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EVIDENCE-BASED APPROACH TO DRUG CRISIS

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EVIDENCE-BASED APPROACH TO DRUG CRISIS

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
Graduate School
at the University of Kentucky

By

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ABSTRACT OF DISSERTATION

EVIDENCE-BASED APPROACH TO DRUG CRISIS

I am devoted to health policy research, especially tackling the opioid crisis, and evaluating marijuana laws and newly emerging issues associated with legal recreational drugs. Opioid overdose in the United States continues to jeopardize public health. Meanwhile, the majority of states have legalized medical marijuana and one third of them further liberalized recreational marijuana. Marijuana liberalization, although originally independent of the growing opioid crisis, may be a harm reduction approach to the crisis because marijuana may be a substitute for opioids in pain management at a relatively lower risk. However, marijuana liberalization may also lead to marijuana-related harms, such as marijuana-related emergency department visits. Moreover, e-cigarette use has been rising among youth and young adults at an alarming rate and led to the current outbreak of lung diseases.

My dissertation consists of three papers: "Paper 1: The Impact of Medical and Recreational Marijuana Laws on Opioid Prescribing in Employer-Sponsored Health Insurance," "Paper 2: The Impact of Medical Marijuana Smoking Ban on Emergency Department Visits Related to Marijuana and Opioid Use," and "Paper 3: Marijuana Use in E-Cigarettes among U.S. Youth."

Paper 1 Abstract:

Marijuana may provide an alternative for pain management at a relatively lower risk of addiction and virtually no risk of overdose. Using data from Truven Health MarketScan Commercial Claims and Encounters Database between 2009 and 2015, I studied the effects of medical and recreational marijuana laws on opioid prescribing in employer-sponsored health insurance. I used a differences-in-differences (DD) approach and found that the implementation of medical marijuana laws (MML) and recreational marijuana laws (RML) reduced morphine milligram equivalents (MME) per enrollee by 7% and 13%, respectively. The reduction associated with medical marijuana laws was largely in people aged 55-64, while the reduction associated with recreational marijuana laws was mainly in people aged 45-54. My findings suggest that both medical and recreational marijuana laws have the potential to reduce opioid prescribing in the privately-insured population, especially for the middle-aged population and pain patients.

Paper 2 Abstract:

Medical marijuana liberalization has been spreading across U.S. states and empirical studies have found that medical marijuana and prescription opioids may be substitutes, yet no study has examined the impact of medical marijuana smoking bans on marijuana- and opioid-related emergency department visits, despite the fact that people historically prefer to smoke marijuana for medical purposes, and most marijuana-related emergency department visits were associated with Cannabinoid hyperemesis caused by smoking marijuana. The purpose of this study is to examine the impact of smoking bans by analyzing a nationally representative sample of the privately-insured population.

Using data from Truven Health MarketScan Commercial Claims and Encounters Database between 2011 and 2016, I employed a differences-in-differences (DD) quasi-experimental design to examine the differences in marijuana- and opioid-related ED visits between states with medical marijuana smoking bans and states without such bans. I aggregated the data at the state/month level.

I found that state medical marijuana laws with smoking bans were associated with a decrease in the number of marijuana-related ED visits by -3.289 per month (95% CI=-5.453, -1.125), which can be translated to a 16.3 percent decrease. State medical marijuana laws with smoking bans were associated with a decrease in the number of opioid-related ED visits by -3.808 per month (95% CI=-6.703, -0.913). The combination of medical marijuana laws with smoking bans and legal dispensaries was consistently associated with decreases in marijuana- and opioid-related ED visits among all ages.

The findings suggest that medical marijuana laws with smoking bans coupled with legal dispensaries may improve the safety of marijuana use without compromising the accessibility of marijuana.

Paper 3 Abstract:

Non-nicotine substances, including marijuana and THC concentrates, can be used in e-cigarettes. By 2014, e-cigarettes had replaced traditional combusted tobacco products, such as cigarettes, and become the most prevalently used nicotine products among US youth. E-cigarette use among US youth continues to grow rapidly. State liberalization of medical and recreational marijuana makes marijuana more accessible and further reduces public perceived riskiness associated with marijuana use. Previous research has documented youth concurrent use of nicotine and other substances in e-cigarettes.

I used data from the 2016, 2017 and 2018 National Youth Tobacco Survey (NYTS), a nationally representative sample of US 6 to 12 grade students to examine the trend of marijuana use in e-cigarettes as well as behavioral and environmental factors associated with marijuana use in e-cigarettes.

I found that marijuana vaping increased among high school students but not among middle school students from 2016 to 2018. Being male was at greater odds of marijuana vaping. Compared to White non-Hispanic students, Hispanic students were at greater odds of marijuana vaping, while other non-Hispanic students were at lower odds of marijuana vaping. High school students were at greater odds of marijuana vaping than middle school students. The odds of marijuana vaping increased among high-school Hispanic females and among other non-Hispanic males from 2017 to 2018. The odds of marijuana vaping increased among high-school black females and among middle-school Hispanic females from 2016 to 2017. Both high-school Hispanic females and males were increasingly more likely to vape marijuana from 2016 to 2018 after controlling for behavioral and environmental factors. The odds of marijuana vaping continuously increased among those who did not report flavors as one of the reasons of using e-cigarettes from 2016 to 2018, among those who did not report less cost as one of the reasons of using e-cigarettes from 2016 to 2018, and among those who did not report less harmfulness as one of the reasons of using e-cigarettes from 2016 to 2018.

My findings suggest that E-cigarette policy may need to focus on the increase in marijuana vaping among Black and Hispanic female students, and Hispanic students in general. Banning flavored e-cigarettes may not reduce marijuana vaping among youth. Lower cost and less perceived harmfulness associated with e-cigarette use may not be associated with the trend of marijuana vaping among youth.

KEYWORDS: Medical Marijuana Laws, Recreational Marijuana Laws, Prescription Opioids, Emergency Department Visits, Smoking Ban, Marijuana Vaping

Jiebing Wen

05/01/2020

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DEDICATION

To my husband Qian Zhong, a dedicated and brilliant scientist, who encouraged me to be fearless and supported me unconditionally.

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Moreover, I thank my colleagues and friends at Martin School, especially Andrew Sullivan, Xin Chen, and Dr. Alex Combs. Thank you for standing by me through my ups and downs. I also thank all faculty members at Martin School, as well as those in the College Public Health and College of Pharmacy, especially Dr. Rajeev Darolia, Dr. Joseph A. Benitez, Dr. Tyrone Borders and Dr. Karen Blumenschein. I learned the best from you all.

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Still, I apologize to anyone I do not adequately acknowledge above. I will continue to make all of you proud.

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CHAPTER 1. THE IMPACT OF MEDICAL AND RECREATIONAL MARIJUANA LAWS ON OPIOID PRESCRIBING IN EMPLOYER-SPONSORED HEALTH INSURANCE

1.1 Introduction

The opioid epidemic in the United States has reached a crisis level. The economic cost of the crisis was estimated at $504 billion in 2015, or 2.8 percent of the total gross domestic product (GDP) (The Council of Economic Advisers, 2017). Excessive prescribing of opioids for pain management is viewed as a major driver of the ongoing opioid epidemic in the U.S. (Rudd et al., 2016; Volkow, 2014; Manchikanti et al., 2012).

Prescription opioids are primarily used for adult pain management in the U.S. (e.g. Brummett et al., 2017). However, the scientific evidence to back the effectiveness of prescription opioids in chronic non-cancer pain is limited (Manchikanti et al., 2012; Lee et al., 2011), and there is evidence of serious consequences of opioid use, including opioid addiction, opioid-induced hyperalgesia and opioid-related deaths (Rudd et al., 2016; Lee et al., 2011; Chu et al., 2006; Yin et al., 1999).

Marijuana may provide an alternative for pain management at a relatively lower risk of addiction and virtually no risk of overdose (National Academies of Sciences, Engineering, and Medicine, 2017; Reiman, Welty, & Solomon, 2017; Hill, 2015; Whiting et al., 2015; Lynch & Campbell, 2011; Abrams et al., 2011). While marijuana is still a Schedule I drug at the federal level,[1] 33 states and the District of Columbia have legalized medical marijuana use as of January 2019 (ProCon.org, 2019; Berke & Gould, 2019). Ten

[1] There are two categories of cannabinoid drugs in the U.S. The first category is cannabis-derived medicines including nabilone (schedule II) and dronabinol (Schedule III) that were approved by the U.S. Food and Drug Administration (FDA). The second category is phytocannabinoid-dense botanicals including marijuana plants (schedule I) and other forms of cannabinoids (Borgelt et al., 2013).

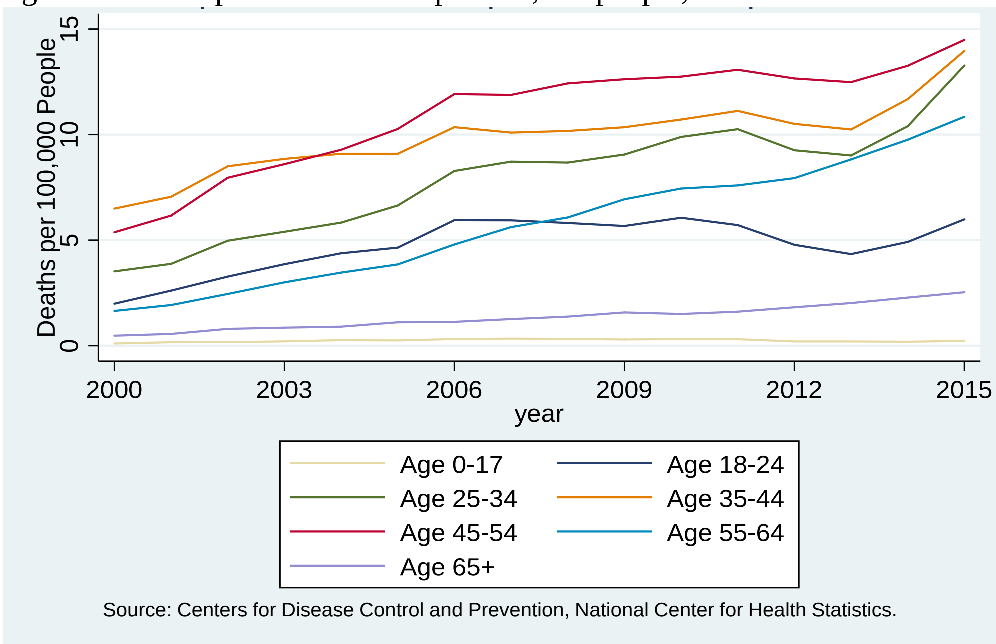
states with medical marijuana laws and the District of Columbia further legalized adult recreational marijuana use as of January 2019 (ProCon.org, 2018; Berke & Gould, 2019).

Although medical and recreational marijuana laws were not originally adopted to reduce opioid prescribing and harms associated with opioid use, empirical studies have found that state medical marijuana laws (MMLs) and recreational marijuana laws (RMLs) are associated with reductions in opioid prescribing for Medicare Part D enrollees (Bradford et al., 2018) and for Medicaid enrollees (Wen & Hockenberry, 2018; Shi et al., 2019), as well as reductions in opioid-related overdose deaths (Powell, Pacula, & Jacobson, 2017; Livingston et al., 2017; Bachhuber et al., 2014), treatment rates related to opioid addiction and overdose (Powell, Pacula, & Jacobson, 2017; Shi, 2017), and opioid-related fatal accidents (Kim et al., 2016a). Those empirical findings suggest that medical and recreational marijuana laws may affect opioid use and downstream adverse consequences.

I contribute to the growing literature by examining how state medical and recreational marijuana laws may affect opioid prescribing in the working age population (age from 18 to 64) with employer-sponsored health insurance and by exploring the heterogeneous effects of the marijuana laws in different age groups. Nearly four in ten people addicted to opioids are covered by private health insurance, yet this population has not been studied extensively in research on marijuana policy and opioid prescribing (Cox, Rae, & Sawyer, 2018). My study population is of particular importance in the current opioid crisis, which is largely a crisis in the working age population. The opioid overdose death rates of working age population (age from 18 to 64) are substantially higher than those of other age groups and have increased significantly since 1999 (Figure 1.1).

Particularly, the U.S. opioid crisis is also a midlife crisis. Drug overdose deaths, especially opioid-related drug overdose deaths, disproportionally contributed to the mortality rate of individuals aged 45 to 54 (Figure 1.1). Opioid overdose has shortened the life expectancy of middle-aged people in the U.S. (Case & Deaton, 2015). My study looks into different age groups among individuals with employer-sponsored health insurance, thus better capturing the at-risk population than the previously studied Medicare and Medicaid populations (Bradford et al., 2018; Wen & Hockenberry, 2018).

Figure 1.1 U.S. opioid death rates per 100,000 people, 2000-2015



Source: Centers for Disease Control and Prevention, National Center for Health Statistics. Multiple Cause of Death 1999-2016 on CDC WONDER Online Database, released December, 2017. Data are from the Multiple Cause of Death Files, 1999-2016, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/mcd-icd10.html

1.2 Literature Review

The effects of medical and recreational marijuana laws on opioid prescribing depend on whether marijuana is a substitute for or complement to prescription opioids as both laws de facto lower the price of qualified marijuana use through removing legal penalties and increasing marijuana supply.

State MMLs authorize both adults and minors to use marijuana to treat qualified conditions. Conditions qualified for medical marijuana use vary from state to state, but generally include severe or chronic pain, as well as other conditions, such as cancer, glaucoma, AIDS (or HIV positive), and Hepatitis C. The majority of the medical marijuana states require patient registration, meaning that patients generally need to provide a physician written certification, in exchange for legal protection. Some states provide affirmative defense for medical use of marijuana even if self-claimed medical marijuana patients fail to register with states (PDAPS, 2017; ProCon.org, 2019).

State RMLs (i.e., adult-use marijuana laws) expanded the reach of marijuana legalization by allowing almost all adults aged 21 and above to use marijuana (ProCon.org, 2018). On the demand side, the laws provide additional legal protection for people who were not qualified as medical marijuana patients. On the supply side, expecting increases in demand for marijuana, marijuana producers may supply more marijuana for adult uses. Overproduction of marijuana, which leads to decreases in wholesale prices, has been seen in several states with recreational marijuana laws (Mongelia, 2018; Roig, 2018).

Empirical studies have found that state MMLs and RMLs are associated with decreases in opioid use. Bradford et al. (2018) find that a MML with either operational dispensaries or home cultivation provisions is associated with reductions in daily doses of opioid prescriptions in state Medicare Part D populations between 2010 and 2015. Wen and Hockenberry (2018) find that MMLs and RMLs are associated with reductions in opioid prescribing rates and spending in Medicaid enrollees between 2011 and 2016. Shi et al. (2019) find that RMLs are associated with reductions in the number of prescriptions, morphine milligram equivalents (MME), and spending specific to Schedule III opioids in Medicaid enrollees between 2010 and 2017.

MMLs and RMLs are also found to reduce harms related to opioid use, such as opioid-related overdose deaths (Bachhuber et al., 2014; Powell, Pacula, & Jacobson, 2017; Livingston et al., 2017), opioid-positive fatalities (Kim et al., 2016a), and opioid-related hospitalization (Shi, 2017).

1.3 Research Question

How do medical and recreational marijuana laws affect opioid prescribing in those with employer-sponsored health insurance?

1.4 Data and Methods

1.4.1 Data and Sample

I used the Truven Health MarketScan Commercial Claims and Encounters Database between 2009 and 2015, which captures medical claims and encounters of a national and state representative sample of active employees and their dependents, early retirees, and Consolidated Omnibus Budget Reconciliation Act (COBRA) enrollees.[2] My data were aggregated at the state/month level. I also limited my sample to those aged 18-64 with at least one-year continuous enrollment (enrollment span greater than or equal to 365 days). Please see Table 1.1 for the number of enrollees in each state and each year.

[2] See https://truvenhealth.com/Portals/0/Assets/2017-MarketScan-Databases-Life-Sciences-Researchers-WP.pdf; only the data between 2009 and 2015 were available to us in the study period.

Table 1.1 Number of Enrollees in private health insurance as reported by Truven Health MarketScan, 2009-2015

State	2009	2010	2011	2012	2013	2014	2015
Alabama	276,736	356,747	377,010	379,821	318,168	307,370	230,450
Alaska	20,106	29,347	29,390	30,651	23,720	23,676	15,888
Arizona	281,398	399,443	408,000	392,377	347,440	331,600	230,649
Arkansas	126,136	172,337	177,975	179,590	164,823	141,192	97,458
California	2,975,112	3,792,430	3,937,641	4,229,747	3,947,465	2,898,627	996,281
Colorado	279,136	387,037	426,273	438,169	395,334	379,647	208,001
Connecticut	613,211	744,857	657,583	650,687	576,008	536,358	159,078
Delaware	102,220	120,878	125,132	127,185	121,580	121,848	101,546
Florida	855,109	1,218,002	1,345,027	1,395,904	1,293,339	1,293,414	1,000,151
Georgia	836,391	1,318,865	1,489,766	1,564,890	1,328,517	1,282,609	806,653
Hawaii	4,200	6,058	6,091	5,880	4,493	3,651	1,098
Idaho	46,839	60,791	246,612	282,526	265,598	289,180	234,111
Illinois	1,530,183	1,918,971	2,131,557	2,089,083	718,400	677,282	442,033
Indiana	707,299	1,137,904	1,199,916	1,242,408	1,076,375	943,275	304,622
Iowa	205,418	248,220	196,640	221,783	176,582	163,809	106,591
Kansas	121,395	170,580	184,355	188,132	159,332	146,534	93,662
Kentucky	318,610	484,992	561,831	589,328	509,618	625,452	353,082
Louisiana	174,618	234,150	788,601	891,686	852,089	871,513	717,827
Maine	188,346	237,294	231,990	219,252	159,766	149,700	40,300
Maryland	197,367	274,387	277,978	270,055	233,341	233,054	164,155
Massachusetts	373,918	490,080	485,089	477,588	421,468	395,957	251,978
Michigan	835,239	1,032,679	1,064,816	1,089,297	1,023,883	973,878	664,506
Minnesota	187,806	266,440	313,758	318,039	267,975	241,145	154,767

Table 1.1 Number of Enrollees in private health insurance as reported by Truven Health MarketScan, 2009-2015 (continued)

Mississippi	255,014	312,994	335,583	339,738	300,521	296,599	235,647
Missouri	454,549	599,445	645,737	646,509	565,164	515,752	321,931
Montana	121,851	157,568	145,901	161,344	133,170	28,026	17,963
Nebraska	78,999	100,485	97,161	100,065	80,428	71,933	42,669
Nevada	166,398	210,307	206,932	185,650	176,728	172,280	109,484
New Hampshire	136,428	205,330	227,110	232,663	173,587	159,433	48,604
New Jersey	461,781	630,674	680,780	706,276	639,829	604,052	385,634
New Mexico	292,595	364,833	380,638	376,821	219,249	216,814	167,374
New York	1,149,976	1,766,580	2,533,673	2,615,506	2,588,323	2,423,923	1,459,784
North Carolina	451,493	1,040,323	1,119,436	1,132,361	606,676	606,527	379,079
North Dakota	14,788	20,230	25,924	27,861	18,246	15,879	9,802
Ohio	984,151	1,463,913	1,632,696	1,686,670	1,515,439	1,386,430	709,264
Oklahoma	406,763	498,047	466,663	475,685	181,032	265,543	221,448
Oregon	217,546	290,170	306,737	361,086	322,893	312,843	240,431
Pennsylvania	1,940,868	2,340,134	2,404,040	2,245,836	891,886	878,648	595,991
Rhode Island	53,063	68,059	69,489	68,338	52,755	52,750	27,738
South Carolina	761,135	949,359	1,001,117	1,005,774	941,084	992,841	807,040
South Dakota	22,467	31,371	35,228	38,748	29,801	29,936	19,346
Tennessee	489,166	653,840	711,549	728,482	642,352	594,600	444,280
Texas	2,586,423	3,257,147	3,422,780	3,471,734	1,665,610	1,642,708	1,211,750
Utah	72,091	169,399	194,893	208,281	189,662	189,375	141,682
Vermont	19,666	26,274	26,832	27,025	19,051	17,792	10,521

Table 1.1 Number of Enrollees in private health insurance as reported by Truven Health MarketScan, 2009-2015 (continued)

Virginia	368,806	990,664	592,006	623,726	527,686	515,299	318,481
Washington	307,222	412,699	465,120	577,225	520,721	499,338	348,132
West Virginia	244,080	312,617	328,756	304,880	94,029	83,907	39,207
Wisconsin	301,425	462,039	516,027	539,582	460,517	444,215	255,402
Wyoming	24,647	31,134	34,908	39,683	25,953	21,334	13,699

Source: Truven Health MarketScan Commercial Claims and Encounters Database.

