 years after MML	−0.060 (0.063)	−0.034 (0.059)	−0.014 (0.052)	−0.023 (0.057)
5+ years after MML	−0.243*** (0.069)	−0.203*** (0.070)	−0.157** (0.066)	−0.116* (0.061)
Mean BMI (MML = 0)	27.000	27.000	27.000	27.000
Demographic and economic controls	Yes	Yes	Yes	Yes
State policy controls	No	Yes	Yes	Yes
Food prices	No	No	Yes	Yes
State time trends	No	No	No	Yes
N	5,428,399	5,428,399	5,428,399	5,428,399

Note: Each column represents a result from separate unweighted regressions that include state and year fixed effects. Demographic and economic controls include gender, race (White, Black, and Hispanic), education, marital status, average wage by state and year (Current Population Survey), and state-level unemployment rate (Bureau of Labor Statistics Local Area Unemployment Statistics). State-level policy controls include marijuana decriminalization laws, zero-tolerance laws, and state-level alcohol and cigarette taxes. Food prices are collected from American Chamber of Commerce Research Association survey (ACCRA) and include prices for potatoes, bananas, lettuce, sweet peas, tomatoes, peaches, frozen corn, hamburger, pizza, and fried chicken. Standard errors are below each coefficient estimate in parentheses and are clustered by state. State time trends consist of interacting a linear time and a squared time variable with state fixed effects to generate a state-specific quadratic time trend.
*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.

Table IV. Difference-in-difference estimates of the relationship between MMLs and obesity

	(1)	(2)	(3)	(4)
Panel I: contemporaneous effects				
MML	−0.010*** (0.003)	−0.009*** (0.003)	−0.007** (0.003)	−0.005* (0.003)
Panel II: lagged effects				
Year of law change	−0.005 (0.003)	−0.004 (0.003)	−0.005 (0.003)	−0.003 (0.003)
1 year after MML	−0.006** (0.003)	−0.005** (0.002)	−0.005* (0.003)	−0.004 (0.003)
2 years after MML	−0.010** (0.004)	−0.009** (0.004)	−0.010*** (0.003)	−0.008** (0.003)
3 years after MML	−0.011*** (0.004)	−0.010** (0.004)	−0.009** (0.004)	−0.008* (0.005)
4 years after MML	−0.005 (0.004)	−0.004 (0.004)	−0.002 (0.004)	−0.001 (0.005)
5+ years after MML	−0.015*** (0.004)	−0.013*** (0.005)	−0.009** (0.004)	−0.005 (0.005)
Mean obesity (MML = 0)	0.240	0.240	0.240	0.240
Demographic and economic controls	Yes	Yes	Yes	Yes
State policy controls	No	Yes	Yes	Yes
Food prices	No	No	Yes	Yes
State time trends	No	No	No	Yes
N	5,428,399	5,428,399	5,428,399	5,428,399

Note: Each column represents a result from separate unweighted regressions that include state and year fixed effects. Demographic and economic controls include gender, race (White, Black, and Hispanic), education, marital status, average wage by state and year (CPS), and state-level unemployment rate (BLS LAUS). State-level policy controls include marijuana decriminalization laws, zero-tolerance laws, and state-level alcohol and cigarette taxes. Food prices are collected from ACCRA and include prices for potatoes, bananas, lettuce, sweet peas, tomatoes, peaches, frozen corn, hamburger, pizza, and fried chicken. Standard errors are below each coefficient estimate in parentheses and are clustered by state. State time trends consist of interacting a linear time and a squared time variable with state fixed effects to generate a state-specific quadratic time trend.
*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.

In Table IV, we replace our continuous measure of BMI with a dichotomous indicator of obesity. The pattern of results is consistent with what we find in Table III. Controlling for all observables and state-specific time trends (panel I, column 4), we find that the enforcement of MMLs is associated with a 2.1% (0.005/0.240)

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reduction in obesity. Across specifications, we generally find the largest effects on obesity 5 or more years after implementation with estimated effects reaching as large as 6.2% (0.015/0.240) (panel II, column 1).

One possible threat to the common trends assumption underlying our difference-in-difference model could be if pre-treatment trends in body weight in MML states were different from non-MML states. In Table V, we present specifications that add 3 years of policy leads on the right-hand side of the estimating equation. Reassuringly, we find no evidence that body weight was trending differently in states that implemented MMLs versus those that did not in the years leading up to effective dates. Moreover, neither the magnitude nor significance of the contemporaneous or lagged MML effects were affected by the inclusion of policy leads, either in models without state trends (column 1) or with state-specific quadratic time trends (column 2).

5.2. Synthetic control analysis

To examine the sensitivity of our estimates to the choice of counterfactuals, we generate a synthetic state for each state that implemented an MML based on pre-treatment levels and trends in body weight, race, age, average wage, at least attended college, unemployment, beer taxes, marijuana decriminalization, and cigarette taxes. As noted earlier, the counterfactual synthetic control for each treated state is generated as a linear combination of donor states that do not enforce an MML within the period covered by our sample. The weight that each donor state contributes to the counterfactual synthetic control state is chosen to minimize pre-treatment state aggregate differences across covariates in each treatment and synthetic state (Abadie *et al*. 2010). For example, the synthetic counterfactual for California is composed of 32.6% in Minnesota, 16.4% in New York, 43.1% in Utah, and 8.0% in Wisconsin. To take another example, the synthetic counterfactual for Montana is composed of 16.1% in Florida, 12.5% in Idaho, 12.6% in Oklahoma, 19.6% in South Dakota, and 39.2% in Utah. In Supporting Information Table AI, we show balancing tests of the observables in aggregated treatment and synthetic control states. The findings suggest that the synthetic control method is effective in minimizing pre-treatment differences in these characteristics.