1.4.2 Variable Measurement

My main outcome is monthly morphine milligram equivalents (MME) [3,4] per enrollee. MME is the most commonly used and best available way to standardize prescription opioids according to the formulation, strength, and dosage.

I identified opioid prescriptions based on Medispan Generic Product Identifiers (GPI).[5] I tracked each prescription back to seven days prior to its fill date to link the prescription to at least one diagnosis. I excluded prescriptions prescribed for the patients in hospice or palliative care (ICD-9: V66.7 and ICD-10: Z51.5), with cancer diagnosis (ICD-9: 140-239.90 and ICD-10: C00-C97),[6] and with missing diagnoses (no diagnosis recorded in the seven days prior to the prescription fill date). I also excluded buprenorphine prescriptions that are commonly prescribed for medication-assisted treatment of opioid addiction (e.g. Wen et al., 2017).

I further studied MME per enrollee separately by age groups (i.e., aged 18 to 24, 25 to 34, 35 to 44, 45 to 54 and 55 to 64) to investigate the potential policy heterogeneity.

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[3] See https://www.cdc.gov/drugoverdose/data-files/SAScodetouseMMEconvsnfileSept2017.sas

[4] Based on the CDC oral MME conversion factors, I converted the strengths of prescription opioids to MME in three steps. First, I multiplied the unit strength of a prescription opioid by the number of units; second, I multiplied the total strength obtained in the first step by the MME conversion factor; third, I added up the total MME by month for each state.

[5] See http://www.wolterskluwercdi.com/drug-data/why-medispan/?leadsource=2052522&gclid=EAIaIQobChMI9diL8LqX2wIVQb7ACh3CWQA5EAAYAiAAEgI0sfD_BwE

[6] The Centers for Disease Prevention and Control (CDC) exempts hospice, palliative care or cancer treatment which often involve intense or prolonged treatment for pain from its guidelines for opioid prescribing (CDC, 2016). Opioid use in non-cancer conditions is more likely to be subject to abuse or misuse. The current opioid crisis is largely caused by the use of opioids in the treatment of non-cancer pain (e.g. Edlund et al., 2010; Kolodny et al., 2015).

MME per enrollee in each age group is calculated as the total MME prescribed in an age group divided by the total number of enrollees in that age group.

I also looked into the sources of changes in MME (i.e., extensive margin vs. intensive margin). Considering that prescription opioids are primarily used in pain management, while off-label drug use is also a common practice in the U.S., I estimated the effects of MMLs and RMLs in pain patients and non-pain patients separately. I identified pain patients based on ICD-9 or ICD-10 codes and included all diagnoses likely to be associated with chronic or acute pain conditions (Mack et al., 2015; Narayana et al., 2015; CDC, 2013; Ilgen et al., 2013). To explore the intensive margin (i.e., MME prescribed to each patient) and extensive margin (the number of patients prescribed opioids) of the changes in MME per enrollee, I studied the following four additional outcomes: MME per pain patient prescribed opioids, MME per non-pain patient prescribed opioids, the number of pain patients prescribed opioids per 1,000 enrollees, and the number of non-pain patients prescribed opioids per 1,000 enrollees.

The key independent variables are the implementation of a medical marijuana law and the implementation of a recreational marijuana law in a given state during a given month. I defined a medical marijuana law in a state to be in effect if the state provides legal protection for patients who possess or use marijuana for medical purposes based on their physicians' recommendations complying with the law and for physicians who recommend medical marijuana to their patients complying with the law. I defined a recreational marijuana law in a state to be in effect if the state provides legal protection for adults who possess or use marijuana for non-medical purposes complying with the law.[7] Please see Tables 1.2 and 1.3 for detailed policy summaries of medical and recreational marijuana laws.

[7] Although most MML and RML states did not have home cultivation rules and legal dispensaries when the legal protection was in place, patients may obtain marijuana through illegal home cultivation or black market purchase (Murphy, 2019).

Table 1.2 State medical marijuana law effective dates (as of December 31st, 2017)

State	Effective date	Data source
Alaska	1999/03	PDAPS.org
Arizona	**2011/04**	PDAPS.org
Arkansas	2016/11	PDAPS.org
California	1996/11	PDAPS.org
Colorado	2001/06	ProCon.org
Connecticut	**2012/06**[a]	PDAPS.org
Delaware	**2011/07**	PDAPS.org
Florida	2017/01	PDAPS.org
Hawaii	2000/06	PDAPS.org
Illinois	**2014/01**	PDAPS.org
Louisiana	2016/08	ProCon.org
Maine	1999/12	PDAPS.org
Maryland	**2014/06**	ProCon.org
Massachusetts	**2013/01**	PDAPS.org
Michigan	2008/12	PDAPS.org
Minnesota	**2014/06**[a]	PDAPS.org
Montana	2004/11	PDAPS.org
Nevada	2001/10	PDAPS.org
New Hampshire	**2013/07**	PDAPS.org
New Jersey	**2010/10**	PDAPS.org
New Mexico	2007/07	PDAPS.org
New York	**2014/07**	PDAPS.org
North Dakota	2016/12 to 2017/01[b]	PDAPS.org
Ohio	2016/09	PDAPS.org
Oregon	1998/12	PDAPS.org
Pennsylvania	2016/05	PDAPS.org
Rhode Island	2006/01	PDAPS.org
Vermont	2004/07	PDAPS.org

Table 1.2 State medical marijuana law effective dates (as of December 31st, 2017) (continued)

Washington	1998/12	PDAPS.org
West Virginia	2017/04	ProCon.org

Sources: Prescription Drug Abuse Policy System (PDAPS, 2017) and ProCon.org (2019)

Notes: [a] Connecticut and Minnesota had MML in effect at the end of the months, so the effective month is the next month.
[b] North Dakota had MML effective for less than a month, and then put MML on hold.

Table 1.3 State recreational marijuana law effective dates (as of December 31st, 2017)

State	Effective date	Data source
Alaska	**2015/02**	APIS
California	2016/11	APIS
Colorado	**2012/12**	APIS
Maine	2017/01	APIS
Massachusetts	2016/12	APIS
Nevada	2017/01	APIS
Oregon	**2015/07**	APIS
Washington	**2012/12**	APIS

Sources: Alcohol Policy Information System (APIS, 2019).

State-level time-varying covariates include concurrent polices (i.e., state prescription drug monitoring programs and mandates, and pain clinic laws), general economy indicators (i.e., unemployment rate, median household income, and poverty rate), other health-related measures (i.e., primary care physician supply and binge drinking rate), and state population. Please see Table 1.4 for the descriptive summary of the study variables.

Table 1.4 Descriptive summary of opioid prescribing outcome variable, policy indicators and other covariates

Opioid prescribing outcome variables	Mean (S.D.) / Proportion
MME per enrollee	32.442 (36.834)
MME per enrollee aged 18-24	5.462 (0.094)
MME per enrollee aged 25-34	16.482 (0.441)
MME per enrollee aged 35-44	31.234 (0.480)
MME per enrollee aged 45-54	51.119 (0.851)
MME per enrollee aged 55-64	55.852 (1.024)
MME per pain patient prescribed opioids	1399.965 (22.664)
MME per non-pain patient prescribed opioids	1672.112 (29.799)
# Pain patients prescribed opioids per 1,000 enrollees	21.419 (0.095)
# Non-pain patients prescribed opioid per 1,000 enrollees	8.591 (0.040)
Policy indicators	
Medical marijuana law in effect 0/1	0.346
Recreational marijuana law in effect 0/1	0.022
The physical availability of medical marijuana 0/1	0.220
The physical availability of recreational marijuana 0/1	0.014
Other covariates	
PDMP 0/1	0.835
PDMP mandate 0/1	0.064
Pain clinic law 0/1	0.120
$ Median household income ($10,000s)	5.220 (0.878)
% Poverty rate	13.825 (3.374)
% Unemployment rate	7.135 (2.153)
% Binge drinkers	16.321 (3.248)
# Primary care physicians (per 100,000 population)	119.203 (26.230)
# State population (1,000,000s)	6.266 (6.933)

Sources: Prescription Drug Abuse Policy System (PDAPS, 2017), ProCon.org (2018), ProCon.org (2019), Alcohol Policy Information System (APIS, 2019), Bradford and Bradford (2017) and Multiple Media Outlets (Table 1.5).

Table 1.5 Supplemental Data Sources

Data	Sources	Links
Medical marijuana dispensary opening dates	Portland Press Herald	http://www.pressherald.com/2011/03/09/all-abuzz-maine-dispensary-set-to-sell-pot_2011-03-09/
	The Republican	http://www.masslive.com/business-news/index.ssf/2015/06/massachusetts_first_medical_marijuana_di.html
	Michigan Radio	http://michiganradio.org/post/timeline-short-history-michigans-medical-marijuana-law
	Reuters	https://www.reuters.com/article/us-oregon-potcafe/first-u-s-marijuana-cafe-opens-in-portland-idUSTRE5AD06O20091114
	Marijuana Doctors	https://www.marijuanadoctors.com/medical-marijuana/RI/state-laws
	Brattleboro Reformer	http://www.reformer.com/stories/2-medical-marijuana-dispensaries-open-in-vt,379379
RML home cultivation rules and first recreational marijuana dispensary opening dates	New York Post	https://nypost.com/2015/02/24/alaska-is-3rd-state-to-legalize-recreational-marijuana/
	Time	http://time.com/4565438/california-marijuana-faq-rules-prop-64/
	Ballotpedia	https://ballotpedia.org/Colorado_Marijuana_Legalization_Initiative,_Amendment_64_(2012)
	Ballotpedia	https://ballotpedia.org/Washington_Marijuana_Legalization_and_Regulation,_Initiative_502_(2012)
	Business Insider	http://www.businessinsider.com/where-can-you-legally-smoke-weed-2017-1
	Maine State Legislature	https://legislature.maine.gov/9419
	Leafly	https://www.leafly.com/news/politics/legalization-nevada-heres-happens-next
	Oregon.gov	http://www.oregon.gov/olcc/marijuana/pages/faqs-personal-use.aspx
	Huffington Post	https://www.huffingtonpost.com/2013/11/21/worlds-first-recreational_n_4317190.html

Table 1.5 Supplemental Data Sources (continued)

RML home cultivation rules and first recreational marijuana dispensary opening dates	CBS News	https://www.cbsnews.com/pictures/recreational-pot-dispensaries-open-in-washington/
	KATU News	http://katu.com/news/local/this-dispensary-just-became-oregons-first-licensed-recreational-pot-retailer
	Westword	http://www.westword.com/marijuana/alaska-opens-its-first-recreational-dispensary-8473631
	Anchorage Daily News	https://www.adn.com/alaska-news/2016/07/29/heres-how-many-cannabis-plants-alaskans-can-now-legally-possess-at-home/
	I love growing marijuana	http://www.ilovegrowingmarijuana.com/growing-marijuana-nevada/
	The Oregonian	http://www.oregonlive.com/marijuana/index.ssf/2016/09/recreational_marijuana_sales_i.html
Pain clinic laws	Alabama Board of Medical Examiners	https://www.albme.org/Documents/Rules/Temp/540-X-19%20eff%204-16-2014.pdf
	Miami Herald	http://www.miamiherald.com/news/health-care/article31685432.html
	Lexology	https://www.lexology.com/library/detail.aspx?g=87d871bb-7364-4cca-bcda-a6423bfa836b
	Indiana State Medical Association	http://scope.medicine.iu.edu/files/documents/ResponsiblePrescribingRedefiningtheStandardsofCare.pdf
	McBrayer, McGinnis, Leslie & Kirkland, PLLC	http://www.mmlk.com/blogs-Healthcare-Law-Blog,prescribers-beware-kentucky-enacts-pain-clinic-and-controlled-substances-legislation
	Centers for Disease Control and Prevention	https://www.cdc.gov/phlp/docs/menu-pmcr.pdf
	Justia	https://law.justia.com/codes/louisiana/2006/48/321411.html

Table 1.5 Supplemental Data Sources (continued)

Pain clinic laws	Mississippi Secretary of State	http://www.sos.ms.gov/acproposed/00019152b.pdf
	Ohio.gov	http://codes.ohio.gov/oac/4731-29
	Tennessee Med	http://www.omagdigital.com/display_article.php?id=876174
	Texas Medical Board	http://www.tmb.state.tx.us/page/pain-management-clinics-with-disciplinary-action
	Jackson Kelly PLLC	http://healthlawmonitor.jacksonkelly.com/2012/04/west-virginia-legislature-enacts-comprehensive-substance-abuse-laws.html
The number of primary care physicians	The United Health Foundation	https://www.americashealthrankings.org/explore/2015-annual-report/measure/PCP/state/ALL
The percentage of binge drinkers	CDC Behavioral Risk Factor Surveillance System (BRFSS)	https://www.cdc.gov/brfss/brfssprevalence/
State population and median household income	U.S. Census Bureau	https://www.census.gov/
Unemployment rate	Bureau of Labor Statistics (BLS)	https://www.bls.gov/home.htm
Poverty rate	Current Population Survey (CPS)	https://www.census.gov/topics/income-poverty/poverty/data/tables/cps.2009.html

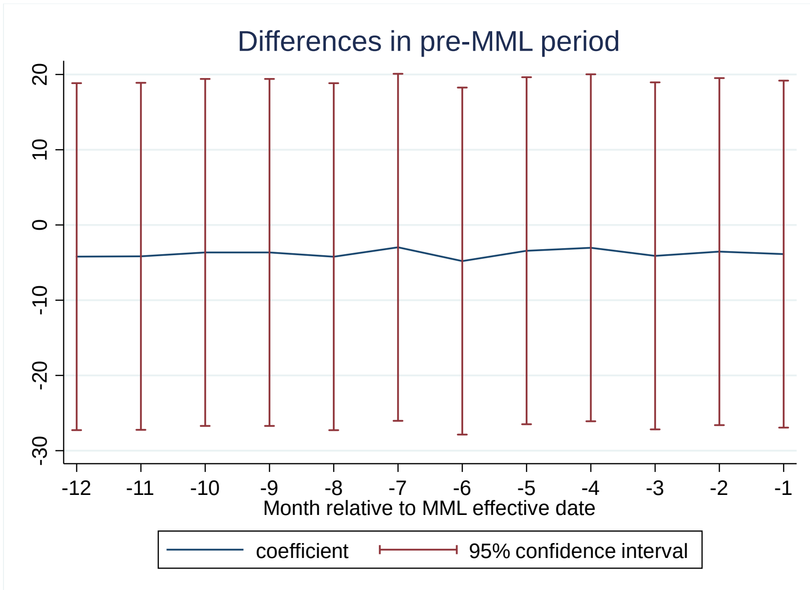
1.4.3 Analytic Strategies

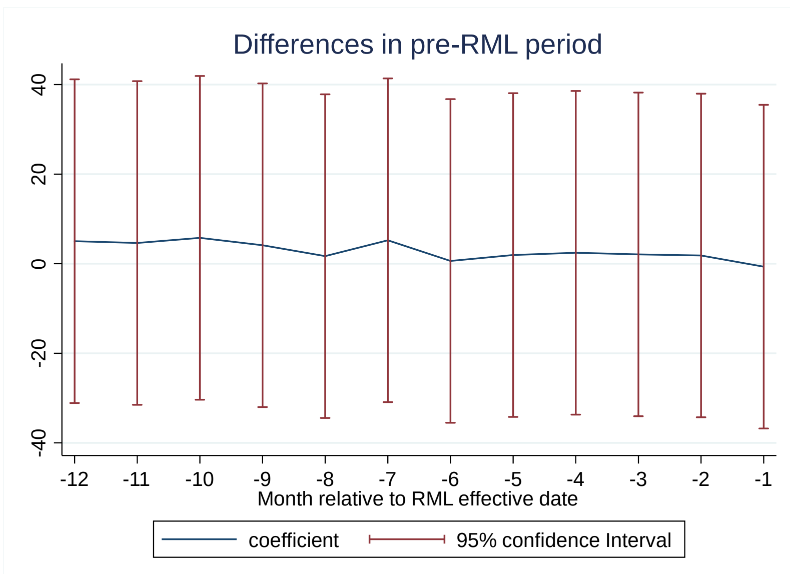
To estimate the effects of medical and recreational marijuana laws on opioid prescribing, I used a differences-in-differences (DD) approach, operationalized through a two-way fixed-effects model:

$$\boldsymbol{Y}_{s.t} = \beta_0 + \beta_1 mml_{s,t} + \beta_2 rml_{s,t} + \gamma \boldsymbol{X}_{s,t} + \delta_s + \eta_t + \theta_{s,t} + \varepsilon_{s,t},$$

where *s* denotes a state and *t* denotes a month in a year. $\boldsymbol{Y}_{s,t}$ represents the opioid-related outcomes. $mml_{s,t}$ and $rml_{s,t}$ are the DD indicators for state implementation of MMLs and RMLs. $\boldsymbol{X}_{s,t}$ is a vector of state-level covariates. I included state fixed effects δ_s and year-month fixed effects η_t to account for the unobserved time-invariant state heterogeneity and the national secular trend and common shocks in opioid prescribing. I also included state-specific linear time trends $\theta_{s,t}$ to account for state-wide confounding factors that evolve at a constant rate over time**.** Test results in Figure 1.2 confirms the parallel-trend assumption regarding my policy indicators—that is, in the pre-policy period, changes in MME per enrollee in policy states overtime are not different from those in control states.

Figure 1.2 Differences in MME per enrollee between policy states and control states in pre-policy period





Notes: Estimates in all figures are simultaneously estimated. The year-month fixed effect was controlled for all estimations. To estimate the recreational marijuana law pre-trend, the implementation of medical marijuana laws was also controlled for as recreational marijuana laws were adopted after the adoption of medical marijuana laws.

1.5 Results

1.5.1 Estimated effects of medical and recreational marijuana laws on MME per enrollee

State implementation of medical and recreational marijuana laws was associated with reductions in MME per enrollee (Table 1.6; Table 1.7). Specifically, the implementation of MMLs was associated with a reduction of 2.41 MME per enrollee, which can be translated to a 7% relative reduction. The implementation of RMLs was associated with a reduction of 4.43 MME per enrollee, equivalent to a 13% relative reduction.

Table 1.6 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on MME per enrollee

Marginal effect	MME per enrollee
MML in effect	**-2.41****
	(0.80)
RML in effect	**-4.43****
	(1.47)
Baseline predicted mean	33.37
# Observations	4,200
R-squared	0.80

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: * 5 percent; ** 1 percent; *** 0.1 percent. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982). Baseline predicted mean was calculated as the average of predicted values when setting $mml_{i,t}$ and $rml_{i,t}$ to 0, and leaving the other covariates as the observed values.

Table 1.7 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on MME per enrollee (effects of covariates reported)

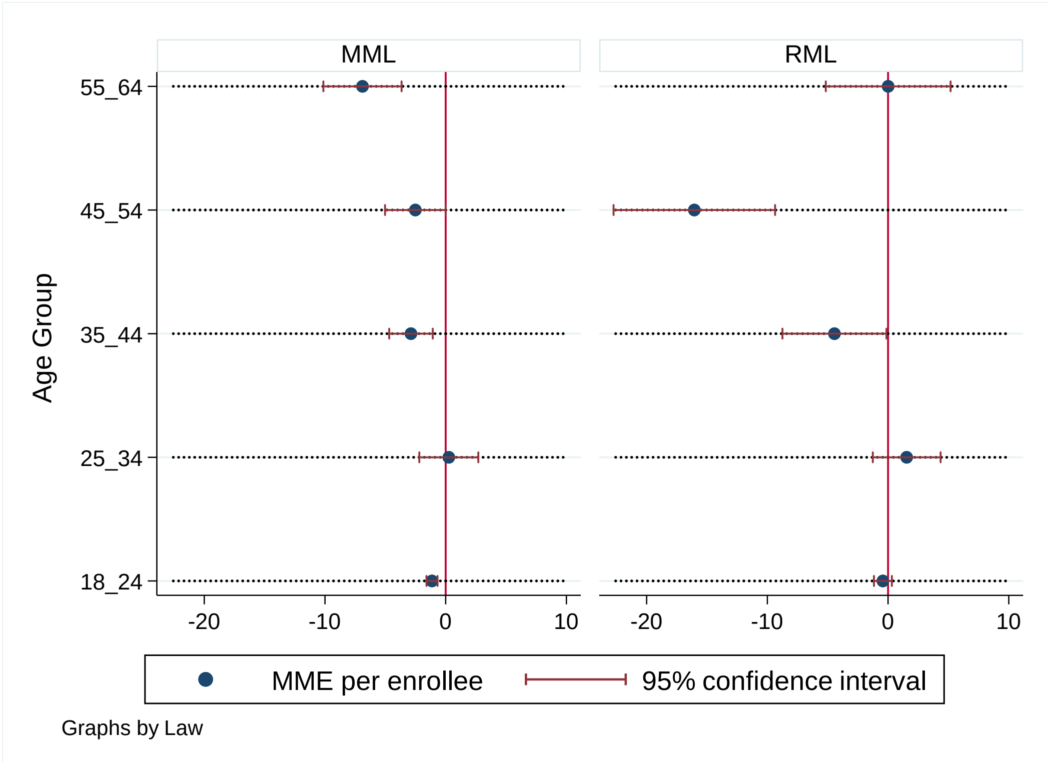
Marginal effects	MME per enrollee
MML in effect 0/1	**-2.41****
	(0.80)
RML in effect 0/1	**-4.43****
	(1.47)
Baseline predicted mean	33.37
PDMP 0/1	**4.31*****
	(1.11)
PDMP mandate 0/1	2.59
	(1.68)
Pain clinic law 0/1	**-21.72*****
	(2.97)
$ Median household income ($10,000s)	**-10.64****
	(3.56)
% Poverty rate	**1.21*****
	(0.29)
% Unemployment rate	**2.03*****
	(0.60)
% Binge drinkers	**0.76****
	(0.29)
# Primary care physicians (per 100,000 population)	-0.04
	(0.17)
# State population (1,000,000s)	6.48
	(7.11)
# Observations	4,200
R-squared	0.80

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** $p<0.05$; ****** $p<0.01$; ******* $p<0.001$. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982). Baseline predicted mean was calculated as the average of predicted values when setting $mml_{i,t}$ and $rml_{i,t}$ to 0, and leaving the other covariates as the observed values.

1.5.2 Heterogeneity of estimated effects of medical and recreational marijuana laws in different age groups

When examining the changes in MME per enrollee across age groups (Figure 1.3; Table 1.8), I found that the reduction associated with MMLs was concentrated in the age 55-64 group, whereas the reduction associated with RMLs was concentrated in the age 35-44 and 45-54 groups.

Figure 1.3 The effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on MME per enrollee in different age groups



Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: 95% confidence intervals were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982). Baseline predicted mean is calculated as the average of predicted values when setting $mml_{i,t}$ and $rml_{i,t}$ to 0, and leaving the other covariates as the observed values.

Table 1.8 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on MME per enrollee in multiple age groups

Marginal effects	MME per enrollee aged 18-24	MME per enrollee aged 25-34	MME per enrollee aged 35-44	MME per enrolled aged 45-54	MME per enrollee aged 55-64
MML in effect 0/1	**-1.14*** **	0.26	**-2.88** **	**-2.51* **	**-6.89*** **
	(0.23)	(1.25)	(0.92)	(1.28)	(1.65)
RML in effect 0/1	-0.43	1.54	**-4.44* **	**-16.05*** **	0.01
	(0.38)	(1.43)	(2.20)	(3.41)	(2.64)
Baseline predicted mean	5.86	16.36	32.33	52.34	58.24
PDMP 0/1	**1.05*** **	**4.08*** **	**2.97** **	**4.20* **	**8.62*** **
	(0.27)	(1.15)	(1.14)	(1.68)	(2.38)
PDMP mandate 0/1	0.31	0.99	1.07	**9.62* **	**5.24* **
	(0.26)	(1.16)	(1.21)	(4.14)	(2.18)
Pain clinic law 0/1	**-3.41*** **	**-13.98*** **	**-15.79*** **	**-28.99*** **	**-39.57*** **
	(0.55)	(1.96)	(2.25)	(4.02)	(5.40)
$ Median household income	**-2.88** **	**-10.78* **	2.34	**-17.78** **	**-21.93*** **
($10,000s)	(0.95)	(4.70)	(3.85)	(6.06)	(6.81)
% Poverty rate	**0.27*** **	**0.97** **	**0.95*** **	**2.01*** **	**2.10*** **
	(0.05)	(0.32)	(0.27)	(0.44)	(0.55)
% Unemployment rate	-0.02	0.29	-1.07	**2.41* **	1.41
	(0.14)	(0.69)	(0.65)	(1.18)	(1.16)
% Binge drinkers	0.03	-0.06	0.33	0.50	**1.17* **
	(0.07)	(0.36)	(0.27)	(0.51)	(0.53)
# Primary care physicians	**0.11* **	-0.12	-0.22	-0.95	-0.44
(per 100,000 population)	(0.04)	(0.19)	(0.25)	(0.52)	(0.36)
# State population	0.02	-4.24	**-15.16** **	-17.61	**39.99* **
(1,000,000s)	(1.16)	(4.27)	(5.49)	(10.58)	(16.09)
# Observations	4,200	4,200	4,200	4,200	4,200
R-squared	0.64	0.30	0.74	0.75	0.78

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** p<0.05; ****** p<0.01; ******* p<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982). Baseline predicted mean was calculated as the average of predicted values when setting $mml_{i,t}$ and $rml_{i,t}$ to 0, and leaving the other covariates as the observed values.

1.5.3 Sources of changes in MME per enrollee

In patients with chronic or acute pain conditions, medical and recreational marijuana laws were shown to reduce MME per enrollee through reducing both MME per pain patient prescribed opioids (intensive margin) and the number of pain patients prescribed opioids per 1,000 enrollees (extensive margin) (Table 1.9; Table 1.10). In addition to the policy effects in pain patients, the implementation of MMLs was associated with a reduction in MME per non-pain patient prescribed opioids but not the number of non-pain patients prescribed opioids per 1,000 enrollees. In comparison, the implementation of RMLs was associated with a reduction in the number of non-pain patients prescribed opioids per 1,000 enrollees while not MME per non-pain patient prescribed opioids.

Table 1.9 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on opioid outcomes

Marginal effects	MME per pain patient prescribed opioids	MME per non-pain patient prescribed opioids	# Pain patients prescribed opioids per 1,000 enrollees	# Non-pain patients prescribed opioids per 1,000 enrollees
MML in effect	**-96.19****	**-159.72*****	**-0.23****	0.03
	(34.67)	(44.20)	(0.09)	(0.06)
RML in effect	**-149.25***	-88.95	**-1.37*****	**-0.83*****
	(64.64)	(88.61)	(0.22)	(0.15)
Baseline predicted mean	1436.52	1729.37	12.94	8.60
# Observations	4,200	4,200	4,200	4,200
R-squared	0.80	0.73	0.94	0.93

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: * 5 percent; ** 1 percent; *** 0.1 percent. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982). Baseline predicted mean was calculated as the average of predicted values when setting $mml_{i,t}$ and $rml_{i,t}$ to 0, and leaving the other covariates as the observed values.

Table 1.10 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on opioid prescribing outcomes for pain and non-pain patients (effects of covariates reported)

Marginal effects	MME per pain patient prescribed opioids	MME per non-pain patients prescribed opioids	# Pain patients prescribed opioids per 1,000 enrollees	# Non-pain patients prescribed opioid per 1,000 enrollees
MML in effect 0/1	**-96.19****	**-159.72*****	**-0.23****	0.03
	(34.67)	(44.20)	(0.09)	(0.06)
RML in effect 0/1	**-149.25***	-88.95	**-1.37*****	**-0.83*****
	(64.64)	(88.61)	(0.22)	(0.15)
Baseline predicted mean	1436.52	1729.37	12.94	8.60
PDMP 0/1	47.41	109.99	**0.81*****	**0.56*****
	(47.43)	(63.55)	(0.09)	(0.07)
PDMP mandate 0/1	-16.79	400.75*	-0.04	0.08
	(54.59)	(188.07)	(0.14)	(0.10)
Pain clinic law 0/1	**-777.10*****	**-1151.39*****	-0.11	**-0.34*****
	(115.45)	(158.24)	(0.11)	(0.09)
$ Median household income	-253.61	-161.46	**-1.45*****	**-1.30*****
($10,000s)	(148.15)	(204.15)	(0.32)	(0.23)
% Poverty rate	**35.27*****	**59.60*****	0.01	0.02
	(10.28)	(14.13)	(0.02)	(0.01)
% Unemployment rate	**61.33***	**79.90***	0.04	0.02
	(24.11)	(33.25)	(0.04)	(0.03)
% Binge drinkers	**43.64*****	**52.66*****	**-0.06****	**-0.05****
	(10.45)	(15.80)	(0.02)	(0.02)
# Primary care physicians	-2.81	-1.74	**-0.07*****	**-0.05*****
(per 100,000 population)	(8.18)	(11.00)	(0.01)	(0.01)
# State population	259.43	**855.98***	-0.04	-0.33
(1,000,000s)	(297.00)	(435.74)	(0.47)	(0.40)
# Observations	4,200	4,200	4,200	4,200
R-squared	0.80	0.73	0.94	0.93

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** p<0.05; ****** p<0.01; ******* p<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982). Baseline predicted mean was calculated as the average of predicted values when setting $mml_{i,t}$ and $rml_{i,t}$ to 0, and leaving the other covariates as the observed values.

1.6 Robustness Checks

1.6.1 Event study

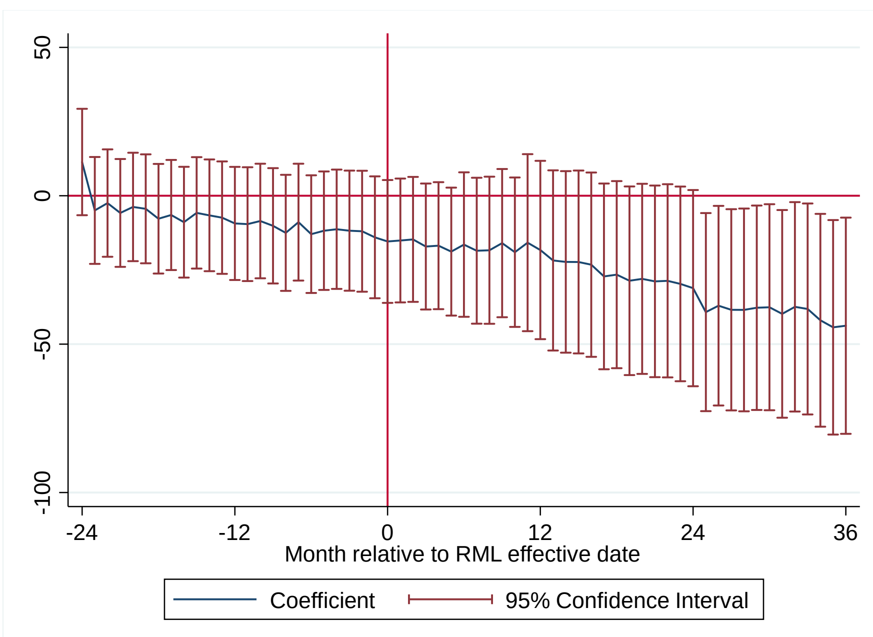
An event analysis with lag and lead policy indicators allows us to estimate the differential effects of MMLs and RMLs on the basis of the current month relative to the effective date (Model, 1993) (Figure 1.4).

I discerned no pre-policy difference in MME per enrollee between states with and without marijuana laws, which lends weight to the parallel-trend assumption of the DD approach. After medical and recreational marijuana laws taking effect, I observed immediate and sustained policy effects on MME per enrollee. The lagged effects of MMLs, however, appeared to have more variations than those of RMLs.

Figure 1.4 Pre- and post-trend in MME per enrollee in policy states relative to the control states

Pre- and Post-MML

Pre- and post-RML



Source: Truven Health MarketScan Commercial Claims and Encounters Database.
Notes: Estimates were simultaneously estimated in each model, controlling for state-level covariates, state fixed effects, year-month fixed effects, and state-specific linear time trends.

1.6.2 State-specific policy effects

The effects of medical and recreational marijuana laws on MME per enrollee varied across states, with some of the largest reductions in Colorado and Oregon (two of the RML states), as well as Maryland and Delaware (two of the MML states) (Table 1.11; Table 1.12). The state-specific policy effects were not precisely estimated in other MML and RML states. Note that the point estimate for the implementation of MML in New York was positive, albeit not significant. An explanation could be that the law in New York that took effect in July 2014 only allowed medical marijuana to be used to treat pain associated with debilitating or life-threatening conditions but not pain associated with severe or chronic conditions as approved by most other state medical marijuana laws (Assembly bill 6357).[8] Nonetheless, Governor Andrew Cuomo signed another bill into law in September, 2018, including pain as a qualifying condition for medical marijuana use.[9]

The state-specific policy effects on MME per pain and non-pain patient prescribed opioids were overall consistent with those on MME per enrollee. However, the reductions for both pain and non-pain subgroups were significant in Connecticut, while the reductions for both pain and non-pain subgroups in Delaware and the reduction for the non-pain subgroup in Oregon were not precisely estimated.

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[8] See https://medicalmarijuana.procon.org/sourcefiles/new-york-ab-6357-2013.pdf
[9] See https://www.governor.ny.gov/news/governor-cuomo-signs-bill-adding-pain-management-list-eligible-conditions-treatment-medical

Table 1.11 State-specific policy effects on MME per enrollee

Marginal effects	MME per enrollee	MME per pain patient prescribed opioids	MME per non-pain patient prescribed opioids
<u>MML states</u>			
~ Arizona	-19.47	-779.29	-652.20
	(9.97)	(409.61)	(554.38)
~ Connecticut	-16.04	**-711.89***	-481.99
	(8.10)	(318.94)	(469.95)
~ Delaware	**-15.53***	-381.81	-369.92
	(5.96)	(208.85)	(289.35)
~ Illinois	-16.26	-865.24	-658.98
	(11.62)	(448.97)	(629.02)
~ Maryland	**-21.91*** **	**-704.14****	**-805.49****
	(6.20)	(218.03)	(286.72)
~ Massachusetts	-13.56	-776.25	-254.92
	(10.21)	(453.96)	(554.47)
~ Minnesota	-9.58	-258.40	-93.94
	(8.65)	(306.38)	(434.21)
~ New Hampshire	-8.48	-492.01	-241.52
	(8.24)	(299.99)	(418.96)
~ New Jersey	1.46	13.15	30.06
	(6.91)	(266.09)	(342.05)
~ New York	9.84	73.12	465.91
	(5.04)	(222.90)	(242.34)
<u>RML states</u>			
~ Alaska	-12.55	-260.36	-268.47
	(6.27)	(205.73)	(257.26)
~ Colorado	**-22.42****	-1,003.33**	-917.66*
	(7.70)	(306.63)	(436.83)
~ Oregon	**-21.83***	-954.51*	-950.68
	(10.84)	(406.18)	(554.83)
~ Washington	-4.55	-284.81	-284.60
	(3.55)	(160.89)	(200.30)
# Observations	4,200	4,200	4,200
R-squared	0.56	0.57	0.47

Source: Truven Health MarketScan Commercial Claims and Encounters Database.
Notes: * 5 percent; ** 1 percent; *** 0.1 percent. Standard errors in parentheses were clustered at the state level. Estimates were simultaneously estimated in each model, controlling for state-level covariates, state fixed effects and year-month fixed effects.

Table 1.12 Results for covariates in model estimating state-specific policy effects on MME per enrollee (effects of covariates reported)

Marginal effects	MME per enrollee
PDMP 0/1	**-10.69*** **
	(6.73)
PDMP mandate 0/1	-16.78
	(9.93)
Pain clinic law 0/1	6.91
	(10.78)
$ Median household income	**3.12**
($10,000s)	(16.35)
% Poverty rate	0.87
	(0.78)
% Unemployment rate	-1.28
	(3.14)
% Binge drinkers	-0.31
	(1.18)
# Primary care physicians	0.71
(per 100,000 population)	(1.13)
# State population	-6.74
(1,000,000s)	(10.74)
# Observations	4,200
R-squared	0.56

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: * 5 percent; ** 1 percent; *** 0.1 percent. Standard errors in parentheses clustered at the state level.

1.6.3 Effects of the physical availability

A medical or recreational marijuana law taking effect does not necessarily mean that the targeted population immediately have legal access to marijuana if the law only protects marijuana use but not commercial production, sales or home cultivation.[10]

In the main model, I defined a medical or recreational marijuana law to be in effect as long as the law provides legal protection for marijuana users. Here I define a medical or recreational marijuana law to be in effect if (1) a law or agency rule explicitly allowing medical or recreational marijuana home cultivation has been in effect for at least 2 months (the minimum time to grow useable marijuana is about eight weeks[11]), or (2) there is at least one active medical or recreational marijuana dispensary, whichever comes first (Tables 1.13 and Table 1.14).

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[10] Nonetheless, anecdotal evidence suggests that even without legal marijuana access, people could grow marijuana at home illegally, or purchase marijuana from the black market. See, for example, https://www.thestranger.com/weed/2018/08/01/29980036/look-at-this-illegal-pot-plant-growing-in-lake-city; https://globalnews.ca/news/4669761/legal-marijuana-black-market/; https://www.coloradoan.com/story/news/2018/12/20/colorado-recreational-marijuana-black-market-cannabis/2369154002/

[11] See http://www.growweedeasy.com/how-long-does-it-take-to-grow-marijuana; https://www.cannabis.info/en/blog/how-much-time-grow-marijuana; and http://www.growweedeasy.com/how-long-does-it-take-to-grow-weed.

Table 1.13 State medical marijuana home cultivation rule, medical marijuana dispensary, and increased medical marijuana accessibility effective dates (as of December 31st, 2017)

State	Home cultivation effective date	First dispensary opening date	Increased accessibility effective date
Alaska	**2010/06**	n/a	**2010/08**
Arizona	**2011/04**	2012/12	**2011/06**
Arkansas	n/a	n/a	n/a
California	2004/01	1996/11	1996/11
Colorado	2011/07	2005/07	2005/07
Connecticut	n/a	**2014/10**	**2014/10**
Delaware	n/a	**2015/06**	**2015/06**
Florida	n/a	2017/06	2017/06
Hawaii	**2011/07**	2017/08	**2011/09**
Illinois	n/a	**2015/11**	**2015/11**
Maine	2013/10	**2011/04**	**2011/04**
Maryland	n/a	2017/12	2017/12
Massachusetts	**2013/05**	2015/07	**2013/07**
Michigan	**2013/04**	n/a[a]	**2013/06**
Minnesota	n/a	**2015/07**	**2015/07**
Montana	**2012/05**	n/a	**2012/07**
Nevada	**2009/07**	2015/08	**2009/09**
New Hampshire	n/a	2016/05	2016/05
New Jersey	n/a	**2012/12**	**2012/12**
New Mexico	2010/12	**2009/03**	**2009/03**
New York	n/a	2016/07	2016/07
North Dakota	n/a	n/a	n/a
Ohio	n/a	n/a	n/a
Oregon	2013/08	**2009/11**	**2009/11**
Pennsylvania	n/a	2018/01	2018/01
Rhode Island	**2012/06**	2013/04	**2012/08**
Vermont	2013/07	**2013/07**[b]	**2013/07**
Washington	**2011/07**	2014/07	**2011/09**
West Virginia	n/a	n/a	n/a

Sources: Prescription Drug Abuse Policy System (PDAPS, 2017), ProCon.org (2019), Bradford and Bradford (2017) and Multiple Media Outlets (Table 1.5)

Notes:

[a] Michigan's MML did not include dispensary registrations. Ever since the first dispensary opened in Michigan, legal battles over the implementation of the law, including the legal status of dispensaries, never stopped. In 2011, the Michigan Court of Appeal found dispensaries in violation of public health provisions; and, in 2013 the Michigan Supreme Court had the similar ruling. As a results, most dispensaries closed following the ruling in 2011. There was no stable legal environment for Michigan patients to shop at a medical dispensary.

[b] The first medical dispensary opened at the end of June,2013 in Vermont, so the effective month is July.

Table 1.14 State recreational marijuana home cultivation rule, recreational marijuana dispensary, and increased recreational marijuana accessibility effective dates (as of December 31st, 2017)

State	Home cultivation effective date	First dispensary opening date	Increased accessibility effective date
Alaska	2016/07	2016/10	2016/09
California	2018/01	2018/01	2018/01
Colorado	**2012/12**	2014/01	**2013/02**
Maine	2016/11	n/a	2017/01
Massachusetts	2016/12	n/a	2017/02
Nevada	2017/01	2017/07	2017/03
Oregon	**2015/07**	2016/10[a] 2015/10[b]	**2015/09**
Washington	n/a	**2014/07**	**2014/07**

Sources: Multiple Media Outlets (Table 1.5)
Notes:
[a] First recreational marijuana retailer opened.
[b] Existing medical retailors were allowed to sell marijuana to recreational users.

I found that the physical availability of recreational marijuana was associated with a reduction of 8.91 MME per enrollee —that is, a 27% relative reduction (Table 1.15; Table 1.16). The effect of the physical availability of recreational marijuana was larger than that of the recreational marijuana law in the main model. However, the physical availability of medical marijuana had no discernable effect on MME per enrollee.

Table 1.15 Effects of legal physical access of medical marijuana and legal physical access of recreational marijuana on MME per enrollee

Marginal effects	MME per enrollee
The physical availability of medical marijuana	0.02 (0.57)
The physical availability of recreational marijuana	**-8.91***** (1.65)
Baseline predicted mean	32.56
# Observations	4,200
R-squared	0.80

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: * 5 percent; ** 1 percent; *** 0.1 percent. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982). Baseline predicted mean was calculated as the average of predicted values when setting legal physical access of medical marijuana in effect and legal physical access of recreational marijuana in effect to 0, and leaving the other covariates as the observed values.