Figures 3–5 show the estimated effects of each state's MML policy. Examining each state individually allows one to fully explore heterogeneity in MML policies across states. We find evidence that the enforcement of an MML is associated with a reduction in body weight in California, Oregon, Colorado, and Montana. One

Table V. Difference-in-difference estimates of the relationship between MMLs, BMI, and obesity: adding leads and lags

	Panel I: BMI		Panel II: obesity	
3 years before	−0.021 (0.036)	−0.01 (0.029)	−0.002 (0.003)	−0.001 (0.002)
2 years before	0.006 (0.036)	−0.007 (0.032)	−0.002 (0.002)	−0.002 (0.002)
1 year before	−0.075* (0.043)	−0.060 (0.041)	−0.004 (0.003)	−0.003 (0.003)
Year of law change	−0.103** (0.040)	−0.105** (0.049)	−0.005 (0.003)	−0.005 (0.004)
1 year after	−0.086** (0.043)	−0.095 (0.065)	−0.006* (0.003)	−0.007 (0.005)
2 years after	−0.178*** (0.051)	−0.195*** (0.070)	−0.011*** (0.004)	−0.011** (0.005)
3 years after	−0.148** (0.057)	−0.174** (0.084)	−0.011** (0.004)	−0.012** (0.006)
4 years after	−0.030 (0.056)	−0.065 (0.082)	−0.004 (0.004)	−0.005 (0.006)
5 years after	−0.177** (0.072)	−0.165* (0.092)	−0.011** (0.005)	−0.009 (0.006)
State time trends	No	Yes	No	Yes
Mean (MML = 0)	27.00	27.00	0.240	0.240
N	5,428,399	5,428,399	5,428,399	5,428,399

Note: Each column represents a result from separate unweighted regressions that include state and year fixed effects. Demographic and economic controls include gender, race (White, Black, and Hispanic), education, marital status, average wage by state and year (CPS), and state-level unemployment rate (BLS LAUS). State-level policy controls include marijuana decriminalization laws, zero tolerance laws, and state level alcohol and cigarette taxes. Food prices are collected from ACCRA and include prices for potatoes, bananas, lettuce, sweet peas, tomatoes, peaches, frozen corn, hamburger, pizza, and fried chicken. Standard errors are below each coefficient estimate in parentheses and are clustered by state. State time trends consist of interacting a linear time and a squared time variable with state fixed effects to generate a state-specific quadratic time trend.
*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.

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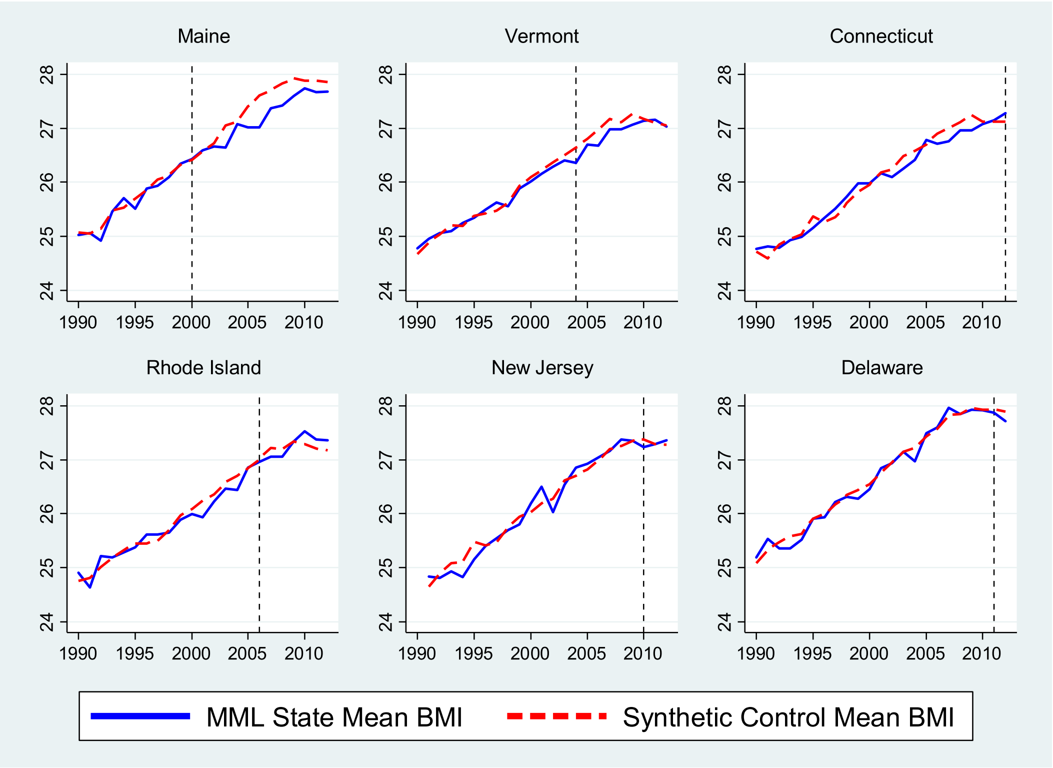

Notes: Plots come from synthetic control analysis for each state, where the synthetic control state is a linear combination of states that do not have MMLs in the sample. The black vertical line denotes the year a given state's MML takes effect.

Figure 3. Trends in BMI in treatment and synthetic control states

explanation for this finding is that these state MMLs were accompanied by relatively few supply-side restrictions (e.g., on dispensaries), which likely led to large spillovers into the recreational market. However, given this explanation, it is perhaps surprising to see MML-associated BMI declines in states such as Hawaii, Vermont, and Maine, which possess relatively more restrictions on dispensaries. However, a closer examination of laws in these states suggests that the allowance of home cultivation, and the difficulty in regulating individual growers (Anderson and Rees 2014), may be an important driver of MML-induced declines in body weight in these states. Subtle differences in MML policy, such as these, may be important. These observations further motivate our discussion of heterogeneity in MMLs in the succeeding discussions.