Table 1.16 Effects of the physical availability of medical and recreational marijuana on MME per enrollee

Marginal effects	MME per enrollee
The physical availability of medical marijuana 0/1	0.02
	(0.57)
The physical availability of recreational marijuana 0/1	**-8.91*** **
	(1.65)
Baseline predicted mean	32.56
PDMP 0/1	**3.98*** **
	(1.11)
PDMP mandate 0/1	2.51
	(1.61)
Pain clinic law 0/1	**-21.54*** **
	(2.85)
$ Median household income	**-9.38** **
($10,000s)	(3.62)
% Poverty rate	**1.19*** **
	(0.29)
% Unemployment rate	**2.03*** **
	(0.58)
% Binge drinkers	**0.72* **
	(0.29)
# Primary care physicians	-0.03
(per 100,000 population)	(0.17)
# State population	8.10
(1,000,000s)	(7.17)
# Observations	4,200
R-squared	0.80

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: * 5 percent; ** 1 percent; *** 0.1 percent. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982). Baseline predicted mean was calculated as the average of predicted values when setting MMA in effect and RMA in effect to 0, and leaving the other covariates as the observed values.

1.7 Discussion and conclusions

This study advances our understanding of the impact of both medical and recreational marijuana laws on opioid prescribing in the privately-insured population. I found that the implementation of MMLs was associated with a 7% relative reduction in MME per enrollee and the implementation of RMLs was associated with a 13% relative reduction in MME per enrollee. The reduction associated with MMLs was concentrated in the age 55-64 group, whereas the reduction associated with RMLs was largely in the age 35-44 and 45-54 groups. With respect to the source of reductions, MMLs and RMLs may have lowered MME per enrollee at both intensive and extensive margins for patients with chronic or acute pain conditions. As for non-pain patients, the implementation of MMLs was associated with a reduction at the intensive margin but not extensive margin, while the implementation of RMLs was associated with a reduction at the extensive margin but not at the intensive margin.

Similar effects of MMLs and RMLs on opioid prescribing have been found in Medicaid and Medicare population (Wen & Hockenberry, 2018; Bradford et al., 2018). I also found RMLs were associated with larger reductions in MME than MMLs. The physical availability of recreational marijuana was associated with further reductions in MME beyond the effect of only providing legal protection for recreational marijuana use.

I also observed that RMLs were associated with a significant reduction in the number of non-pain patients prescribed opioids. The majority of primary diagnoses of these non-pain patients were conditions for which opioids were not commonly prescribed, and MML states did not include them in the qualified medical marijuana conditions.

My study further suggests that MMLs and RMLs may directly benefit middle-aged people in the opioid crisis. The reduction in MME per enrollee aged 45 to 54 associated with RMLs was the largest across all age groups, and the economically significant reductions associated with both laws were concentrated in the middle-aged population. Those results were consistent with the studies that found the use of marijuana among middle-aged adults increased significantly from 2006 to 2016 (Han et al., 2017; Han & Palamar, 2018). The increasing use of marijuana by middle-aged people might have steered them away from opioid-related harms.

However, my study has the following limitations. First, due to the nature of my claim data, I was unable to observe the individual drug substitution mechanism. I only have the records of prescribed opioids that were covered by the employer-sponsored insurance. Therefore, I did not know whether those individuals used marijuana or not, or whether those individuals also bought opioids with cash. Thus, my results did not mean to imply causality. It merits future research to explore the mechanisms between marijuana liberalization and changes in opioid prescribing in the privately-insured population.

Second, the differential decline in enrollment, particularly from 2014 to 2015, could potentially bias the results. Therefore, I conducted four additionally robustness checks (Tables 1.17-1.24).[12] My results suggested that the changes in enrollment were unlikely to have biased the results.

[12] First, I limited my data to 2009-2013. The estimates were overall consistent with the main results (Tables 1.17-1.19), albeit smaller in magnitude. This is partly due to the fact that states (i.e., Illinois, Maryland, Minnesota, New York, Alaska, and Oregon) which had MMLs or RMLs in effect after 2013 were excluded. Second, I conducted analyses without states (California, Connecticut, Hawaii, Indiana, Maine, Montana, and New Hampshire) that had noticeable declines in enrollment in 2014 and 2015 (Tables 1.20-1.22). I identified the aforementioned states by calculating the retention rate for each state from 2014 to 2015 as the total enrollment in 2015 divided by the total enrollment in 2014. Then, I calculated the standard deviation of the retention rate, which is 0.15. The distribution of the retention rate is left-skewed with a skewness of -1.00. Therefore, I used three standard deviations, which is 0.45, to identify the low retention rate states. Any state with a retention rate less than 0.45 was considered to have a relatively large decline in disenrollment. The outliers in 2015 were California (0.34), Connecticut (0.30), Hawaii (0.30), Indiana (0.32), Maine (0.27), and New Hampshire (0.30). I did the similar calculation for the retention rate from 2013 to 2014, finding only Montana (0.21) to be an outlier in 2014. After excluding these outlier states, the estimates are consistent with the main results. Third, I used the yearly pain patient ratio among enrollees as the dependent variable and ran the same model (Table 1.23). I found that MMLs and RMLs were not associated with changes in the pain patient ratio in my study period, which suggests that the effects of MMLs and RMLs were not confounded by changes in the pain patient ratio. Forth, I estimated the same model but used the number of enrollees each year as the dependent variable. I did not find any association of MMLs or RMLs with changes in the number of enrollees (Table 1.24). Thus, it is unlikely that the changes in enrollment resulted in spurious correlations.

Table 1.17 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on MME per enrollee between 2009 and 2013

Marginal effects	MME per enrollee
MML in effect 0/1	**-1.44***
	(0.73)
RML in effect 0/1	**-4.16***
	(1.88)
PDMP 0/1	0.04
	(0.69)
PDMP mandate 0/1	**-5.09*****
	(1.10)
Pain clinic law 0/1	0.64
	(0.73)
$ Median household income	**-17.62*****
($10,000s)	(4.16)
% Poverty rate	**0.72****
	(0.26)
% Unemployment rate	0.13
	(0.38)
% Binge drinkers	**-0.73****
	(0.22)
# Primary care physicians	**-0.34***
(per 100,000 population)	(0.17)
# State population	-0.77
(1,000,000s)	(3.52)
# Observations	3,000
R-squared	0.85

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** *p*<0.05; ****** *p*<0.01; ******* *p*<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982).

Table 1.18 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on MME per enrollee in multiple age groups between 2009 and 2013

Marginal effects	MME per enrollee aged 18-24	MME per enrollee aged 25-34	MME per enrollee aged 35-44	MME per enrolled aged 45-54	MME per enrollee aged 55-64
MML in effect 0/1	-0.27	-2.59	-1.16	**-5.73*** **	-2.46
	(0.26)	(1.48)	(0.89)	(1.48)	(1.29)
RML in effect 0/1	-0.36	0.45	**-6.53** **	**-28.97*** **	1.25
	(0.43)	(2.55)	(2.14)	(6.25)	(3.32)
PDMP 0/1	0.25	0.64	0.89	-0.87	3.09
	(0.26)	(1.45)	(1.26)	(1.24)	(1.64)
PDMP mandate 0/1	**-0.72***	-1.40	**-7.63*** **	**-8.75*** **	**-9.83*** **
	(0.28)	(2.34)	(1.34)	(1.86)	(1.89)
Pain clinic law 0/1	-0.05	-0.49	-1.50	-1.58	-0.86
	(0.23)	(1.36)	(0.90)	(1.34)	(1.37)
$ Median household income	**-4.21** **	**-13.98***	1.19	-14.47	**-31.45*** **
($10,000s)	(1.21)	(6.87)	(4.29)	(7.91)	(8.15)
% Poverty rate	**0.16***	0.49	-0.11	0.47	0.28
	(0.07)	(0.59)	(0.28)	(0.48)	(0.51)
% Unemployment rate	**-0.37** **	-0.46	**-1.10***	0.22	0.44
	(0.13)	(0.69)	(0.53)	(1.03)	(0.94)
% Binge drinkers	**-0.20***	-0.81	-0.36	**-0.89***	**-1.05** **
	(0.08)	(0.52)	(0.30)	(0.42)	(0.39)
# Primary care physicians	0.01	**-0.70***	**-1.11*****	**-1.80** **	**-0.93***
(per 100,000 population)	(0.07)	(0.34)	(0.30)	(0.61)	(0.41)
# State population	2.21	-1.65	-1.42	-6.84	4.45
(1,000,000s)	(1.16)	(3.39)	(4.89)	(7.92)	(7.34)
# Observations	3,000	3,000	3,000	3,000	3,000
R-squared	0.66	0.19	0.77	0.81	0.85

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** *p*<0.05; ****** *p*<0.01; ******* *p*<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982).

Table 1.19 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on opioid prescribing outcomes for pain and non-pain patients between 2009 and 2013

Marginal effects	MME per pain patient prescribed opioids	MME per non-pain patients prescribed opioids	# Pain patients prescribed opioids per 1,000 enrollees	# Non-pain patients prescribed opioid per 1,000 enrollees
MML in effect 0/1	-32.76	**-101.01***	0.11	-0.05
	(31.51)	(49.05)	(0.11)	(0.08)
RML in effect 0/1	**-353.89*****	-231.83	-0.27	-0.03
	(84.58)	(134.06)	(0.15)	(0.12)
PDMP 0/1	-46.70	30.90	0.10	-0.03
	(29.57)	(48.55)	(0.11)	(0.08)
PDMP mandate 0/1	**-249.27*****	**-190.52****	**-0.83*****	**-0.74*****
	(51.58)	(70.42)	(0.17)	(0.11)
Pain clinic law 0/1	54.12	28.07	-0.03	-0.11
	(29.96)	(48.08)	(0.10)	(0.09)
$ Median household income	**-514.53****	**-492.24***	**-2.35*****	**-2.25*****
($10,000s)	(168.13)	(232.96)	(0.35)	(0.28)
% Poverty rate	5.65	**34.98***	0.02	0.00
	(10.63)	(16.59)	(0.02)	(0.01)
% Unemployment rate	-24.39	-6.27	0.05	0.05
	(17.38)	(22.40)	(0.05)	(0.04)
% Binge drinkers	-7.14	-17.88	**-0.21*****	**-0.11*****
	(8.33)	(14.11)	(0.03)	(0.02)
# Primary care physicians	-13.91	-19.81	**-0.11*****	**-0.06*****
(per 100,000 population)	(9.84)	(12.38)	(0.02)	(0.01)
# State population	**-347.24***	23.80	**1.15***	0.67
(1,000,000s)	(171.96)	(209.66)	(0.47)	(0.37)
# Observations	3,000	3,000	3,000	3,000
R-squared	0.85	0.75	0.95	0.95

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** *p*<0.05; ****** *p*<0.01; ******* *p*<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982).

Table 1.20 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on MME per enrollee without California, Connecticut, Hawaii, Indiana, Maine, Montana, and New Hampshire

Marginal effects	MME per enrollee
MML in effect 0/1	**-2.57****
	(0.99)
RML in effect 0/1	**-4.04***
	(1.63)
PDMP 0/1	**4.99*****
	(1.37)
PDMP mandate 0/1	2.53
	(1.82)
Pain clinic law 0/1	**-24.49*****
	(3.35)
$ Median household income	**-16.56*****
($10,000s)	(4.47)
% Poverty rate	**1.32*****
	(0.31)
% Unemployment rate	**2.15****
	(0.65)
% Binge drinkers	**1.02****
	(0.33)
# Primary care physicians	0.08
(per 100,000 population)	(0.21)
# State population	9.52
(1,000,000s)	(8.99)
# Observations	3,612
R-squared	0.80

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** p<0.05; ****** p<0.01; ******* p<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982).

Table 1.21 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on MME per enrollee in multiple age groups without California, Connecticut, Hawaii, Indiana, Maine, Montana, and New Hampshire

Marginal effects	MME per enrollee aged 18-24	MME per enrollee aged 25-34	MME per enrollee aged 35-44	MME per enrolled aged 45-54	MME per enrollee aged 55-64
MML in effect 0/1	**-1.29*** **	0.24	**-3.08** **	-2.88	**-7.09** **
	(0.27)	(1.74)	(1.14)	(1.60)	(2.15)
RML in effect 0/1	-0.30	1.83	-4.39	**-16.66*** **	0.29
	(0.41)	(1.77)	(2.36)	(3.67)	(2.92)
PDMP 0/1	**1.00** **	**4.32** **	**3.16***	**5.03***	**9.12** **
	(0.33)	(1.36)	(1.34)	(1.96)	(2.73)
PDMP mandate 0/1	0.26	0.52	-0.14	7.01	3.07
	(0.31)	(1.45)	(1.48)	(4.46)	(2.52)
Pain clinic law 0/1	**-3.81*** **	**-15.26*** **	**-17.94*** **	**-31.74*** **	**-44.41*** **
	(0.64)	(2.31)	(2.48)	(4.27)	(5.81)
$ Median household income	**-3.45** **	**-14.43***	0.89	**-20.41** **	**-29.38** **
($10,000s)	(1.16)	(5.77)	(4.49)	(7.34)	(8.57)
% Poverty rate	**0.31*** **	**1.08** **	**1.08*** **	**1.92*** **	**2.14*** **
	(0.06)	(0.35)	(0.29)	(0.45)	(0.58)
% Unemployment rate	0.07	0.23	-0.85	**2.88***	2.13
	(0.16)	(0.69)	(0.76)	(1.24)	(1.36)
% Binge drinkers	0.09	0.11	**0.82***	**1.76*** **	**2.10*** **
	(0.08)	(0.40)	(0.32)	(0.48)	(0.60)
# Primary care physicians	**0.16** **	**0.18**	0.05	**0.38**	**0.51**
(per 100,000 population)	(0.05)	(0.18)	(0.31)	(0.38)	(0.41)
# State population	0.06	-2.16	**-22.44** **	-16.25	**52.30***
(1,000,000s)	(1.47)	(5.37)	(7.24)	(13.15)	(20.88)
# Observations	3,612	3,612	3,612	3,612	3,612
R-squared	0.63	0.30	0.74	0.76	0.78

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** *p*<0.05; ****** *p*<0.01; ******* *p*<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982).

Table 1.22 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on opioid prescribing outcomes for pain and non-pain patients without California, Connecticut, Hawaii, Indiana, Maine, Montana, and New Hampshire

Marginal effects	MME per pain patient prescribed opioids	MME per non-pain patients prescribed opioids	# Pain patients prescribed opioids per 1,000 enrollees	# Non-pain patients prescribed opioid per 1,000 enrollees
MML in effect 0/1	**-89.55***	**-191.25****	**-0.31****	0.03
	(45.41)	(60.18)	(0.10)	(0.07)
RML in effect 0/1	**-150.73***	-83.98	**-1.19*****	**-0.78*****
	(71.03)	(99.15)	(0.22)	(0.15)
PDMP 0/1	62.23	**172.33***	**0.72*****	**0.44*****
	(56.29)	(74.29)	(0.11)	(0.08)
PDMP mandate 0/1	**-6.86**	**445.88***	**-0.36***	-0.13
	(60.09)	(211.94)	(0.14)	(0.11)
Pain clinic law 0/1	**-878.40*****	**-1267.88*****	**-0.34****	**-0.52*****
	(128.34)	(179.21)	(0.11)	(0.09)
$ Median household income	**-555.70****	-345.92	**-2.02*****	**-1.45*****
($10,000s)	(174.48)	(247.30)	(0.35)	(0.24)
% Poverty rate	**38.33****	**73.15*****	-0.01	-0.00
	(11.40)	(16.06)	(0.02)	(0.01)
% Unemployment rate	**56.50***	**74.20***	0.08	0.05
	(27.51)	(36.50)	(0.05)	(0.03)
% Binge drinkers	**55.60*****	**69.98*****	**-0.09****	**-0.07*****
	(12.39)	(18.83)	(0.03)	(0.02)
# Primary care physicians	-2.13	6.19	**-0.05****	**-0.04****
(per 100,000 population)	(10.47)	(12.37)	(0.02)	(0.01)
# State population	312.39	1189.93	0.23	-0.52
(1,000,000s)	(409.15)	(544.37)	(0.49)	(0.46)
# Observations	3,612	3,612	3,612	3,612
R-squared	0.81	0.74	0.94	0.93

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** *p*<0.05; ****** *p*<0.01; ******* *p*<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982).

Table 1.23 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on yearly pain patient ratio

Marginal effects	Pain Patient Ratio
MML in effect 0/1	0.07
	(0.10)
RML in effect 0/1	0.02
	(0.07)
PDMP 0/1	0.02
	(0.09)
PDMP mandate 0/1	-0.11
	(0.07)
Pain clinic law 0/1	-0.01
	(0.06)
$ Median household income	-0.17
($10,000s)	(0.21)
% Poverty rate	0.02
	(0.01)
% Unemployment rate	0.02
	(0.03)
% Binge drinkers	-0.02
	(0.02)
# Primary care physicians	0.00
(per 100,000 population)	(0.01)
# State population	-0.29
(1,000,000s)	(0.74)
# Observations	350
R-squared	0.66

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** p<0.05; ****** p<0.01; ******* p<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982).

Table 1.24 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on yearly enrollment

Marginal effects	Number of Enrollees
MML in effect 0/1	-83103.92
	(115462.6)
RML in effect 0/1	113451
	(121164.8)
PDMP 0/1	-79335.83
	(65733.68)
PDMP mandate 0/1	13686.83
	(91969.67)
Pain clinic law 0/1	249362.5
	(159246.3)
$ Median household income ($10,000s)	-242582.4
	(275726)
% Poverty rate	-7660.06
	(10032.68)
% Unemployment rate	72283.18
	(53328.17)
% Binge drinkers	-5095.90
	(17088.39)
# Primary care physicians (per 100,000 population)	-8885.27
	(11594.59)
# State population (1,000,000s)	3147661
	(2587824)
# Observations	350
R-squared	0.94

Source: Truven Health MarketScan Commercial Claims and Encounters Database
Notes: ***** p<0.05; ****** p<0.01; ******* p<0.001. Standard errors in parentheses were calculated using bootstrap estimation, because bootstrap estimate standard error does not require distribution assumptions; I set the bootstrap replications to be 1,000 to construct confidence intervals (Efron, 1982).

Third, I also do not know the medical potential of marijuana. Marijuana is still a schedule I drug at the federal level and there was no large-scale clinical trial to investigate its medical use. State medical marijuana laws based on limited clinical evidence suggest its use on certain pain conditions, such as neuropathic pain, due to its analgesic effect in humans (Abrams et al., 2011), which cannot rule out the possibility that medical marijuana can be used to treat other conditions for which opioids were prescribed. More studies, perhaps individual-level surveys, are needed to further discuss the mechanisms of possible opioid and marijuana substitutions among privately insured population.

Moreover, this study does not imply the safety or effectiveness of marijuana in the treatment of pain and non-pain conditions. More research is needed to examine the potential risks and benefits associated with marijuana use.

CHAPTER 2. The Impact of Medical Marijuana Smoking Ban on Emergency Department Visits Related to Marijuana and Opioid Use

2.1 Introduction

Concerning negative health effects associated with smoking, Minnesota, New York, Pennsylvania, Louisiana, Ohio, Florida, West Virginia, and Utah included a provision that bans smoking via the combustion of marijuana plants in their medical marijuana laws. In addition to the smoking ban, Louisiana also banned vaporization. In 2019, Florida reversed its smoking ban to restore the voters' intent to smoke medical marijuana on the original 2016 ballot (ProCon.org, 2019; Gross, 2019).

The public health concern over smoking bans falls on the potential negative health outcomes associated with consuming edible marijuana (Lamy et al., 2016; Reboussin et al., 2019). Oral ingestion of marijuana leads to prolonged absorption so users may overconsume to seek an immediate intoxication effect (Klein, 2017). However, despite the growing number of adverse events related to edible marijuana reported to poison centers and emergency department (ED) visits related to edible marijuana, inhalable marijuana still contribute the majority of marijuana-related ED visits. Inhalable and edible marijuana also contribute to different acute symptoms that may leads to ED visits. ED visits related to inhalable marijuana are largely due to gastrointestinal syndromes (i.e., Cannabinoid hyperemesis[13]) (Galli, Sawaya, & Friedenberg, 2011), while ED visits related to edible marijuana are overwhelmingly due to acute psychiatric, cardiovascular and intoxication symptoms (Monte et al., 2019). In addition, inhalable and edible marijuana may contribute to the risks of ED visits for persons of different ages.

[13] Cannabinoid hyperemesis which is linked to chronic marijuana use features repeated episodes of nausea and vomiting.