Next, we pool individuals from each treatment state and its synthetic control state to generate our sample for the synthetic control analysis.[16] In Figures 6 and 7, we present event studies using the treatment states and synthetic control states. Our synthetic figures show that both means and pre-treatment trends in body weight in the treatment and control states are nearly identical, an improvement on the event study shown in Figures 1 and 2. Following the effective date of an MML, body weight rises less rapidly in treatment as compared with synthetic states.

[16]Note that because the choice of synthetic control state for each treatment states uses observations from each potential donor state to assign weights, the sample for the synthetic control analysis is the same as for the main difference-in-difference analysis (see Brown *et al*. 2014 for a discussion of synthetic control analysis using individual-level data).

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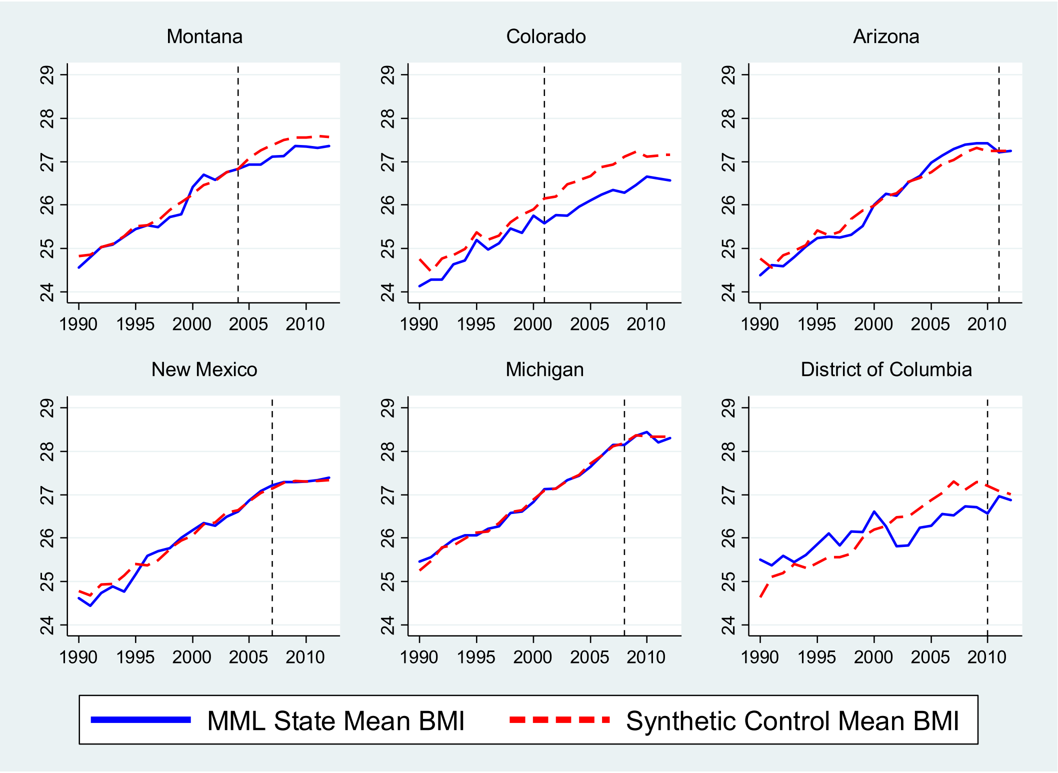

Notes: Plots come from synthetic control analysis for each state, where the synthetic control state is a linear combination of states that do not have MMLs in the sample. The black vertical line denotes the year a given state's MML takes effect.

Figure 4. Central MML states versus synthetic controls for BMI

In Table VI, we show difference-in-difference estimates using the treatment states and their synthetic weighted counterfactual states. We report bootstrapped standard errors in parentheses, where regressions are clustered at the state level. The results are quantitatively and qualitatively similar to our previous difference-in-differences analysis. Compared with our findings in Table III, column 4, the synthetic results indicate somewhat larger negative effects of MMLs on body weight, although we cannot reject the hypothesis that the estimates are statistically equivalent across the two estimation strategies. In summary, our findings provide consistent evidence that MMLs are associated with a reduction in BMI and in the probability of obesity.

5.3. Age-specific estimates

Panel I of Table VII presents the effects of MMLs on BMI by age cohort. In general, we find evidence across the age distribution that MMLs are associated with a reduction in body weight. For 18- to 24-year-olds (column 2), we find that the enactment of MMLs is associated with a 2.3% (0.577/24.59) decline in BMI 5 or more years after enactment. While statistically indistinguishable from zero, we also find a negative relationship for 25- to 49-year-olds (columns 3 and 4). And for those ages 50 years and older (column 5), we find that MMLs reduce BMI by 0.69% (0.190/27.40).[17]

[17]We experimented with examining the effects of MMLs on body weight for those ages 50 to 59 years and 60 years and older. Estimated effects of MMLs on BMI are generally larger (and more consistently statistically distinguishable from zero) for those ages 50 to 59 years as compared with those ages 60 years and older. These results are available upon request of the authors.