Intentional use of inhalable marijuana is the major reason that adults and adolescents experience marijuana-related adverse events, while unintentional ingestion of edible marijuana is the main reason that children suffer from marijuana-related adverse events (Wang et al., 2019). Many regulatory actions targeting edible marijuana have been put in places. For example, Alaska, Colorado, Oregon and Washington have passed laws to regulate labeling and packaging of edible marijuana (Gourdet et al., 2017). Those regulations largely focus on reducing unintentional ingestion of edible marijuana by minors. Accidental ingestion of edible marijuana often happens because minors cannot distinguish edible marijuana from common food products. The appealing appearance of many edibles also attract minors to consume (Wang et al., 2016). However, those regulations may not prevent intentional abuse of edible marijuana. Marijuana edibles are disguised in processed forms so unqualified persons, such as those under age 21, can use them without being noticed and qualified persons can use them on more occasions where marijuana use is prohibited by laws, such as in public spaces (Klein,2017) .

Among the smoking-ban states, although only Ohio and Florida explicitly allowed marijuana edibles in the original law, other states, except Pennsylvania and West Virginia, did not explicitly prohibit marijuana edibles (Procon.org, 2019), which leaves consumers and suppliers discretion. In addition, there is no uniform definition of marijuana edibles. Broadly speaking, marijuana extracts are also edibles. All smoking-ban states allowed marijuana extracts in liquid and pill forms for oral administration, which have the same delayed effect as commercially produced food products, not to mention that patients or caregivers often mix marijuana extracts with food for ingestion (Klein, 2017).

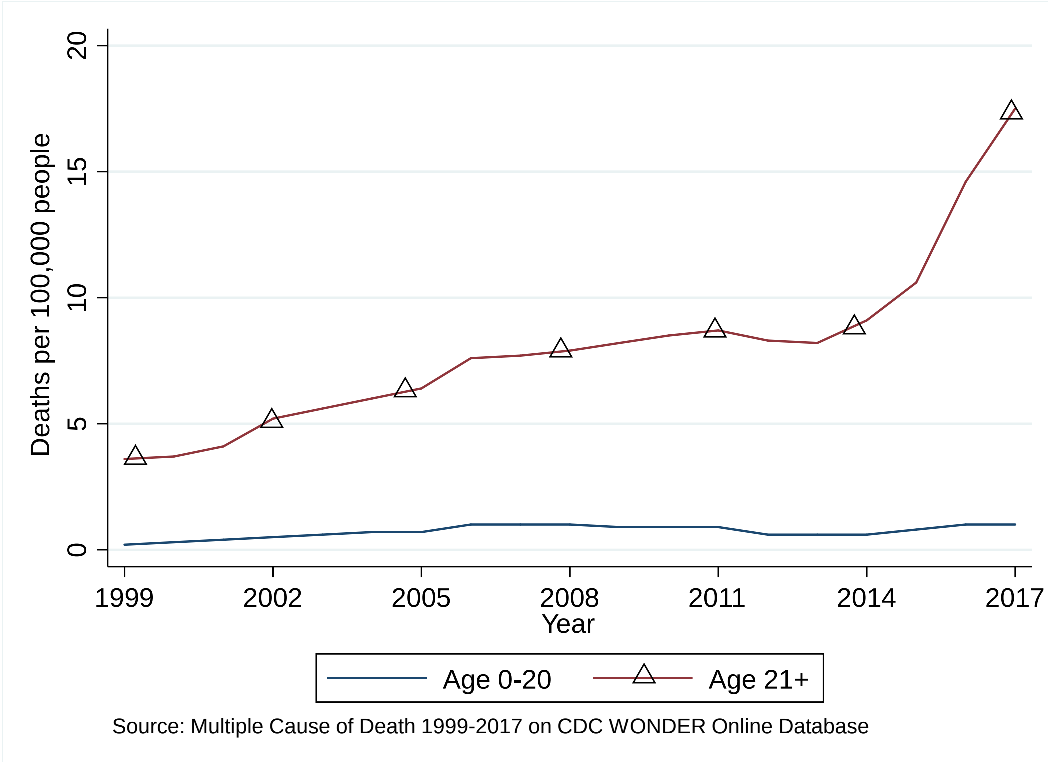
Emergency department (ED) visits related to marijuana and opioid uses often signal an immediate medical need caused by acute drug intoxication. Previous descriptive studies have found increases in ED visits associated with marijuana use (Wang et al., 2017), as well as increases in such ED visits among tourists (Kim et al., 2016b) and children (Wang et al., 2013; Wang et al., 2018) following the implementation of recreational marijuana law in Colorado. On the other hand, Gorman and Huber (2007) reported that medical marijuana laws had no effect on ED visits in metropolitan areas between 1994 and 2002. Furthermore, studies have found that marijuana legalization was associated with reductions in opioid prescribing as well as harms associated with opioid use, suggesting that marijuana and opioids might be substitutes in medical and recreational uses. However, studies have not examined how medical marijuana laws with smoking bans affect ED visits related to marijuana and opioid uses, neither have studies looked into how medical and recreational marijuana laws affect ED visits related to opioid use.

Despite the continued legalization of marijuana in states for medical or recreational uses, the potential adverse effects associated with marijuana use are largely understudied. Self-reported marihuana use as well as marijuana-related emergency department (ED) visits have been increasing in the United States, although the absolute number of marijuana-related ED visits is relatively small (Shen et al., 2019; Han et al., 2018; Wang et al., 2017). Meanwhile, the opioid crisis continues to worsen as reflected in opioid-related ED visits[14] and overdose deaths in the U.S. (Figure 2.1). An increase in marijuana-related ED visits often indicates an increase in marijuana consumption, while

[14] https://www.cdc.gov/vitalsigns/opioid-overdoses/index.html

an increase in marijuana consumption does not necessarily leads to an increase in marijuana-related ED visits if the users have the knowledge related to safe use of marijuana (Kim et al., 2016b).

Figure 2.1 U.S. opioid death rates per 100,000 people, 1999-2017



Source: Centers for Disease Control and Prevention, National Center for Health Statistics. Multiple Cause of Death 1999-2017 on CDC WONDER Online Database, released December, 2018. Data are from the Multiple Cause of Death Files, 1999-2017, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/mcd-icd10.html on Apr 25, 2019.

State medical marijuana laws allow qualified patients to possess and use marijuana products. Caregivers can also legally possess and prepare marijuana products. Qualified patients, including both adults and minors, often have conditions like cancer, debilitating pain, muscle spasms, seizures, etc. State medical marijuana laws vary in their provisions, especially in terms of smoking ban, home cultivation, and physical dispensaries (Procon.org, 2019).

State recreational marijuana laws allow adults aged 21 and above to possess and use marijuana products for any purposes as long as they do not do so in public, motor vehicle or other machinery operations. State recreational marijuana laws also vary in their provisions, particularly with regard to home cultivation and physical dispensaries (Procon.org, 2018).

Medical and recreational marijuana laws de facto reduce the price of marijuana by removing legal penalties and making marijuana physically available. Therefore, increases in marijuana use among qualified users (i.e. medical marijuana cardholders in medical marijuana states and adults aged 21 and above in recreational marijuana states) are often expected. Marijuana legalization may also have spillover effects on marijuana consumption among the unqualified population, including children and adolescents, because the legalization makes marijuana readily accessible, decreases perceived risks associated with marijuana use among public, and lowers law enforcement priority to make arrests for marijuana possession (e.g. Guttmannova et al., 2019; Model, 1993). Moreover, current empirical evidence suggests that marijuana might be a substitute for prescription opioids in medical as well as recreational use (e.g. Wen & Hockenberry, 2018; Bradford et al., 2018; Powell, Pacula, & Jacobson, 2017; Livingston et al., 2017;

Bachhuber et al., 2014). Thus, medical and recreational marijuana laws may also affect opioid use and opioid-related ED visits.

I contribute to the scarce literature by examining the impact of state medical marijuana laws with smoking bans along with other generic state medical and recreational marijuana laws on both marijuana-and opioid-related ED visits in those with employer-sponsored insurance between 2011 and 2016. My study is important due to the following reasons. First, the safety of marijuana use is of public concern, yet no multi-state study has examined the effect of both medical and recreational marijuana laws on marijuana-related ED visits using a nationally representative sample. Second, medical marijuana laws with smoking bans complicate the safe use of marijuana as persons may use an excessive amount of edible marijuana at one time due to failing to realize the delayed intoxication effect of edible marijuana. Third, the U.S. opioid crisis continues to worsen in people covered by private insurance (Cox, Rae, & Sawyer, 2018) and marijuana liberalization introduces additional uncertainty to the crisis. Marijuana liberalization may provide a safer alternative to opioids in pain management as marijuana and opioids have the similar analgesic effect in humans and thus, may reduce opioid-related ED visits if persons use marijuana instead of opioids. However, medical marijuana laws with smoking bans may discourage people from using medical marijuana because people traditionally prefer smokable marijuana. Moreover, if people mix medical marijuana with opioids, the synergistic effect of both types of drugs may produce more harms that may lead to an increase in both marijuana- and opioid-related ED visits. Therefore, it is necessary to examine the effect of both medical and recreational marijuana laws on opioid-related ED visits.

2.2 Literature Review

Existing studies yielded mixed results regarding the impact of medical and recreational marijuana laws on self-reported marijuana use. Some studies found that medical marijuana laws increased marijuana use among adults but not adolescents (Wen, Hockenberry, & Cummings, 2015; Anderson, Hansen, & Rees, 2015; Lynne-Landsman et al., 2013); some other studies actually found adolescents use less marijuana after the enactment of medical marijuana laws in certain statistical model specifications (Cerdá et al., 2018; Harper, Strumpf, & Kaufman, 2012). Pacula et al. (2015) found that the legal protection for dispensaries and home cultivation provisions rather than a generic medical marijuana law increased the prevalence of marijuana use. Other studies, though, found no effect of medical marijuana laws on marijuana use (Khatapoush & Halfors, 2004), especially after adjusting measurement error in the estimates of marijuana use (Harper, Strumpf, & Kaufman, 2012).

With respect to the effect of recreational marijuana laws on self-reported marijuana use, existing studies found that recreational marijuana laws increased marijuana use among those with substance use disorders (Grant et al., 2018), those aged 50 and older (Kerr et al., 2018), patients undergoing surgical procedures (Jennings et al., 2019), those who binge drink (Jones et al., 2018), and those who live in Washington state (Dragone et al., 2019; Cerdá et al., 2017). However, other studies found no changes in marijuana use in eighth, 10th and 12th graders (Cerdá et al., 2017) and college students (Jones, Jones, & Peil, 2018) in Colorado after the enactment of recreational marijuana laws.

Studies of the impact of marijuana laws on marijuana use exclusively relied on survey data so those studies may be unreliable because people tend to give socially acceptable answers (Furnham, 1986). Therefore, those studies may not accurately draw inference about harms or benefits associated with marijuana legalization. Instead, other studies looked into changes in health outcome indicators associated with marijuana legalization by examining administrative records, such as marijuana-related hospitalizations, treatment episodes, and emergency department visits.

Model (1993) studied the effect of marijuana decriminalization between 1973 and 1978 by examining hospital emergency department visits data from the Drug Abuse Warning Network (DAWN). Model (1993) found that marijuana decriminalization was associated with an increase in marijuana-related visits but a decrease in visits involving other drugs, suggesting substitution between marijuana and other drugs. However, the DAWN sample changed over time due to reporting inconsistency. This study only counted the reporting facilities that reported 90% of the cases in the study period. The reporting inconsistency could threaten the internal and external validity of the study.

Gorman and Huber (2007) also used data from the DAWN between 1994 and 2002 to examine ED visits in major metropolitan areas in California, Colorado, and Washington. Employing an interrupted time-series design, they did not find medical marijuana laws had any impact on ED visits. However, they did not have a control group for the study, so other confounding factors may affect the results.

Shi (2017) studied how medical marijuana laws affect hospitalizations related to the misuse and abuse of opioid pain relievers and marijuana. Using the data from the

1997–2014 State Inpatient Databases (SID), she found that medical marijuana laws had no significant effect on hospitalizations involving marijuana.

Shen et al. (2019) examined national treads of marijuana-related ED visits among those aged 12 or above from 2006 to 2014 by using the National Emergency Department Sample data. They found that both the number and the rate of marijuana-related ED visits increased in the period. Those aged 12-17 were more likely to visit ED while using marijuana compared to those of other age groups. Older people were less likely to visit ED with marijuana use. Those with private health insurance were less likely to visit ED while using marijuana compared to those on Medicare and Medicaid, as well as those that are uninsured. Those in the South were at the highest risk to visit ED while using marijuana compared to those in other regions. They also found the association between gastrointestinal symptoms and marijuana-related ED visits but no association between respiratory conditions and marijuana-related ED visits.

Some descriptive studies based on data from Colorado hospitals also found an increase in marijuana-related ED visits after either the medical or recreational marijuana law took effect. For example, a cross-sectional study in Colorado found that the rate of emergency department visits at an urban hospital in Colorado did not fluctuate significantly among in-state residents from 2012 to 2014; however, the rate of visits among out-of-state visitors increased significantly in the period (Kim et al., 2016b). The study suggested the lack of marijuana-safety related knowledge in out-of-state visitors.

Additionally, a series descriptive studies found an increase in marijuana-related ED visits in children and adolescents in Colorado. Wang et al. (2013) retrospectively studied the emergency department visits of children younger than 12 year-old in a tertiary-care children's hospital in Colorado from 2005 and 2011 and found that marijuana-related ingestion increased (from 0 of 790 to 14 of 588) after September, 2009. Almost half of those cases involve marijuana edibles. Using the same method and additional data from a children's hospital and the regional poison center (RPC) in Colorado between 2009 and 2015, Wang et al. (2016) found that the marijuana-related pediatric poison cases increased significantly in the period in Colorado. The marijuana-related pediatric hospital visits also increased. Using data from a Colorado children's hospital between 2005 and 2015, Wang et al. (2018) found that marijuana-related emergency department and urgent care visits significantly increased in adolescents aged 13 to 21. Using discharge data from the Colorado Hospital Association (CHA) and data from the regional poison center (RPC) between 2000 and 2015, Wang et al. (2017) found that after Colorado recreational marijuana legalization, emergency visits and RPC calls significantly increased. All above descriptive studies in Colorado highlighted the widespread use of marijuana edibles, the higher prevalence of mental health diagnoses in marijuana-related visits compared to other visits, and the concurrent use of marijuana and other drugs, mostly alcohol, in non-children population.

The relationship between marijuana legalization and opioid prescribing as well as harms associated with opioid use has been studied extensively. Bradford et al. (2018) found that physical dispensaries and home cultivation provisions were associated with decreases in opioid prescribing for Medicare Part D enrollees between 2010 and 2015. Wen and Hockenberry (2018) found that medical and recreational marijuana laws were associated with decreases in opioid prescribing for Medicaid enrollees between 2011 and 2016.

Studies have also found that medical and recreational marijuana laws reduced harms associated with opioid use. Using data from the Wide-ranging Online Data for Epidemiologic Research (WONDER) in 1999-2000, Bachhuber et al. (2014) found that a medical marijuana law was associated with lower opioid overdose death rates and the effect tended to strengthen over time. Using data from the Wide-Ranging Online Data for Epidemiologic (WONDER) system in 2000-2015, Livingston et al. (2017) found that the recreational marijuana law in Colorado was associated with a reduction in the number of deaths involving opioids. Using data from the Fatality Analysis Reporting System from 1999 to 2003, Kim et al. (2016a) found that a medical marijuana law was associated with a decrease in the tested opioid positivity in 21- to 40-year-old fatally-injured drivers. By examining data from the 1997–2014 State Inpatient Databases (SID), Shi (2017) found that a medical marijuana law was associated with reductions in opioid-related hospitalizations. Those studies suggest marijuana and opioids may be substitutes in medical uses.

Using data from National Vital Statistics System (NVSS) in 1999-2013 and the Treatment Episode Data Set (TEDS) in 1992-2012, Powell, Pacula and Jacobson (2017) found that medical marijuana laws with legally protected dispensaries were associated with reductions in deaths involving opioid misuse or abuse and opioid pain reliever abuse treatment admissions before 2010. However, using data from the Automation of Reports and Consolidated Orders System (ARCOS) in 2010-2013 and the National Survey on Drug Use and Health (NSDUH) in 2002-2012, Powell, Pacula and Jacobson (2017) found a medical marijuana law with legally protected dispensaries had no significant negative effect on self-reported nonmedical use of opioids and legal opioid distribution to a state.

Those results suggest that marijuana may not be a substitute for opioids in non-medical uses as people could obtain legal opioids through drug diversion for non-medical uses.

However, many studies that primarily focused on marijuana laws and marijuana-related outcomes found that medical or recreational marijuana laws increased opioid use, which suggests that marijuana and opioids may be complements in certain situations, such as recreational drug uses by youth and people ever diagnosed with substance use disorders. Cerdá et al. (2018) found that although the enactment of medical marijuana laws had no effect on marijuana use, it was associated with increases in non-medical opioid use and cigarette use in 12th graders. The decreased perception of harmfulness of marijuana use due to the enactment of medical marijuana laws might also decrease the perceived harmfulness of other drug use. Grant et al. (2018) found that those women who exited a substance use intervention program after the liberalization of recreational marijuana were significantly more likely to report marijuana and other substance use compared to women who exited the program before the liberalization. However, other cofounding variables could be the cause of those results.

2.3 Research Questions

a. What is the effect of medical marijuana laws with smoking bans on marijuana-related ED visits?

b. What is the effect of medical marijuana laws with smoking bans on opioid-related ED visits?

2.4 Data and Methods

I used data from the Truven Health MarketScan Commercial Claims and Encounters Database and Medicare Supplemental Database between 2011 and 2016. The Commercial Claims database captures a nation-wide representative sample of de-identified individual-level patient records of medical claims and encounters for active employees and their dependents, early retirees, and Consolidated Omnibus Budget Reconciliation Act (COBRA) enrollees. The Medicare Supplemental Database captures a nation-wide representative sample of de-identified individual-level patient records of retirees with Medicare supplemental insurance sponsored by employers. I aggregated the data at the state/month level and limited the sample to those with at least one-year continuous enrollment (enrollment span greater than or equal to 365 days).

I identified claims from the location of Emergency Room in the Truven database, which has a location code of 23, to identify ED episodes. I identified marijuana- and opioid-related diagnoses based on ICD 9 and ICD 10 codes (Table 2.1). The two categories—marijuana- and opioid-related diagnoses—are not mutually exclusive. One ED episode can be counted as one marijuana-related ED episode as well as one opioid-related ED episode, but will only be counted once in each category regardless of how many marijuana- and opioid-related diagnosis codes were associated with the ED episode.

I studied six outcomes: the number of state monthly marijuana-related ED visits, the number of state monthly marijuana-related ED visits among those aged 0 to 20, the number of state monthly marijuana-related ED visits among those aged 21 and above, the number of state monthly opioid-related ED visits, the number of state monthly opioid-related ED visits among those aged 0 to 20, and the number of state monthly opioid-related ED visits among those aged 21 and above.

Table 2.1 Marijuana- and Opioid-related Diagnosis Codes

	ICD-9-CM Codes	ICD-10 Codes
Marijuana	969.6 305.2 304.3 E854.1	T40.7 F12
Opioids	965.00 965.02 965.09 304.00 304.01 304.02 304.03 304.70 304.71 304.72 304.73 305.50 305.51 305.52 305.53 E850.1 E850.2	T40.0 T40.2 T40.3 T40.4 T40.6 F11

Notes: To identify ED visits possibly associated with marihuana and opioid, poisoning, abuse and dependence were all accounted for.

Sources:

Colorado Department of Public Health & Environment (CDPHE) (2014). "Monitoring Health Concerns Related to Marijuana in Colorado: 2014." Colorado Department of Public Health & Environment (CDPHE). Denver, Colorado. https://www.colorado.gov/pacific/marijuana/news/monitoring-health-concerns-related-marijuana-colorado-2014 (accessed April 25, 2019).

Centers for Disease Control and Prevention (CDC) (2013). "Prescription Drug Overdose Data & Statistics: Guide to ICD-9-CM and ICD-10 Codes Related to Poisoning and Pain." Centers for Disease Control and Prevention (CDC). Atlanta, Georgia. https://www.cdc.gov/drugoverdose/pdf/pdo_guide_to_icd-9-cm_and_icd-10_codes-a.pdf (accessed April 25, 2019).

Heslin, K., Elixhauser, A., & Steiner, C. (2015). Hospitalizations involving mental and substance use disorders among adults, 2012. *HCUP Statistical Brief*, *191*. https://www.ncbi.nlm.nih.gov/books/NBK310986/ (accessed April 25, 2019).

Slavova, S., O'Brien, D. B., Creppage, K., Dao, D., Fondario, A., Haile, E., ... & Wright, D. (2015). Drug overdose deaths: let's get specific. *Public Health Reports*, *130*(4), 339-342. https://doi.org/10.1177/003335491513000411 (accessed April 25, 2019).