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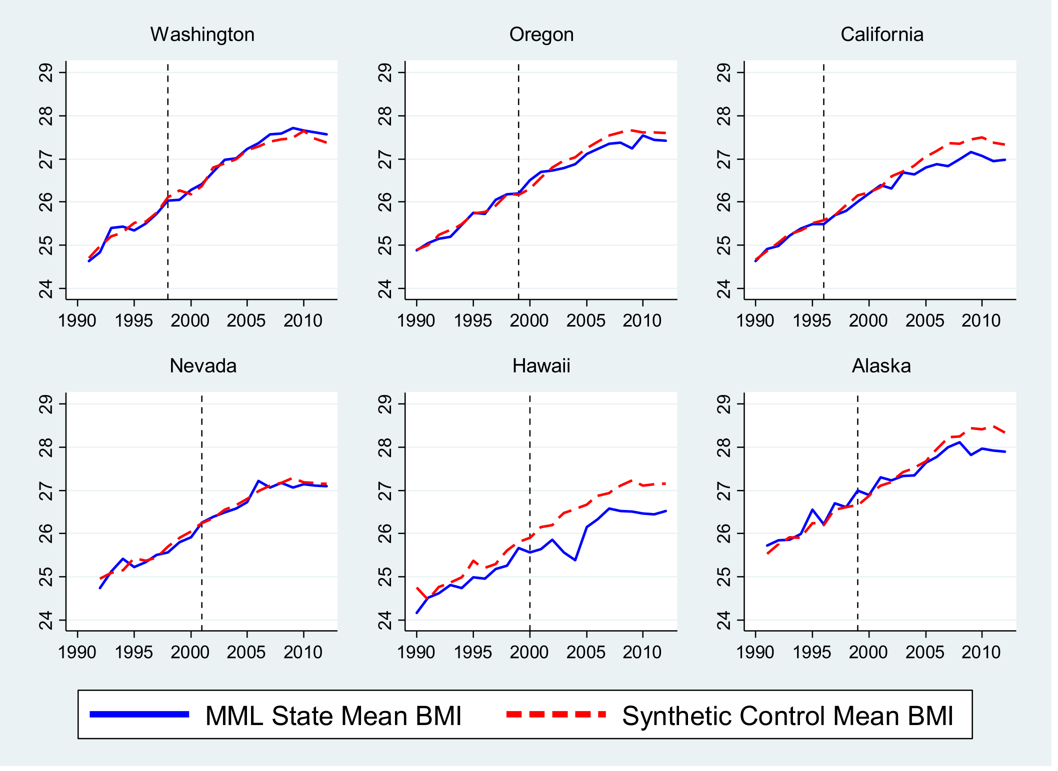

Notes: Plots come from synthetic control analysis for each state, where the synthetic control state is a linear combination of states that do not have MMLs in the sample. The black vertical line denotes the year a given state's MML takes effect.

Figure 5. Western MML states versus synthetic controls for BMI

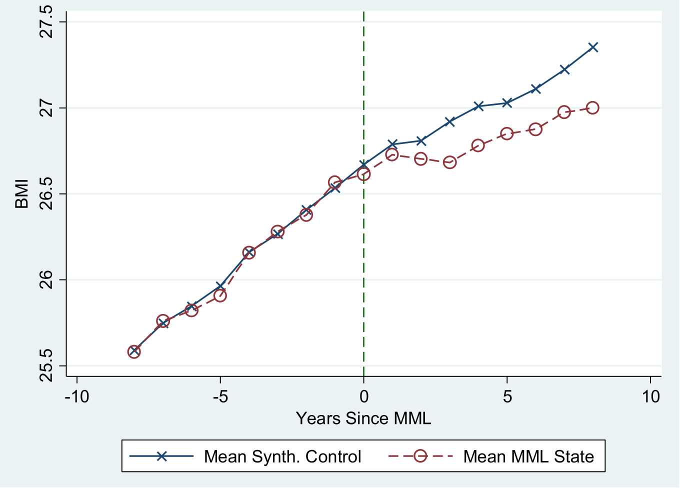

Figure 6. Event study of BMI in treatment and synthetic control states

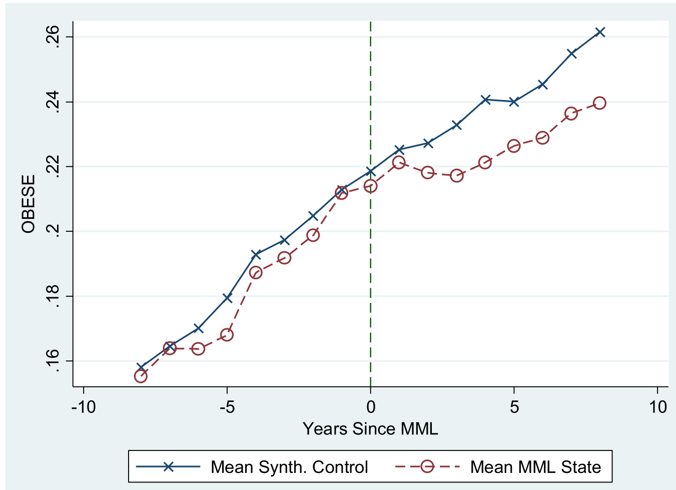

Figure 7. Event study of obesity in treatment and synthetic control states

Table VI. Synthetic control weighted difference-in-difference estimates

	(1)	(2)	(3)	(4)
Panel I: BMI				
MML	−0.088*** (0.020)	−0.075*** (0.019)	−0.066*** (0.020)	−0.098*** (0.027)
With lagged MML indicators				
Year of law change	−0.040 (0.036)	−0.029 (0.037)	−0.040 (0.036)	−0.086*** (0.033)
1 year after	−0.050 (0.035)	−0.046 (0.032)	−0.046 (0.036)	−0.086*** (0.033)
2 years after	−0.079* (0.048)	−0.076* (0.076)	−0.087* (0.047)	−0.134*** (0.040)
3 years after	−0.146** (0.059)	−0.139** (0.059)	−0.141** (0.051)	−0.184*** (0.063)
4 years after	0.019 (0.050)	0.037 (0.054)	0.051 (0.044)	−0.019 (0.047)
5 years after	−0.137** (0.026)	−0.119* (0.028)	−0.096** (0.031)	−0.101* (0.055)
Mean BMI (MML = 0)	26.214	26.214	26.214	26.214
Panel II: obesity				
MML	−0.006** (0.001)	−0.005** (0.002)	−0.004** (0.001)	−0.006** (0.002)
With lagged MML indicators				
Year of law change	0.002 (0.003)	0.002 (0.003)	0.001 (0.003)	−0.002 (0.003)
1 year after	−0.004 (0.003)	−0.004* (0.003)	−0.004 (0.003)	−0.006** (0.003)
2 years after	−0.006 (0.004)	−0.006 (0.004)	−0.006* (0.003)	−0.009*** (0.004)
3 years after	−0.013** (0.006)	−0.013*** (0.006)	−0.012** (0.005)	−0.016*** (0.005)
4 years after	−0.000 (0.004)	0.000 (0.004)	0.002 (0.003)	−0.003 (0.004)
5 years after	−0.008*** (0.002)	−0.008*** (0.002)	−0.005** (0.002)	−0.006 (0.004)
Mean obesity (MML = 0)	0.191	0.191	0.191	0.191
Demographic and economic controls	Yes	Yes	Yes	Yes
State policy controls	No	Yes	Yes	Yes
Food prices	No	No	Yes	Yes
State time trends	No	No	No	Yes
N	5,428,399	5,428,399	5,428,399	5,428,399