2.4.1 Variable measurement

The key independent variables are the implementation of a medical marijuana law with smoking ban, the implementation of a medical marijuana law without smoking ban, the implementation of a recreational marijuana law, the allowance of medical/recreational home cultivation, and the presence of medical/recreational dispensaries (Table 2.2). I define the implementation of a state medical marijuana law as a state that protects patients who possess or use the legally allowable amount of marijuana for medical purposes based on doctors' recommendations from arrest, prosecution and penalty, and protects doctors who recommend the use of medical marijuana in medical treatment to their patients from arrest, prosecution and penalty. I define the implementation of a state recreational marijuana law as a state that protects adults who possess or use the legally allowable amount of marijuana for any purposes on occasions where marijuana use is not prohibited from arrest, prosecution and penalty.

State-level time-varying policy shocks include Good Samaritan Overdose Prevention Laws,[15] Naloxone Overdose Prevention Laws,[16] Prescription Drug Monitoring Programs (PDMP), PDMP mandates[17], and pain clinic laws (Table 2.3).

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[15] Those laws create immunities for people experiencing an overdose to encourage them to call for medical help to avoid preventable deaths.

[16] Those laws provide legal protection for certified healthcare providers and lay responders to distribute, possess and administer naloxone, an opioid antagonist.

[17] Those laws require prescribers or dispensers to check PDMP patient records before prescribing or dispensing. Those states already have the mandatory reporting requirement prior to the mandatory checking requirement.

Table 2.2 State marijuana law effect dates (as of March 31st, 2019)

State	**Medical Marijuana Laws**				**Recreational Marijuana Laws**
	Law without Smoking Ban	Law with Smoking Ban	Home Cultivation Rule	First Dispensary	
Alabama	n/a		n/a	n/a	n/a
Alaska	1999/03		2010/06	n/a	**2015/02**
Arizona	**2011/04**		**2011/04**	**2012/12**	n/a
Arkansas	2016/11		n/a	n/a	n/a
California	1996/11		2004/01	1996/11	2016/11
Colorado	2001/06		**2011/07**	2005/07	**2012/12**
Connecticut	**2012/06**		n/a	**2014/10**	n/a
Delaware	**2011/07**		n/a	**2015/06**	n/a
Florida	2019/03	2017/01- 2019/03	n/a	2017/06	n/a
Georgia	n/a		n/a	n/a	n/a
Hawaii	2000/06		**2011/07**	2017/08	n/a
Idaho	n/a		n/a	n/a	n/a
Illinois	**2014/01**[a]		n/a	**2015/11**	n/a
Indiana	n/a		n/a	n/a	n/a
Iowa	n/a		n/a	n/a	n/a
Kansas	n/a		n/a	n/a	n/a
Kentucky	n/a		n/a	n/a	n/a
Louisiana		**2016/08**[b]	n/a	2018/10[c]	n/a
Maine	1999/12		**2013/10**	**2011/04**	2016/11
Maryland	**2014/06**		n/a	2017/12	n/a
Massachusetts	**2013/01**		**2013/05**	**2015/07**	2016/12
Michigan	2008/12		2008/12	2010/01- **2011/08** 2019/02	2018/12
Minnesota		**2014/06**	n/a	**2015/07**	n/a
Mississippi	n/a		n/a	n/a	n/a
Missouri	2018/12		n/a	n/a	n/a
Montana	2004/11		**2011/07**	2009/04- **2011/08** 2016/12	n/a
Nebraska	n/a		n/a	n/a	n/a
Nevada	2001/10		2009/07	**2015/08**	2017/01
New Hampshire	**2013/07**		n/a	**2016/05**	n/a
New Jersey	2010/10		n/a	**2012/12**	n/a
New Mexico	2007/07		2010/12	2009/03	n/a
New York		**2014/07**	n/a	**2016/07**	n/a
North Carolina	n/a		n/a	n/a	n/a
North Dakota	2017/04		n/a	2019/03	n/a
Ohio		**2016/09**	n/a	2019/04	n/a
Oklahoma	2018/07		2018/08	2018/11	n/a

Table 2.2 State marijuana law effect dates (as of March 31st, 2019) (continued)

Oregon	1998/12		**2013/08**	2009/11	**2015/07**
Pennsylvania		**2016/05**	n/a	2018/01	n/a
Rhode Island	2006/01		**2012/06**	**2013/04**	n/a
South Carolina	n/a		n/a	n/a	n/a
South Dakota	n/a		n/a	n/a	n/a
Tennessee	n/a		n/a	n/a	n/a
Texas	n/a		n/a	n/a	n/a
Utah		2018/12	n/a	n/a	n/a
Vermont	2004/07		**2013/07**	**2013/07**	2018/07
Virginia	n/a		n/a	n/a	n/a
Washington	1998/12		**2011/07**	**2014/07**	**2012/12**
West Virginia		2017/04	n/a	2017/08	n/a
Wisconsin	n/a		n/a	n/a	n/a
Wyoming	n/a		n/a	n/a	n/a

Notes:

a. Senate Bill 2636 that took effect in January, 2015 only allows non-smokable forms for minors (under age 18). However, since this is not a complete smoking ban, I treat the Illinois MML as the MML without smoking ban..
b. Smoking, Inhalation and vaping, as well as marijuana in raw form, are not the acceptable forms in the law.
c. First medical marijuana clinic

Sources: PDAPS (2018), ProCon.org (2018), ProCon.org (2019), and Multiple Media Outlets (Table 1.5).

Table 2.3 Other state law effect dates (as of March 31st, 2019)

State	Overdose Good Samaritan Laws	Naloxone Access Laws	Prescription Drug Monitoring Program (PDMP) Operational	PDMP Mandates[a]	Pain Clinic Laws
Alabama	2015/06	2015/06	2006/01	n/a	2014/01
Alaska	2014/10	2016/03	2011/08	2017/07	n/a
Arizona	2018/04	2016/08	2008/10	2017/10	2019/01
Arkansas	2015/07	2015/07	2013/03	2017/07	n/a
California	2013/01	2014/01	1939/01	2017/07	n/a
Colorado	2012/05	2013/05	2007/07	2018/05	n/a
Connecticut	2011/10	2003/10	2008/07	2015/10	n/a
Delaware	2013/08	2014/08	2012/03	n/a	n/a
Florida	2012/10	2015/06	2011/09	2018/07	2011/07
Georgia	2014/04	2014/04	2013/07	2018/07	2013/07
Hawaii	2015/07	2016/06	1943/01	2018/07	n/a
Idaho	2018/07	2015/07	1967/01	n/a	n/a
Illinois	2012/06	2010/01	1968/01	n/a	n/a
Indiana	2016/07	2015/04	1998/01	2014/07	2014/01
Iowa	2018/07	2016/05	2009/01	n/a	n/a
Kansas	n/a	2017/07	2011/02	n/a	n/a
Kentucky	2015/03	2013/06	1999/01	2012/07	2012/07
Louisiana	2014/08	2015/08	2008/11	2014/08	2006/01
Maine	n/a	2014/04	2004/07	2017/01	n/a
Maryland	2014/10	2013/10	2013/08	2018/07	n/a
Massachusetts	2012/08	2012/08	1994/01	2014/07	n/a
Michigan	2017/01	2014/10	1989/01	n/a	n/a
Minnesota	2014/07	2014/05	2010/01	n/a	n/a
Mississippi	2015/07	2015/07	2005/01	n/a	2011/04
Missouri	2017/08	2016/08	n/a	n/a	n/a

Table 2.3 Other state law effect dates (as of March 31st, 2019) (continued)

Montana	2017/05	2017/05	2012/03	n/a	n/a
Nebraska	2017/08	2015/05	2011/04	n/a	n/a
Nevada	2015/10	2015/10	1997/01	2015/10	n/a
New Hampshire	2015/09	2015/06	2014/09	2016/01	n/a
New Jersey	2013/05	2013/07	2011/09	2015/11	n/a
New Mexico	2007/06	2001/04	2005/01	2012/09	n/a
New York	2011/09	2006/04	1973/04	2013/08	n/a
North Carolina	2013/04	2013/04	2007/07	n/a	n/a
North Dakota	2015/08	2015/08	2007/09	2014/10	n/a
Ohio	2016/09	2014/03	2006/07	2015/12	2011/06
Oklahoma[b]	n/a	2013/11	1991/01	2015/11	n/a
Oregon	2016/01	2013/06	2011/06	n/a	n/a
Pennsylvania	2014/12	2014/12	1973/01	2015/06	n/a
Rhode Island	2012/06-2015/06 2016/01-2018/07	2012/06	1979/01	2016/07	n/a
South Carolina	2017/06	2015/06	2008/02	2017/05	n/a
South Dakota	2017/07	2016/07	2011/12	n/a	n/a
Tennessee	2015/07	2014/07	2006/12	2013/04	2012/01
Texas	n/a	2015/09	1982/01	2019/09	2010/09
Utah	2014/03	2014/05	1996/01	2017/05	n/a
Vermont	2013/06	2013/07	2009/01	2015/05	n/a
Virginia	2015/07	2013/07	2003/09	2015/07	n/a
Washington	2010/06	2010/06	2011/10	2012/01[c]	n/a
West Virginia	2015/06	2015/05	1995/07	2012/06	2012/06
Wisconsin	2014/04	2014/04	2013/04	2017/04	2016/03
Wyoming	n/a	2017/07	2004/07	n/a	n/a

Notes.

a. Require prescribers or dispensers to check PDMP patient records before prescribing or dispensing. Those states already have the mandatory reporting requirement prior to the mandatory checking requirement.

b. The law prohibits prosecutions under limited circumstances. See https://legiscan.com/OK/bill/SB1367/2018

c. Only apply to Workers Compensation Providers.

Sources. PDAPS (2018) and Multiple Media Outlets

Other state-level time-varying covariates include unemployment rate, median household income, poverty rates, the number of primary care physicians, and state population. Please see Table 2.4 for the descriptive summary of the outcome and independent variables.

Table 2.4 Descriptive summary of ED outcome variables, policy indicators and other covariates

ED outcome variables	Mean (S.D.) / Proportion
# Marijuana-related ED visits	20.007 (27.494)
# Marijuana-related ED visits_age under 21	8.207 (11.391)
# Marijuana-related ED visits_age 21 and older	11.800 (16.747)
# Opioid-related ED visits	30.351 (39.667)
# Opioid-related ED visits_age under 21	7.390 (10.424)
# Opioid-related ED visits_age 21 and older	22.961 (30.009)
Medical and recreational marijuana laws	
Medical marijuana laws with smoking ban 0/1	0.022
Medical marijuana laws without smoking ban 0/1	0.376
Recreational marijuana laws 0/1	0.039
Combinations of homegrown rule, dispensaries and smoking ban	
Medical marijuana laws with homegrown rule only	0.113
Medical marijuana laws with dispensaries only	0.053
Medical marijuana laws with smoking ban only	0.015
Medical marijuana laws with homegrown rule and dispensaries	0.137
Medical marijuana laws with dispensaries and smoking ban	0.007
Recreational marijuana laws with homegrown rule only	0.010
Recreational marijuana laws with homegrown rule and dispensaries	0.023
Other covariates	
Overdose Good Samaritan laws 0/1	0.336
Naloxone access Laws 0/1	0.412
PDMP 0/1	0.914
PDMP mandate 0/1	0.158
Pain clinic law 0/1	0.178
% Unemployment rate	6.268 (1.922)
$ Median household income ($10,000s)	5.385 (0.914)
% Poverty rate	13.581 (3.385)
# State population (1,000,000s)	6.321 (6.996)
# Primary care physicians (per 10,000 population)	12.370 (2.894)

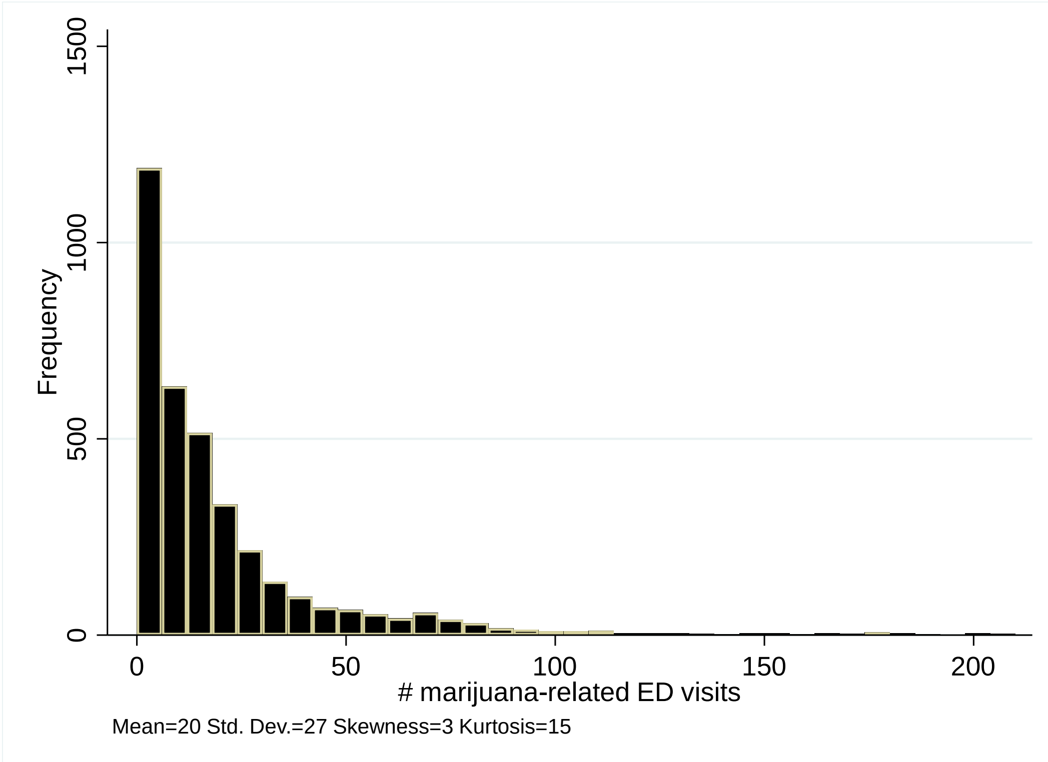
2.4.2 Analytic strategy

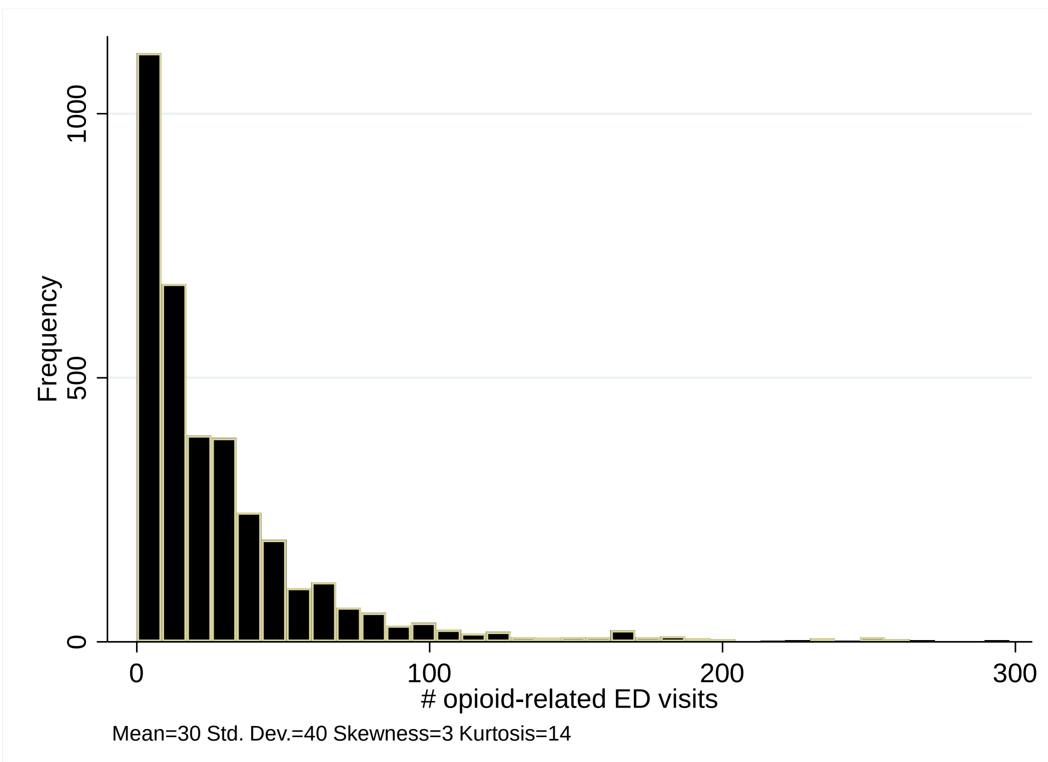
The outcome variables are count variables with many zeros, the distributions of which are also highly skewed with overdispersion (Figure 2.2), so to estimate the effects of medical and recreational marijuana laws on opioid prescribing, I used the following negative binomial model with two-way fixed-effects:

$$\ln(\mathbf{Y}_{s.t}) = \beta_0 + \beta 1 mml\_with\_ban_{s,t} + \beta_2 mml\_no\_ban_{s,t} + \beta_3 rml_{s,t} + \gamma \mathbf{X}_{s,t} + \delta_s + \theta_t + \ln(n_{s,t}) + \varepsilon_{s,t},$$

where *s* denotes a state and *t* denotes a month in a year. $\boldsymbol{Y}_{s,t}$ represents the ED outcomes. $mml\_with\_ban_{s,t}$ is the policy indicator for state implementation of MMLs with smoking-ban provisions. $mml\_no\_ban_{s,t}$ is the policy indicator for state implementation of MMLs without smoking-ban provisions. $rml_{s,t}$ is the policy indicator for state implementation of RMLs. $\boldsymbol{X}_{s,t}$ is a vector of state-level covariates. I included state fixed effects δ_s and year-month fixed effects θ_t to account for the unobserved time-invariant state heterogeneity and the national secular trend and common shocks in ED visits. The exposure count is $n_{s,t}$ (i.e. total enrollment) for a state in a month, and $\varepsilon_{s,t}$ accounts for overdispersion. I clustered standard errors at the state level.

Figure 2.2 Distributions of marijuana- and opioid-related ED visits





2.5 Results

2.5.1 Estimated effects of medical and recreational marijuana laws on ED visits

State implementation of medical marijuana laws with smoking ban was associated with decreases in marijuana-related and opioid-related visits (Table 2.5). State medical marijuana laws with smoking ban was associated with 3.289 less marijuana-related ED visits, which can be translated to a 16.3 percent decrease. State medical marijuana law with smoking bans was associated with 3.808 less opioid-related ED visits, which can be translated to a 12.5 percent decrease. The decrease in marijuana-related ED visits was concentrated in those aged 21 and older, while the decrease in opioid-related ED visits was concentrated in those aged under 21.

Table 2.5 Effects of MMLs and RMLs on ED visits

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs with smoking ban						
Discrete change from the baseline predicted number of events	**-3.289***** **(-5.453,** **-1.125)**	-0.836 (-1.875, 0.204)	**-1.904***** **(-3.335,** **-0.473)**	**-3.808**** **(-6.703,** **--0.913)**	**-0.743**** **(-1.310,** **-0.176)**	**-2.591**** **(-5.048,** **-0.134)**
Baseline predicted number of events (MMLs with smoking ban=0)	20.182	8.230	11.941	30.374	7.397	22.978
Relative percentage change from baseline predicted number of events	-16.3%	-10.2%	-15.9%	-12.5%	-10.0%	-11.3%

Table 2.5 Effects of MMLs and RMLs on ED visits (continued)

MMLs without smoking ban						
Discrete change from the baseline predicted number of events	1.949 (-1.411, 5.309)	0. 629 (-1.090, 2.348)	1.709 (-0.651, 4.070)	1.241 (-4.818, 7.300)	0.410 (-1.375, 2.195)	1.242 (-3.743, 6.226)
Baseline predicted number of events (MMLs without smoking ban=0)	19.359	7.989	11.262	29.860	7.255	22.498
Relative percentage change from baseline predicted number of events	10.1%	7.9%	15.2%	4.2%	5.7%	5.5%

Table 2.5 Effects of MMLs and RMLs on ED visits (continued)

RMLs

Discrete change from the baseline predicted number of events	4.129 (-1.093, 9.351)	1.185 (-0.982, 3.352)	3.283 (-0.446, 7.011)	1.246 (-5.423, 7.915)	0.979 (-0.540, 2.498)	0.892 (-4.078, 5.861)
Baseline predicted number of events (MMLs without smoking ban=0)	19.899	8.161	11.747	30.216	7.355	22.863
Relative percentage change from baseline predicted number of events	20.7%	14.5%	27.9%	4.1%	13.3%	3.9%
n	3,593	3,593	3,593	3,593	3,593	3,593

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level.