Note: Each column represents a result from separate unweighted regressions that include state and year fixed effects. Demographic and economic controls include gender, race (White, Black, and Hispanic), education, marital status, average wage by state and year (CPS), and state-level unemployment rate (BLS LAUS). State-level policy controls include marijuana decriminalization laws, zero-tolerance laws, and state-level alcohol and cigarette taxes. Food prices are collected from ACCRA and include prices for potatoes, bananas, lettuce, sweet peas, tomatoes, peaches, frozen corn, hamburger, pizza, and fried chicken. Bootstrapped standard errors are reported in parentheses. Sample size magnitudes are smaller than other tables because the unit of observation is now the state year. State time trends consist of interacting a linear time and a squared time variable with state fixed effects to generate a state-specific quadratic time trend.
*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.

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When we examine obesity (panel II), we find a similar pattern of results. The estimated effects appear largest for younger (ages 18 to 24 years) and older (ages 50+ years) individuals. For older individuals, as was observed for BMI, we find that 5 or more years after implementation MMLs lead to a 5.0% (0.013/0.259) reduction in the likelihood of obesity (column 5). The results in Table VII generally suggest that MMLs are effective in reducing BMI for both younger and older individuals. But could the mechanisms through which these body weight reductions differ across the age distribution? We explore this in the succeeding discussions.

5.4. Mechanisms

In Table VIII, we present results on the potential mechanisms that could explain the relationship between MMLs and body weight. Panel I shows estimates of the relationship between MMLs and the probability of experiencing poor physical health days in the last 30 days. For the full sample (column 1), we find that the enforcement of MMLs is associated with a 2.5% (0.009/0.354) reduction in the probability of experiencing at least one poor physical health day in the last 30 days. While this result is sensitive to the inclusion of state time trends, it appears concentrated on older individuals, consistent with the hypothesis of the pain-alleviating effects of MMLs. Indeed, according to registry data, medical marijuana is most commonly prescribed for chronic pain (Anderson and Rees, 2013), a condition that becomes increasingly common with age (Rustøen *et al.*, 2005; Institute of Medicine, 2011). [18] Demographic data collected from public registries support this notion and find that those most likely to obtain a prescription for medical marijuana are those aged 40 through 60 years (Doyle and Sheasley, 2012).[19] Thus, while spillovers to the recreational market are likely important for older individuals as well, there also appears to be a health-related benefit, which could indicate some pain-alleviating benefit.

Panel II of Table VIII explores the effect of MMLs on exercise at the extensive margin. There is some evidence that MMLs are associated with a reduction in exercise participation, particularly for younger individuals, consistent with the hypothesis of lethargy-inducing effects of marijuana use (Pesta *et al.*, 2013). In panel III, we present estimates at the intensive margin. While for all age groups under 50 years (columns 1 to 4), we find that MMLs are negatively related to minutes of physical exercise per week, for those ages 50 years and older (column 5), we find that MMLs are positively related to time spent performing physical exercise.[20]

When we look more closely at the intensive margin at more frequent exercise, measured as at least 90 min per week or about 15 min per day (panel IV), we find that for individuals' ages 35 years and older, the enforcement of MMLs is positively related to exercise. Specifically, for those ages 35 to 49 years, we find that MMLs are associated with a 2.7% (0.019/0.716) to 7.3% (0.052/0.716) increase in the probability of exercising at least 90 min per week (about 15 min per day). These findings provide some suggestive evidence that marijuana use—particularly for pain-alleviating purposes—may improve physical mobility for older individuals with some previous mobility.

While improved physical wellness and increased exercise (among those with some mobility) might explain part of the reduction in body weight for older individuals in our sample, what explains the reduction

[18]Colorado had 128,698 patients of whom 94% reported chronic pain in 2011. In Arizona, 86% of the medical marijuana patients suffered from chronic pain.

[19]For example, most users in Nevada are between 55 and 60 years old, while the average age for patients in Colorado and Montana is 41 and 46 years, respectively.

[20]Estimation of a two-part model via probit (extensive margin) and GLM (intensive margin) to obtain an overall exercise estimate produced a similar pattern of results as shown in panels II and III.

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Table VII. Age-specific estimates of the effect of MMLs on body weight

	All ages	18–24 years	25–34 years	35–49 years	50+ years
Panel I: BMI					
3 years before	−0.010 (0.029)	−0.213* (0.115)	−0.045 (0.069)	−0.026 (0.058)	−0.002 (0.048)
2 years before	−0.007 (0.032)	−0.121 (0.105)	0.023 (0.107)	0.040 (0.064)	−0.046 (0.040)
1 year before	−0.060 (0.041)	0.066 (0.103)	−0.100 (0.070)	−0.021 (0.055)	−0.078 (0.060)
Year of law change	−0.105** (0.049)	−0.217 (0.179)	0.063 (0.127)	−0.071 (0.077)	−0.138** (0.061)
1 year after	−0.095 (0.065)	−0.150 (0.161)	−0.106 (0.128)	0.000 (0.102)	−0.088 (0.069)
2 years after	−0.195*** (0.070)	−0.425** (0.178)	−0.088 (0.154)	−0.117 (0.103)	−0.179** (0.078)
3 years after	−0.174** (0.084)	−0.275* (0.164)	−0.098 (0.168)	−0.060 (0.113)	−0.190** (0.088)
4 years after	−0.065 (0.082)	−0.226 (0.162)	0.085 (0.164)	0.044 (0.125)	−0.090 (0.093)
5 years after	−0.165* (0.092)	−0.577** (0.222)	−0.019 (0.181)	−0.029 (0.144)	−0.190* (0.096)
Mean BMI (MML = 0)	27.00	24.59	26.22	27.21	27.40
State time trends	Yes	Yes	Yes	Yes	Yes
N	5,428,399	316,544	722,704	1,445,107	2,915,976
Panel II: obesity					
3 years before	−0.001 (0.002)	−0.010 (0.007)	−0.003 (0.005)	0.001 (0.004)	0.000 (0.004)
2 years before	−0.002 (0.002)	−0.004 (0.009)	−0.001 (0.009)	0.000 (0.004)	−0.005 (0.003)
1 year before	−0.003 (0.003)	0.007 (0.008)	−0.012** (0.005)	0.003 (0.003)	−0.005 (0.005)
Year of law change	−0.005 (0.004)	−0.013 (0.013)	0.006 (0.009)	−0.003 (0.005)	−0.007 (0.006)
1 year after	−0.007 (0.005)	−0.014 (0.011)	−0.002 (0.009)	−0.001 (0.007)	−0.007 (0.006)
2 years after	−0.011** (0.005)	−0.036*** (0.013)	−0.003 (0.011)	−0.001 (0.007)	−0.012* (0.006)
3 years after	−0.012** (0.006)	−0.013 (0.012)	−0.008 (0.011)	−0.006 (0.009)	−0.013* (0.007)
4 years after	−0.005 (0.006)	−0.016 (0.011)	−0.002 (0.012)	0.005 (0.009)	−0.006 (0.008)
5 years after	−0.009 (0.006)	−0.041*** (0.014)	0.004 (0.013)	0.005 (0.010)	−0.013 (0.008)
Mean obese (MML = 0)	0.240	0.129	0.201	0.250	0.259
State quadratic time trends	Yes	Yes	Yes	Yes	Yes
N	5,428,399	316,544	722,704	1,445,107	2,915,976

Note: Each column represents a result from separate unweighted regressions that include state and year fixed effects. Demographic and economic controls include gender, race (White, Black, and Hispanic), education, marital status, average wage by state and year (CPS), and state-level unemployment rate (BLS LAUS). State-level policy controls include marijuana decriminalization laws, zero-tolerance laws, and state-level alcohol and cigarette taxes. Food prices are collected from ACCRA and include prices for potatoes, bananas, lettuce, sweet peas, tomatoes, peaches, frozen corn, hamburger, pizza, and fried chicken. Standard errors are below each coefficient estimate in parentheses and are clustered by state. State time trends consist of interacting a linear time and a squared time variable with state fixed effects to generate a state-specific quadratic time trend.
*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.

in body weight for the younger cohorts? One answer could be the alcohol effects of MMLs. For those ages 18 to 24 years, our findings show that the enactment of MMLs is associated with a 3.1% (0.017/0.551) reduction in the probability of alcohol consumption (panel V, column 2) and a 4.8% (0.013/0.269) reduction in the probability of binge drinking (panel VI, column 3). Therefore, MMLs may induce younger individuals to substitute away from highly caloric alcoholic beverages toward a lower-calorie marijuana 'high', resulting in lower body weight and likelihood of obesity. There is also some evidence of substitution effects among older individuals, suggesting a recreational component to MML-induced marijuana use for these individuals.

In panel VII, we find some evidence that MMLs are associated with reductions in food consumption. Taken at face value, these results do not seem consistent with the hypothesis that marijuana induces greater appetite. However, it is important to note that our measures for consumption primarily capture the consumption of relatively healthy foods. It is possible that MMLs reduce the consumption of healthy food as individuals substitute toward less healthy, higher-calorie alternatives (Kirkham, 2009; Foltin *et al*., 1988).

Finally, in panel VIII, we find evidence a negative relationship between MMLs and the probability that a respondent has reported any poor mental health days in the last 30 days, consistent with Anderson, Rees, and Sabia (2014), although this finding is somewhat sensitive to the inclusion of state time trends. This could suggest that improved mental health improves efficiency of production of

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Table VIII. Examining mechanisms through which MMLs may affect body weight