2.5.2 Estimated effects of medical and recreational marijuana provisions and dispensaries on ED visits

I estimated the main model while replacing the effects of medical marijuana laws with the effects of all combinations of medical marijuana provisions and dispensaries—that is, medical marijuana smoking ban, home cultivation allowance and legal dispensaries (Figure 2.3; Table 2.6). The combination of medical marijuana laws with smoking bans and legal dispensaries was consistently associated with decreases in marijuana- and opioid-related ED visits among all ages.

Figure 2.3 Effects of medical marijuana provisions and dispensaries on ED visits

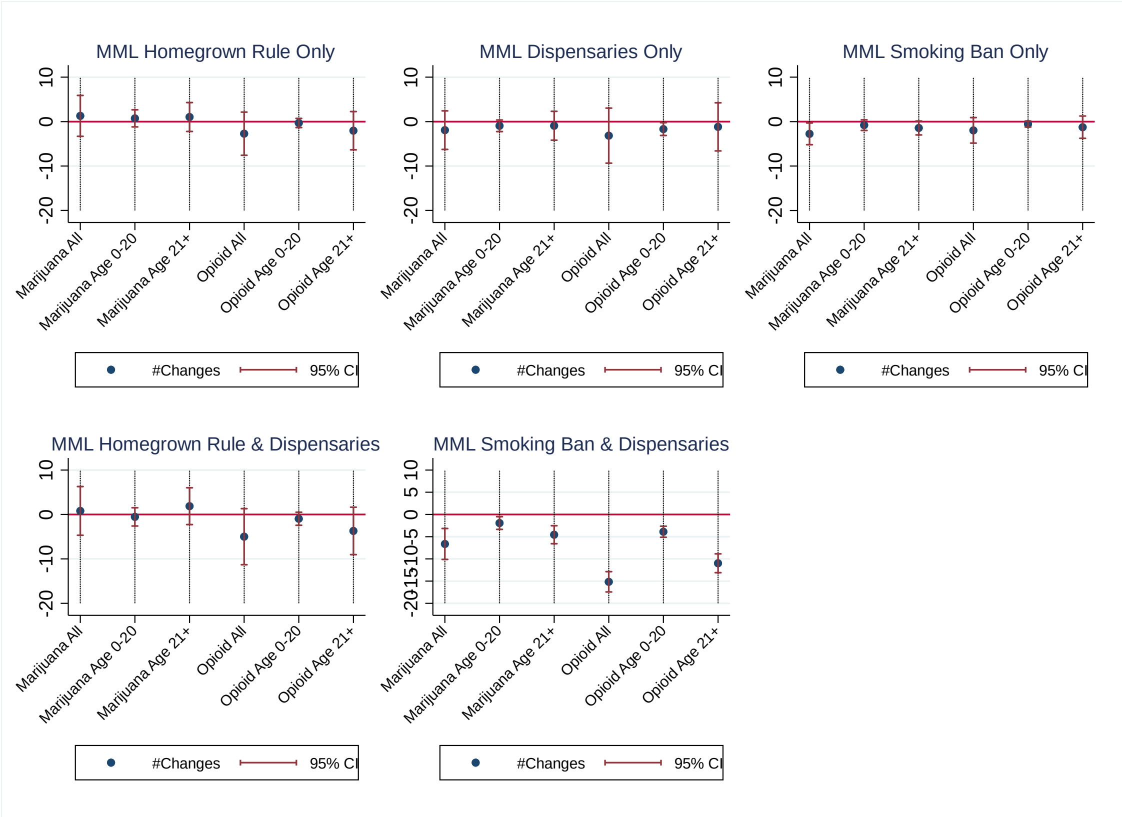


Table 2.6 Effects of medical marijuana provisions and dispensaries on ED visits

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs with homegrown rule only						
Discrete change from the baseline predicted number of events	1.289	0.728	1.035	-2.718	-0.309	-2.043
	(-3.313, 5.890)	(-1.193, 2.650)	(-2.213, 4.284)	(-7.587, 2.150)	(-1.336, 0.719)	(-6.351, 2.264)
Baseline predicted number of events (MMLs with homegrown rule only =0)	19.919	8.144	11.759	30.467	7.402	23.054
Relative percentage change from baseline predicted number of events	6.5%	8.9%	8.8%	-8.9%	-4.2%	-8.9%

Table 2.6 Effects of medical marijuana provisions and dispensaries on ED visits (continued)

MMLs with dispensaries only						
Discrete change from the baseline predicted number of events	-1.918 (-6.259, 2.423)	-0.945 (-2.249, 0.359)	-0.934 (-4.171, 2.302)	-3.157 (-9.348, 3.034)	**-1.678**** **(-3.121, -0.236)**	-1.175 (-6.589, 4.239)
Baseline predicted number of events (MMLs with dispensaries only =0)	20.087	8.230	11.873	30.341	7.438	22.916
Relative percentage change from baseline predicted number of events	-9.5%	-11.5%	-7.9%	-10.4%	-22.6%	-5.1%

Table 2.6 Effects of medical marijuana provisions and dispensaries on ED visits (continued)

MMLs with smoking ban only						
Discrete change from the baseline predicted number of events	**-2.750****	-0.793	-1.430*	-1.969	-0.550	-1.258
	(-5.193, -0.307)	(-1.986, 0.400)	(-2.999, 0.138)	(-4.842, 0.904)	(-1.227, 0.126)	(-3.772, 1.256)
Baseline predicted number of events (MMLs with smoking ban only =0)	20.136	8.224	11.907	30.294	7.392	22.917
Relative percentage change from baseline predicted number of events	-13.7%	-9.6%	-12.0%	-6.5%	-7.4%	-5.5%

Table 2.6 Effects of medical marijuana provisions and dispensaries on ED visits (continued)

MMLs with homegrown rule and dispensaries						
Discrete change from the baseline predicted number of events	0.809 (-4.677, 6.294)	-0.540 (-2.593, 1.512)	1.873 (-2.266, 6.012)	-4.991 (-11.299, 1.318)	-0.954 (-2.420, 0.512)	-3.699 (-9.040, 1.642)
Baseline predicted number of events (MMLs with homegrown rule and dispensaries =0)	19.859	8.301	11.487	31.217	7.553	23.616
Relative percentage change from baseline predicted number of events	4.1%	-6.5%	16.3%	-16.0%	-12.6%	-15.7%

Table 2.6 Effects of medical marijuana provisions and dispensaries on ED visits (continued)

MMLs with dispensaries and smoking ban						
Discrete change from the baseline predicted number of events	**-6.632***** **(-10.111, -3.152)**	**-1.924***** **(-3.356, -0.493)**	**-4.555***** **(-6.573, -2.537)**	**-15.155***** **(-17.436, -12.874)**	**-3.886***** **(-5.128, -2.643)**	**-10.975***** **(-13.088, -8.862)**
Baseline predicted number of events (MMLs with dispensaries and smoking ban =0)	20.080	8.210	11.885	30.307	7.388	22.937
Relative percentage change from baseline predicted number of events	-33.0%	-23.4%	-38.3%	-50.0%	-52.6%	-47.8%

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level.

2.5.3 Estimated effects of state-specific medical and recreational marijuana laws on ED visits

I estimated the main model while allowing for the state-specific effects (Figure 2.4; Table 2.7). State implementation of medical marijuana laws with smoking bans did not increase marijuana-related ED visits among all ages. In states (i.e. Minnesota and New York) with legal dispensaries, medical marijuana laws with smoking bans were associated with decreases in marijuana- and opioid-related ED visits. In Pennsylvania, where commercially produced edibles were banned, the medical marijuana law with smoking ban was associated with decreases in marijuana-related ED visits, especially among those aged 21 and older. On the other hand, in Ohio, where no legal dispensary was present, the medical marijuana law with smoking ban was associated with increases in opioid-related ED visits, especially among those aged 21 and older. Other medical marijuana laws had heterogeneous effects in different states. The positive effect of recreational marijuana laws on expected marijuana-related ED visits was concentrated in Alaska and Washington. Oregon recreational marijuana law was associated with a decrease in expected marijuana-related ED visits in those aged under 21 but an increase in expected marijuana-related ED visits in those aged 21 and older. Washington recreational marijuana law was associated with increases in expected opioid-related ED visits among all ages, while Alaska recreational marijuana law was associated with decreases in expected opioid-related ED visits, especially among those aged under 21.

Figure 2.4 State-specific effects of MMLs and RMLs on ED visits

Table 2.7 State-specific effects of MMLs and RMLs on ED visits

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs with smoking ban						
Louisiana						
Discrete change from the baseline predicted number of events	-4.042* (-8.428, 0.343)	**-1.992**** **(-3.725, -0.259)**	-2.412 (-5.312, 0.489)	-0.962 (-8.957, 7.034)	-0.583 (-2.935, 1.770)	-2.206 (-8.047, 3.634)
Baseline predicted number of events (Louisiana MML=0)	20.021	8.193	11.847	30.213	7.374	22.869
Relative change from baseline predicted number of events	-20.2%	-24.3%	-20.4%	-3.2%	-7.9%	-9.6%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs with smoking ban						
Minnesota						
Discrete change from the baseline predicted number of events	**-1.425**** **(-2.553, -0.296)**	**-1.386**** **(-2.533, -0.239)**	**-1.866**** **(-3.604, -0.127)**	**-6.693***** **(-10.860, -2.526)**	-0.204 (-1.321, 0.913)	**-4.934***** **(-8.289, -1.580)**
Baseline predicted number of events (Minnesota MML=0)	20.027	8.196	11.845	30.231	7.374	22.878
Relative change from baseline predicted number of events	-20.6%	-16.9%	-15.8%	-22.1%	-2.8%	-21.6%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs with smoking ban						
New York						
Discrete change from the baseline predicted number of events	**-2.851** **(-5.302, -0.399)**	-0.382 (-1.460, 0.696)	**-1.878** **(-3.483, -0.273)**	**-3.530** **(-6.732, -0.329)**	**-0.767** **(-1.425, -0.108)**	-2.169 (-4.784, 0.446)
Baseline predicted number of events (New York MML=0)	20.119	8.202	11.914	30.305	7.390	22.925
Relative percentage change from baseline predicted number of events	-14.2%	-4.7%	-15.8%	-11.6%	-10.4%	-9.5%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs with smoking ban						
Ohio						
Discrete change from the baseline predicted number of events	1.693 (-1.609, 4.996)	-0.010 (-1.159, 1.140)	1.451 (-0.885, 3.787)	6.099* (0.410, 10.518)	0.302 (-1.839, 2.444)	**5.121** (0.256, 9.986)**
Baseline predicted number of events (Ohio MML=0)	20.005	8.189	11.834	30.205	7.374	22.858
Relative change from baseline predicted number of events	8.5%	-0.1%	12.3%	20.2%	4.1%	22.4%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs with smoking ban						
Pennsylvania						
Discrete change from the baseline predicted number of events	**-4.872**** **(-8.611, -1.133)**	-1.263 (-3.255, 0.729)	**-3.166***** **(-5.435, -0.896)**	-5.223 (-11.836, 1.389)	-2.155* (-4.522, 0.213)	-3.628 (-8.735, 1.478)
Baseline predicted number of events (Pennsylvania MML=0)	20.024	8.192	11.849	30.221	7.375	22.873
Relative change from baseline predicted number of events	-24.3%	-15.4%	-26.7%	-17.3%	-29.2%	-15.9%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs without smoking ban						
Arizona						
Discrete change from the baseline predicted number of events	2.044 (-1.108, 5.196)	**4.218*** (2.348, 6.089)**	-1.473* (-3.205, 0.260)	**-9.805*** (-12.677, -6.934)**	**-1.574*** (-2.343, -0.804)**	**-8.067*** (-10.387, -5.747)**
Baseline predicted number of events (Arizona MML=0)	19.980	8.143	11.865	30.462	7.412	23.073
Relative change from baseline predicted number of events	10.2%	51.8%	-12.4%	32.2%	-21.2%	-35.0%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs without smoking ban						
Connecticut						
Discrete change from the baseline predicted number of events	0.815 (-2.617, 4.247)	1.651* (-0.155, 3.456)	-0.557 (-2.525, 1.411)	-2.111 (-6.466, 2.244)	-0.053 (-1.190, 1.083)	-1.986 (-5.493, 1.522)
Baseline predicted number of events (Connecticut MML=0)	19.998	8.167	11.847	30.244	7.375	22.897
Relative change from baseline predicted number of events	4.1%	20.2%	-4.7%	-7.0%	-0.7%	-8.7%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs without smoking ban						
Delaware						
Discrete change from the baseline predicted number of events	**10.521*** (2.884, 18.158)**	-0.705 (-2.518, 1.108)	**26.779*** (15.768, 37.790)**	7.667* (-0.933, 16.267)	1.101 (-0.560, 2.762)	7.163* (-0.327, 14.653)
Baseline predicted number of events (Delaware MML=0)	19.978	8.192	11.798	30.179	7.369	22.835
Relative change from baseline predicted number of events	52.7%	-8.6%	227.0%	25.4%	14.9%	31.4%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs without smoking ban						
Illinois						
Discrete change from the baseline predicted number of events	2.900* (-0.482, 6.282)	1.099 (-0.630, 2.829)	**2.783** (0.593, 4.973)**	**10.094*** (4.260, 15.928)**	**2.781*** (1.188, 4.374)**	**8.803*** (3.942, 13.665)**
Baseline predicted number of events (Illinois MML=0)	19.980	8.178	11.812	30.155	7.356	22.820
Relative change from baseline predicted number of events	14.5%	13.4%	23.6%	33.5%	37.8%	38.6%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs without smoking ban						
Maryland						
Discrete change from the baseline predicted number of events	0.783 (-2.564, 4.129)	**-1.451**** **(-2.564, -0.338)**	1.538 (-0.930, 4.007)	-1.050 (-5.440, 3.340)	**-2.257***** **(-3.043, -1.470)**	0.325 (-3.443, 4.094)
Baseline predicted number of events (Maryland MML=0)	20.005	8.197	11.830	30.215	7.380	22.864
Relative change from baseline predicted number of events	3.9%	-17.7%	13%	-3.5%	-30.6%	1.4%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs without smoking ban						
Massachusetts						
Discrete change from the baseline predicted number of events	**7.771**** **(1.504, 14.038)**	2.210* (-0.346, 4.766)	**7.317***** **(2.674, 11.961)**	0.641 (-6.377, 7.658)	0.187 (-1.316, 1.690)	1.339 (-4.522, 7.200)
Baseline predicted number of events (Massachusetts MML=0)	19.955	8.170	11.799	30.206	7.372	22.854
Relative change from baseline predicted number of events	38.9%	27.1%	62.0%	2.1%	2.5%	5.9%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs without smoking ban						
New Hampshire						
Discrete change from the baseline predicted number of events	**-3.406**** **(-6.058, -0.755)**	**-2.102***** **(-3.167, -1.036)**	-1.573 (-3.455, 0.309)	-0.666 (-4.023, 2.691)	0.249 (-0.810, 1.309)	-0.943 (-3.722, 1.836)
Baseline predicted number of events (New Hampshire MML=0)	20.023	8.197	11.845	30.214	7.373	22.868
Relative change from baseline predicted number of events	-17.0%	-25.6%	-13.3%	-2.2%	3.4%	4.1%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
RMLs						
Alaska						
Discrete change from the baseline predicted number of events	**10.452*** (3.390, 17.514)**	**8.299*** (4.558, 12.041)**	3.198 (-0.772, 7.168)	**-7.422*** (-12.773, -2.071)**	**-3.996*** (-4.702, -3.290)**	-4.435* (-9.075, 0.206)
Baseline predicted number of events (Alaska RML=0)	20.006	8.187	11.838	30.213	7.375	22.866
Relative change from baseline predicted number of events	52.2%	101.4%	27.0%	-24.6%	-54.2%	19.4%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
RMLs						
Colorado						
Discrete change from the baseline predicted number of events	1.580 (-2.708, 5.867)	1.320 (-0.610, 3.250)	0.779 (-2.023, 3.580)	-2.152 (-8.268, 3.964)	0.063 (-1.254, 1.380)	-1.493 (-6.526, 3.539)
Baseline predicted number of events (Colorado RML=0)	19.990	8.174	11.829	30.232	7.373	22.878
Relative change from baseline predicted number of events	7.9%	16.1%	6.6%	-7.1%	0.9%	6.5%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
RMLs						
Oregon						
Discrete change from the baseline predicted number of events	0.755 (-2.287, 3.797)	**-1.490*** (-2.534, -0.446)**	**3.089*** (0.763, 5.414)**	-2.774 (-6.195, 0.647)	0.478 (-0.705, 1.661)	-1.782 (-4.424, 0.861)
Baseline predicted number of events (Oregon RML=0)	20.008	8.193	11.832	30.216	7.373	22.868
Relative change from baseline predicted number of events	3.8%	-18.2%	26.1%	-9.2%	6.5%	7.8%

Table 2.7 State-specific effects of MMLs and RMLs on ED visits (continued)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
RMLs						
Washington						
Discrete change from the baseline predicted number of events	**8.712***** **(3.524, 13.899)**	**2.186**** **(0.282, 4.091)**	**6.602***** **(2.792, 10.413)**	**7.608***** **(2.339, 12.876)**	**2.054***** **(0.935, 3.174)**	**5.183**** **(0.920, 9.446)**
Baseline predicted number of events (Washington RML=0)	19.906	8.164	11.758	30.121	7.349	22.803
Relative change from baseline predicted number of events	43.8%	26.8%	56.1%	25.3%	27.9%	22.7%

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level.

2.6 Robustness checks

2.6.1 Event study

Identification of the effects of medical marijuana laws with and without smoking ban as well as recreational marijuana laws relies on the common pre-intervention trends assumption to rule out policy endogeneity, which is reflected as parallel outcome trends in the treatment and control states in the pre-intervention period.

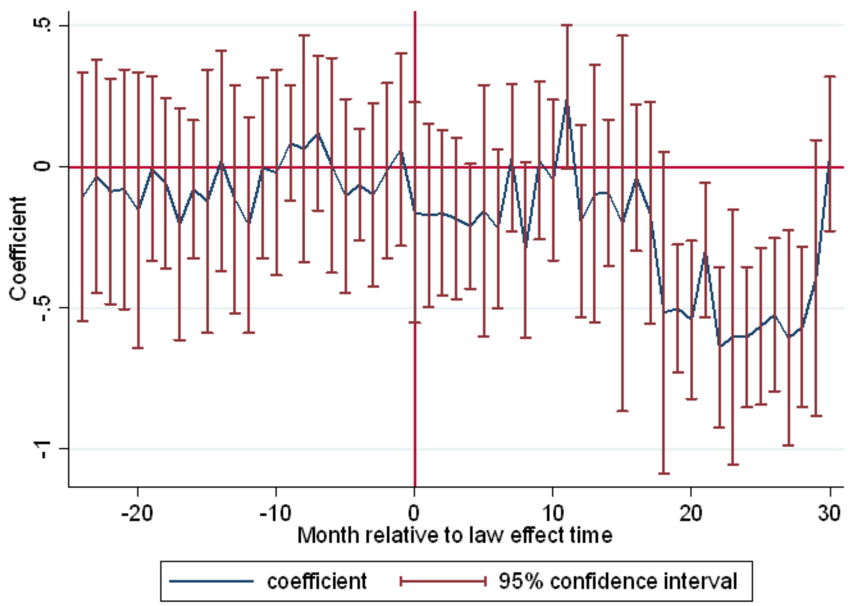
An event study allows me to test for pre-existing trends as well as to estimate lagged effects of medical and recreational marijuana laws based on the time relative to the effective month (Model, 1993) (Figure 2.5).

I found no pre-intervention difference in either marijuana- or opioid-related ED visits between states with and without medical marijuana laws with smoking ban in the pre-intervention period. After medical marijuana laws with smoking bans take effect, I discerned pronounced negative effects on marijuana- and opioid-related ED visits driven by two earlier adopting states—Minnesota and New York—as time elapsed.