	All ages		18–24 years		25–34 years		35–49 years		50+ years	
Panel I: any poor physical health days										
Poor physical health days	−0.009* (0.005)	−0.010 (0.006)	−0.011* (0.007)	−0.007 (0.013)	−0.003 (0.006)	−0.012 (0.011)	−0.008 (0.006)	−0.018** (0.009)	−0.009* (0.005)	−0.005 (0.004)
Mean (MML = 0)	0.354		0.354		0.328		0.343		0.368	
N	5,176,842		287,599		669,034		1,377,555		2,802,428	
Panel II: any minimal physical exercise										
Any minimal exercise	0.008 (0.010)	−0.025* (0.013)	0.004 (0.013)	−0.071 (0.049)	−0.002 (0.019)	−0.022 (0.016)	0.005 (0.011)	−0.035* (0.009)	0.014 (0.009)	−0.018 (0.012)
Mean (MML = 0)	0.388		0.583		0.529		0.476		0.294	
N	1,650,516		83,103		203,563		448,655		902,953	
Panel III: minutes of exercise (conditioned on any minimal exercise)										
Minutes of exercise	−2.029 (4.831)	−9.452 (8.840)	0.948 (15.212)	−27.596 (33.289)	−11.026 (8.335)	−25.316 (20.747)	−6.748 (8.440)	−17.006 (8.499)	2.228 (4.198)	2.281 (15.062)
Mean (MML = 0)	223.55		260.91		209.98		211.78		231.83	
N	665,592		49,504		109,943		220,050		281,655	
Panel IV: at least 90 min per week (conditional on any minimal exercise)										
Exercise ≥ 90 min per week	0.011** (0.005)	0.025*** (0.008)	0.005 (0.016)	0.019 (0.025)	−0.006 (0.016)	0.019 (0.028)	0.019* (0.028)	0.052*** (0.015)	0.011* (0.005)	0.008 (0.014)
Mean (MML = 0)	0.725		0.758		0.724		0.716		0.726	
N	665,592		49,504		109,943		220,050		281,655	
State time trends	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Panel V: consumed any alcohol in the last 30 days										
Drink anything	−0.009 (0.006)	−0.006 (0.005)	−0.021** (0.010)	−0.017** (0.008)	−0.016* (0.009)	−0.008 (0.008)	−0.002 (0.007)	−0.009 (0.005)	−0.009 (0.005)	−0.003 (0.005)
Mean (MML = 0)	0.486		0.551		0.583		0.562		0.418	
N	5,181,180		286,441		667,771		1,359,434		2,828,214	

(*Continues*)

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Table VIII. (Continued)

	All ages		18–24 years		25–34 years		35–49 years		50+ years	
Panel VI: any binge drinking in the last 30 days										
Binge drinking	−0.009*** (0.003)	−0.005** (0.002)	−0.021** (0.007)	−0.013* (0.007)	−0.010 (0.006)	−0.006 (0.006)	−0.010** (0.004)	−0.007* (0.004)	−0.005** (0.002)	−0.003* (0.002)
Mean (MML = 0)	0.118		0.269		0.213		0.155		0.061	
N	5,127,666		238,118		661,835		1,3466269		2,798,323	
Panel VII: food consumption										
	All ages		18–24 years		25–34 years		35–49 years		50+ years	
Appetite	0.976 (1.133)	−2.527 (1.611)	1.647 (1.441)	−3.49** (1.505)	2.035 (1.619)	−2.764 (2.434)	1.221 (1.227)	−3.138* (1.578)	0.955 (1.108)	−2.045 (1.634)
Mean (MML = 0)	117.86		107.69		110.27		113.36		124.15	
N	2,262,538		140,954		332,665		657,606		1,117,259	
Panel VIII: had any poor mental health days in the last 30 days										
Mental health	−0.013* (0.008)	−0.001 (0.010)	−0.038** (0.014)	−0.016 (0.019)	−0.021* (0.011)	−0.000 (0.018)	−0.013 (0.010)	−0.001 (0.012)	−0.004 (0.005)	−0.002 (0.006)
Mean (MML = 0)	0.315		0.458		0.399		0.375		0.251	
N	5,191,627		287,738		667,574		1,374,420		2,821,617	
State time trends	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Note: Each column represents a result from separate unweighted regressions that include state and year fixed effects. Demographic and economic controls include gender, race (White, Black, and Hispanic), education, marital status, average wage by state and year (CPS), and state-level unemployment rate (BLS LAUS). State-level policy controls include marijuana decriminalization laws, zero-tolerance laws, and state-level alcohol and cigarette taxes. Food prices are collected from ACCRA and include prices for potatoes, bananas, lettuce, sweet peas, tomatoes, peaches, frozen corn, hamburger, pizza, and fried chicken. Standard errors are below each coefficient estimate in parentheses and are clustered by state. State time trends consist of interacting a linear time and a squared time variable with state fixed effects to generate a state-specific quadratic time trend.
*Significant at 10% level. **Significant at 5% level. ***Significant at 1% level.

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Table IX. Exploring heterogeneity in MMLs

Panel I: *BMI*	(1)	(2)	(3)	(4)	(5)
Any MML	−0.084** (0.034)				
MML for pain		−0.088*** (0.030)			−0.063** (0.030)
MML with collective cultivation allowed			−0.110** (0.054)		−0.072 (0.054)
MML that allows for dispensaries				−0.081 (0.051)	−0.011 (0.026)
Mean BMI (MML = 0)	27.00	27.00	27.00	27.00	27.00
Panel II: *obese*					
Any MML	−0.005* (0.003)				
MML for pain		−0.004** (0.002)			−0.003 (0.002)
MML with collective cultivation allowed			−0.005 (0.004)		−0.003 (0.003)
MML that allows for dispensaries				−0.005 (0.004)	−0.001 (0.002)
Mean obese (MML = 0)	0.240	0.240	0.240	0.240	0.240
State time trends	Yes	Yes	Yes	Yes	Yes
N	5,428,399	5,428,399	5,428,399	5,428,399	5,428,399

Note: Each column represents a result from separate unweighted regressions that include state and year fixed effects. Column (1) presents the coefficient estimates of the standard measure of MML used in this paper, following the interpretation of MML effective dates by Anderson *et al*. Column (2) is a measure of MMLs (effective dates from Anderson and Rees (2013)) that allow for pain according to Pacula *et al*. (2013). Column (3) estimates the effect of MMLs that allow for collective cultivation according to Anderson and Rees (2013). Column (4) estimates the effect of MMLs for states that have at least one operating dispensary following coding by Pacula *et al*. (2015). Demographic and economic controls include gender, race (White, Black, and Hispanic), education, marital status, average wage by state and year (CPS), and state-level annual unemployment rate (BLS LAUS). State-level policy controls include marijuana decriminalization laws, zero-tolerance laws, and state-level alcohol and cigarette taxes. Food prices are collected from ACCRA and include prices for potatoes, bananas, lettuce, sweet peas, tomatoes, peaches, frozen corn, hamburger, pizza, and fried chicken. Standard errors are below each coefficient estimate in parentheses and are clustered by state. State time trends consist of interacting a linear time and a squared time variable with state fixed effects to generate a state-specific quadratic time trend.
*Significant at 10% level; **Significant at 5% level; ***Significant at 1% level.

physical health. However, it is also possible that improved mental health could be a consequence of lower body weight. [21]

5.5. Heterogeneity in MMLs

The results from our synthetic cohort analysis suggest that there may be heterogeneous effects of MMLs on body weight. We explore this issue further in Table IX. Column (1) shows estimates of the effect of the average MML on body weight. In the remaining columns, we explore the effects of state MMLs that allow (i) medical marijuana to be prescribed for pain (column 2), (ii) collective cultivation of medical marijuana (column 3), and (iii) medical marijuana dispensaries (column 4). Column (5) includes controls for each of these types of MMLs in the same regression.

We find that MMLs that are pain-inclusive (column 2) and allow for collective cultivation of marijuana (column 3), which generates the largest negative body weight effects (see Supporting Information Table AII for examples of allowable conditions). These findings are consistent with the

[21]In results available upon request, we explore the relationship between MMLs and the probability of visiting a primary care physician in the last year. We find little evidence that MMLs affect contact with primary healthcare providers. However, there are a number of important limitations with this measure. Patients seeking a prescription for marijuana might choose to visit a medical marijuana evaluation clinic rather than their primary care physician, where doctors regularly write medical marijuana recommendations (Reinarman *et al*., 2011). Additionally, if patients are seeking a medical marijuana recommendation for a particular injury, illness, or condition, they may not necessarily visit their primary care physician. The BRFSS does not include data on other contact with healthcare providers.

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hypotheses that (i) there may be some physical mobility benefits of MMLs, and (ii) allowing the home cultivation and distribution of marijuana to other patients (on a non-profit basis) may have spillover effects into recreational markets. The estimated effect of MMLs that permit marijuana dispensaries also suggest negative effects on body weight (column 4), although these estimates are statistically indistinguishable from zero.[22]

6. CONCLUSIONS

This paper is the first to examine the effect of MMLs on body weight, physical well-being, and exercise. Difference-in-differences estimates suggest that the enactment of MMLs lead to a 0.3% to 0.6% decrease in BMI scores and a 2.1% to 6.0% decline in the likelihood that respondents report being obese. We also find evidence of heterogeneous mechanisms for body weight reduction across the age distribution. For older individuals, we find that MMLs are associated with an increase in physical wellness and frequent exercise consistent with the hypothesis of some medicinal use of marijuana. However, the magnitude of the overall body weight effect suggests some spillover effects into the informal 'non-medical' marijuana market as well. For younger individuals, MML-induced reductions in alcohol consumption appear to be relatively more important, consistent with the hypothesis that MMLs lead to substitution toward a less caloric recreational high.

The estimated body weight effects we obtain should be interpreted as 'intent to treat' (ITT) estimates. Because the BRFSS does not include information on marijuana consumption, our approach does not immediately yield estimates of the effect of MMLs on individuals who are induced to use marijuana because of MMLs. Obtaining the implied average effect of treatment on the treated (ATET) estimates from our ITT estimates requires knowledge of the effect of MMLs on marijuana use (Angrist & Pischke, 2009, p. 164). Wen *et al*. (2014) estimate that MMLs increase marijuana consumption by 16% on the extensive margin and 17% on the intensive margin (33% total increase) of use among individuals over age of 21 years. Using their estimate, we obtain implied bounds for ATETs indicating a 0.9% to 1.8% decline in BMI and a 6.3% to 13.0% decrease in the likelihood of obesity. These estimates are actually 45% to 61% smaller in magnitude than those obtained by Le Strat and Le Foll (2011), who document obesity prevalence to be 16% to 23% lower among marijuana users.

Using estimates from Cawley and Meyerhoefer (2012), we estimate a back-of-the-envelope per-person reduction in MML-induced obesity related medical costs of \$58 to \$115 per year.[23] These, too, could be rescaled by a factor of 3 to 5 (from first stage of Wen *et al*. (2014) and Anderson and Rees (2013), respectively) if we believe compliers drive these effects. However, note that there are limitations to this partial equilibrium calculation. MML-induced reductions in obesity-related expenses may be offset by other types of medical expense because of general equilibrium effects, some directly related to marijuana use. Future work (with richer data) is needed in order to explore the impact of MMLs on other health outcomes and to conduct a more complete welfare analysis.

[22]The coding of dispensary states is the subject of debate because of the heterogeneity in the legality and operation of dispensaries in different states (Anderson and Rees, 2014). For our analysis, we follow the coding outlined by Pacula *et al*. (2015), in which an MML is considered dispensary inclusive if the legislation contains legal language allowing for the operation of dispensaries and have at least one dispensary in operation. There are important limitations to coding MMLs in this fashion. Even though a state may statutorily allow for dispensaries, state agencies may strictly regulate them, allowing very few to operate; for instance, there may be statutory limitations on the number of dispensaries that are allowed to operate, such as in Maine. Moreover, the enforcement of federal anti-marijuana laws by federal agents may affect the number of operating dispensaries (Mikos, 2011). While using counts of dispensaries may provide better information on the availability of marijuana in a state, they also likely capture demand-side factors, which could exacerbate endogeneity bias if unmeasured factors that affect the demand for marijuana also affect health.

[23]This is obtained by taking the Cawley and Meyerhoefer (2012) estimate, \$2,741, and multiplying by estimates from Table 4, row 1, column 4 (which gives the lower bound) and column 1 (which gives the upper bound).

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CONFLICT OF INTEREST

None of the authors have a financial interest in the policy being discussed in this manuscript. This study uses secondary data, and there are no ethical conflicts with this study.

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