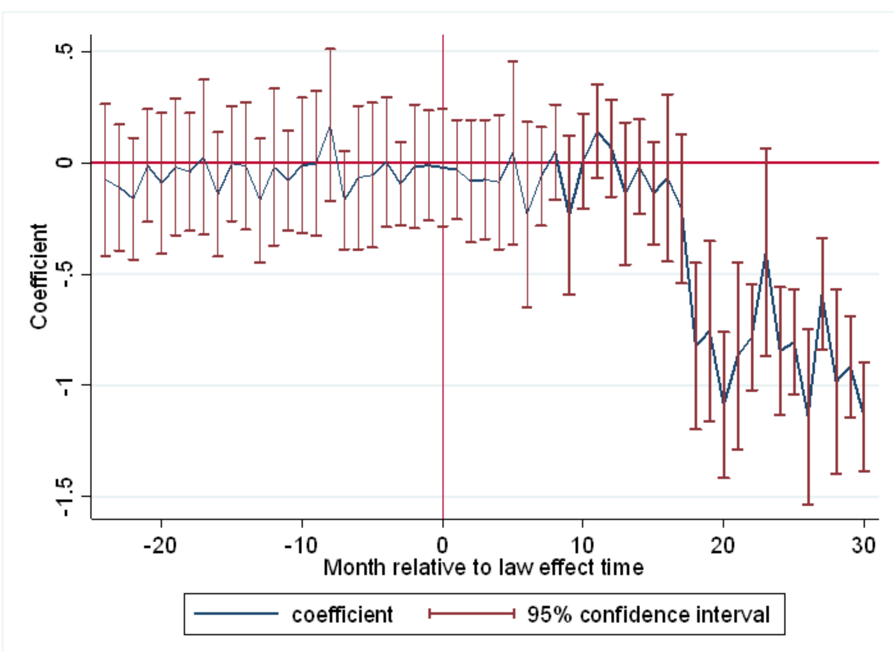
However, I did find possible policy endogeneity in states with medical marijuana laws without smoking bans and states with recreational marijuana laws because the trends in the treatment states were different from the trends in the control states in the pre-intervention period. Therefore, I cannot interpret the associations between medical marijuana laws without smoking bans and the ED visits and between recreational marijuana laws and the ED visits as causation.

Figure 2.5 Pre- and post-trend in ED visits in law states relative to the control states

Relative changes in marijuana-related ED visits in states with smoking ban



Relative changes in opioid-related ED visits in states with smoking ban



2.6.2 Ordinary least squares (OLS) regression

I also estimated the main model using OLS regression with the outcome variables being marijuana- and opioid-related ED visit rates (the number of ED visits per 1,000,000 enrollees) (Table 2.8).

Overall, the results from the OLS estimation are consistent with those from the negative binomial estimation—that is, state implementation of medical marijuana laws with smoking ban was associated with decreases in the number of marijuana- and opioid-related ED visits per 1,000,000 enrollees.

Table 2.8 Effect of medical marijuana laws (MMLs) with smoking ban on ED visits (OLS regression results)

Marginal effect	Marijuana ED visits per 1,000,000 enrollees	Marijuana ED visits under 21 per 1,000,000 enrollees	Marijuana ED visits 21 and older per 1,000,000 enrollees	Opioid ED visits per 1,000,000 enrollees	Opioid ED visits under 21 per 1,000,000 enrollees	Opioid ED visits 21 and older per 1,000,000 enrollees
MMLs with smoking ban	**-6.298*** (-10.464, -2.132)**	-6.952* (-14.669, 0.765)	**-5.486** (-9.704, -1.268)**	**-4.709** (-9.032, -0.386)**	-4.633* (-9.392, 0.127)	-4.436* (-9.431, 0.560)

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level.

2.6.3 Outcomes at the state/quarter level

To check the sensitivity of my main results, I collapsed the outcome and independent variables at the state/quarter level to estimate the main model (Table 2.9). The results are consistent with the main results.

Table 2.9 Effects of medical marijuana laws (MML) and recreational marijuana laws (RML) on ED outcomes (quarter as the time unit)

Marginal effect	Marijuana ED visits	Marijuana ED visits under 21	Marijuana ED visits 21 and older	Opioid ED visits	Opioid ED visits under 21	Opioid ED visits 21 and older
MMLs with smoking ban	**-0.164****	-0.105	**-0.157****	**-0.162****	-0.083	**-0.157****
	(-0.297, -0.031)	(-0.245 0.036)	**(-0.310, -0.004)**	**(-0.288, -0.036)**	(-0.231, 0 .065)	**(-0.292, -0.021)**
Discrete change from the baseline predicted number of events	**-9.159*****	-2.451	**-5.129****	**-13.476*****	-1.762	**-10.010**
	(-16.072, -2.246)	(-5.592 0.690)	**(-9.871, -0.386)**	**(-23.397, -3.555)**	(-4.789, 1.266)	**(-18.052, -1.968)**
Baseline predicted number of events (MMLs with smoking ban=0)	60.524	24.676	35.838	91.300	22.170	69.088
n	1,196	1,196	1,196	1,196	1,196	1,196

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level.

2.7 Discussion and conclusions

This study furthers our understanding of the impact of medical marijuana laws with smoking bans on marijuana- and opioid-related ED visits. I found that state implementation of medical marijuana laws with smoking bans was associated with a 16.3 percent decrease in the marijuana-related ED visit rate and with a 12.5 percent decrease in the opioid-related ED visit rate. The decrease in expected marijuana-related ED visits was mainly in those aged 21 and older, while the decrease in expected opioid-related ED visits was largely in those aged under 21. State implementation of medical marijuana laws with smoking bans coupled with legal dispensaries was associated with both statistical and economical decreases in expected marijuana- and opioid-related ED visits among all ages.

Much media attention has been paid to the danger of overconsuming edible marijuana, yet I found that medical marijuana laws with smoking bans not only did not increase marijuana- and opioid-related ED visits but also may be associated with fewer such ED visits when coupled with legal dispensaries. I am the first to test the effect of medical marijuana laws with smoking bans. My results suggest that non-smokable forms of marijuana may be a safer alternative compared to the smokable form of marijuana. Cannabinoid hyperemesis associated with excessive marijuana smoking has been well documented and using non-smokable form of marijuana may prevent ED visits associated with such syndrome. In addition, medical marijuana laws with smoking bans may prevent people from consuming the plant forms of marijuana that vary in active ingredients from batch to batch, while other standardized forms of marijuana, including marijuana edibles, may be safer and more effective alternatives compared to the smokable plant form. Legal dispensaries may be the frontline to ensure safe use of marijuana as states regulate marijuana products sold in legal dispensaries by lab testing and proper labeling of ingredients, including pesticides, and warnings to encourage safe use. However, since smoking marijuana tend to leave traceable odor that police officers can often discern, smoking ban without legal dispensaries may de facto also ban smoking illegal marijuana. Therefore, smoking ban without legal dispensaries may provide very limited legal protections for people who use marijuana for medical purposes and may also discourage illegal marijuana use, which may discourage overall marijuana use in a state. My results also suggest that non-plant forms of marijuana might be substitutes for opioids in medical uses, especially for those aged under 21. Limited evidence suggests that the effectiveness of marijuana in alleviating pain and other symptoms depends on both the concentration of cannabidiol and delta-9-tetrahydrocannabinol (THC), and the ratio of between those two. Standardized marijuana products have been engineered to achieve the potential therapeutic effects (Hill, 2015). Medical and recreational marijuana dispensaries could be a necessary part of marijuana legalization to provide accessible and standardized marijuana products, and alleviate the current opioid crisis.

Limitations

I recognize that this study has the following limitations. First, the individuals in the sample were identified based on their residents' zip codes, therefore, if the ED visits happen in states that were not their residency, the estimates may be on the conservative side. If I were able to identify ED visit cases based on the ED zip codes, I may find larger effect sizes of marijuana laws. However, the unknown effect of marijuana tourism would not change the direction of the effect of marijuana laws. Second, I did not know the direct causes that those individuals end up in the EDs as all ED visits identified based on the association between ED visits and marijuana or opioid use. This may introduce errors into the estimations.

2.8 Conclusions

This study examines the effect of medical marijuana laws with smoking bans on marijuana- and opioid-related ED visits. The findings suggest that medical marijuana laws with smoking ban may not increase marijuana- and opioid-related ED visits and regulated dispensaries may decrease such ED visits as they may provide safer marijuana products. Although media often draws its attention to accidents related to edible marijuana, smoking may still be a less safe route to use marijuana. Policies that prohibit smoking marijuana and provide other forms of accessible marijuana may make marijuana use safer and result in less ED visits. More studies are needed to test the effect of smoking ban.

CHAPTER 3. Marijuana Use in E-cigarettes among U.S. Youth

3.1 Problem statement

Marijuana use in e-cigarettes has been coupled with the latest trend of e-cigarette use among youth (Katrina et al., 2018; Miech et al., 2019). E-cigarette use among US youth has been growing rapidly. By 2014, e-cigarettes had replaced traditional combusted tobacco products, such as cigarettes, and become the most used nicotine products among US middle and high school students (Neff et al., 2015). Marijuana use in e-cigarettes may introduce additional risks.

This paper is motivated by two potential problems associated with youth marijuana use in e-cigarettes. First, marijuana use among youth may lead to neurocognitive impairments (Schweinsburg, Brown, & Tapert, 2008), which may further lower academic achievement (Arria et al., 2015), thus adulthood success. It may also increase the risk of developing substance use disorders in adulthood (Lynskey et al., 2003), considering that marijuana might be a "gateway" drug to more dangerous drugs (Olfson et al., 2018; Kandel 2002, 1980, & 1975; DuPont, 1984).

Second, although e-cigarettes are considered to be safer substitutes for traditional tobacco products, authorities are less optimistic about their use among youth. Before 2016, e-cigarette products were largely unregulated. E-cigarettes refer to the nicotine administration devices that heat the liquid containing solvents and nicotine as well as other additives, such as flavorings, to generate aerosol for users to inhale. The U.S. Food and Drug Administration's (FDA) implementation of the deeming rule in 2016, which authorizes the FDA to regulate any innovative nicotine-containing products as long as the FDA deems the products as tobacco products, set the minimum age for e-cigarette purchase and use to 18, the same as traditional tobacco products.[18] In December 2019, the U.S. Congress passed a law to further raise the legal minimum age for all tobacco product purchases, including e-cigarettes, to 21. The new law, introduced by Republican Senator Mitch McConnell from Kentucky, and Democratic Senator Tim Kaine from Virginia, gained bipartisan support in the Congress. Even before this new federal minimum age law, 19 states and Washington D.C., as well as hundreds of localities, had already raised the legal age to 21.[19] Those laws were largely responsive to concerns about the widespread e-cigarette use among youth. By 2014, e-cigarettes had replaced traditional combusted tobacco products, such as cigarettes, and become the most used nicotine products among US middle and high school students (Neff et al., 2015). E-cigarette use among US youth continues to grow rapidly (Miech et al., 2019). .

Nicotine induces instant rewarding feelings and leads to addiction. Nicotine dependence is associated with lung diseases, various cancers and cardiovascular diseases. And, nicotine use is particularly detrimental to youth because they are still developing brains and other organs (Schraufnagel, 2015). Vaping has also been found to have an acute impact on blood vessel function (Caporale et al., 2019). Concurrent use of both nicotine and marijuana in e-cigarette devices may produce more harms compared to vaping nicotine alone or using marijuana alone. Use of e-cigarette also increases the likelihood of future initiation of combustible tobacco products (Barrington-Trimis et al., 2016). Therefore, it is also possible that use of marijuana in e-cigarettes leads to future

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[18] https://www.fda.gov/tobacco-products/rules-regulations-and-guidance/fdas-deeming-regulations-e-cigarettes-cigars-and-all-other-tobacco-products

[19] https://www.tobaccofreekids.org/what-we-do/us/sale-age-21; https://www.usatoday.com/story/money/2019/12/26/tobacco-minimum-age-fda-raises-age-buy-tobacco-18-21/2753807001/; https://www.tobaccofreekids.org/assets/factsheets/0398.pdf

initiation of smoking marijuana or tobacco products. Smoking has been proven to be harmful to pulmonary functions and is the one of the major causes of premature death. Moreover, nicotine might be a “gateway” drug to other hard drugs as well.

State liberalization of medical and recreational marijuana makes marijuana more accessible and further reduces youth perceptions of riskiness associated with marijuana use. Meanwhile, perceived riskiness associated with e-cigarettes also declines among youth among whom the popularity of e-cigarettes continues to rise. Given that nonnicotine substances, including marijuana and THC concentrates, can be used in e-cigarettes (Katrina et al., 2018), the concurrent use of marijuana and nicotine products in e-cigarettes is expected.

Evidence concerning marijuana use among U.S. youth is scarce. To my knowledge, no study has examined the individual characteristics associated with marijuana use in e-cigarettes among US youth over a period of time. This study assesses the national trend of prevalence of self-reported marijuana use in e-cigarettes among US middle and high school students.

3.2 Literature Review

One study by the Centers for Disease Control and Prevention (CDC) examined the correlation between various individual characteristics and marijuana use in e-cigarettes among U.S. middle and high schoolers using the 2016 National Youth Tobacco Survey (NYTS). The study found that marijuana use in e-cigarettes was significantly more prevalent among male students, high school students, those students who used e-cigarettes in the past 30 days, those who used e-cigarettes on 20-30 days in the past 30 days, and those who cohabited with a tobacco user (Katrina et al., 2018).

One study analyzed the Monitoring the Future survey and found that the prevalence of marijuana vaping increased from 2017 to 2018, and from 2018 to 2019 among 8th, 10th, and 12th graders. The results were consistent for past 30 day use, past 12 month use and lifetime use (i.e. ever use) (Miech et al., 2019). However, this study did not discuss how demographic characteristics related to marijuana vaping.

Many studies have examined the prevalence of e-cigarette use and the perceived riskiness associated with e-cigarettes use.

A study by the CDC and the Food and Drug Administration (FDA) discussed the use of tobacco products among U.S. youth (i.e., middle and high school students). By examining data from the 2011-2014 NYTS using a logistic regression model, the study found that in 2014, e-cigarettes became the most commonly used tobacco products among U.S. youth, followed by hookahs, cigarettes, cigars, smokeless tobacco, snus, pipes, bidis, and dissolvable nicotine products. From 2011 to 2014, youth current use (use in the past 30 days) of e-cigarettes and hookah increased significantly, while youth current use (use in the past 30 days) of conventional combustible cigarettes decreased significantly. The overall tobacco product use, however, did not increase significantly (Arrazola et al., 2015).

Porter et al. (2015) specifically examined youth use of e-cigarettes and traditional combustible cigarettes among youth (i.e., middle and high school students) in Florida between 2011 and 2014 using data from the Florida Youth Tobacco Survey. They found that ever use and current use (use in the past 30 days) of e-cigarettes increased significantly among both middle and high school students, and in comparison, ever use and current use (use in the past 30 days) of combustible cigarettes decreased significantly.

The above two studies had consistent findings with respect to youth e-cigarette and combustible cigarette use. Both studies used a logistic regression model which allows demographic characteristics, such as school level, gender, race/ethnic, and household tobacco use to be used to predict the probability of e-cigarette ad cigarette use. Those two studies both discussed the association between gender, race and e-cigarette use. Particularly, males were more likely to be current e-cigarette users than females; and, non-Hispanic whites and Hispanics were more likely to be current e-cigarettes users than non-Hispanic other races, including blacks.

Perhaps the mechanism which drives youth e-cigarette use is that youth perceive e-cigarettes to be less harmful compared to traditional tobacco products (Ambrose et al., 2014). After all, e-cigarettes were invented to aid smoking cessation and are considered to be safer than combustible cigarettes as the combustion smoke contains multiple chemical constituents that are directly linked to lung, cardiovascular and other diseases that contribute to premature deaths (Ryu et al., 2001; Boyle, 1997). Or, maybe youth just use e-cigarettes out of curiosity (Surís et al.,2015).

Ambrose et al. (2014) used multinomial logistic regression models to analyze data from the 2012 NYTS to study youth perceived harms associated with e-cigarette and cigarette use. They found that most youth regarded the harms as a function of cigarette doses. The dose-determinant view was more prevalent in middle school students, male students, non-Hispanic whites, and never smokers. Moreover, those with the dose-determinant view were more likely to consider e-cigarettes as less harmful than conventional cigarettes, suggesting youth may be more prone to e-cigarette use. This study limited its analysis to one year of data and therefore was not able to discuss how the perceived harms vary over years. Also, e-cigarettes did not become the most commonly used tobacco products until 2014, so the 2012 study may lack validity and reliability to explain the youth perception now. For example, about half of the respondents had never heard about e-cigarettes in 2012.

Marketing efforts may contribute to the perceived safety associated with e-cigarettes, while state medical and recreational marijuana laws seem to more directly lift the harm labels attached to marijuana. The perceived riskiness associated with marijuana use has been declining over years (Wen et al., 2019).

Wen et al. (2019) used data from the 2004-2012 National Survey on Drug Use and Health (NSDUH) and examined how medical marijuana laws affect perceived riskiness associated with marijuana use among youth and young adults. Employing a difference-in-differences design, they found that the implementation of medical marijuana laws was associated with lowered perceived riskiness. A non-experimental study by Okaneku et al. (2015) also found a decrease in perceived riskiness associated with marijuana use from 2002 to 2012 among all age groups using the NSDUH.

3.3 Research Questions

a. What is the trend of marijuana vaping among middle and high school students after controlling for basic demographics (i.e., sex, race/ethnicity, and school type)?

b. What are the associations between other individual behavioral and environmental factors (i.e., current (past 30 days) use of e-cigarettes, current (past 30 days) use of tobacco products that were not e-cigarettes, cohabiting with at least one tobacco user, ever use e-cigarettes because e-cigarettes cost less compared to other tobacco products, ever use e-cigarettes due to less perceived harmfulness associated with e-cigarette use than other tobacco use, and ever use e-cigarettes because flavored e-cigarettes are available) and marijuana vaping?

c. What are the trends of marijuana vaping among groups of different sex, race/ethnicity, and school type?

d. What are the trends of marijuana vaping among those who reported flavors as one of the reasons for using e-cigarettes and among those who did not report flavors as one of the reasons for using e-cigarettes?

e. What are the trends of marijuana vaping among those who reported less cost as one of the reasons for using e-cigarettes and among those who did not report less cost as one of the reasons for using e-cigarettes?

f. What are the trends of marijuana vaping among those who reported less harmfulness as one of the reasons for using e-cigarettes and among those who did not report less harmfulness as one of the reasons for using e-cigarettes?

3.4 Data and Methods

I used data from the 2016, 2017 and 2018 National Youth Tobacco Survey (NYTS), a nationally representative sample of US 6 to 12 grade students. I limit the study to these years because the NYTS only asked a question about marijuana use in e-cigarettes from 2016 to 2018. The NYTS used a stratified three-stage sample design to produce a school-based sample of both public and private school students. A total of 20,675; 17,872; and 20,189 students completed questionnaires with a participation rate of 71.6%, 68.1%, and 68.2% for the 2016, 2017 and 2018 NYTS, respectively. I estimated the prevalence of marijuana use in e-cigarettes by the response “Yes, I have used an e-cigarette device with marijuana, THC or hash oil, or THC wax,” to the question 37 (Q37) “Have you ever used an e-cigarette device with a substance besides nicotine? (Select one or more)” in the 2016 NYTS. Other responses to Q37 include “Yes, I have used an e-cigarette device with another substance that is not marijuana, THC or hash oil, or THC wax,” “No, I have only used an e-cigarette device with nicotine,” “No, I have never used an e-cigarette device,” and “Don’t know/Not Sure.” The 2017 and 2018 NYTS changed the way to ask the question about marijuana use in e-cigarettes. Therefore, I determined marijuana use in e-cigarettes by the response “Yes,” to the question 34 (Q34) “Have you ever used marijuana, marijuana concentrates, marijuana waxes, THC, or hash oil in an e-cigarette?” in both the 2017 and 2018 NYTSs. Other responses to Q34 include “No,” and “I have never used an electronic product.” The institutional review board (IRB) of the Centers for Disease Control and Prevention (CDC), Atlanta, Georgia, approved the 2016 NYTS data collection. The IRBs of ICF and CDC approved the 2017 and 2018 NYTS data collection. IRB waived the need for its review for my use of the NYTS deidentified data.

I control for the basic demographic variables: sex, race/ethnicity and school level (middle/high). I also control for individual behavioral and environmental factors associated with use of e-cigarettes and other tobacco products: current (past 30 days) use of e-cigarettes, current (past 30 days) use of tobacco products that were not e-cigarettes, cohabiting with at least one tobacco user, ever use e-cigarettes because e-cigarettes cost less compared to other tobacco products, ever use e-cigarettes due to less perceived harmfulness associated with e-cigarette use than other tobacco use, and ever use e-cigarettes because flavored e-cigarettes are available.

Since the dependent variable is a dichotomous variable and I want to know the predicted probability of marijuana use in e-cigarettes, I use the following logistic regression model to estimate the trend of the prevalence of marijuana use in e-cigarettes between 2016 and 2018 among those who ever used e-cigarettes:

$$\ln(\boldsymbol{Y_{i,t}}/(\mathbf{1}- \boldsymbol{Y_{i,t}})) = \beta_0 + \gamma \boldsymbol{X_{i,t}} + \eta_t, \quad (1)$$

where i denotes a student respondent and t denotes a year. $\boldsymbol{Y_{i,t}}$ represents whether a student used marijuana in e-cigarettes in a year. $\boldsymbol{X_{i,t}}$ is a vector of covariates. η_t is the year fixed effects.

3.5 Results

Table 3.1 presents the descriptive results. The percentage of reported marijuana vapers increased from 8.9% in 2016, to 11.1% in 2017 and to 14.7% in 2018 among all participants. The percentage of reported marijuana vapers decreased from 30.6% in 2016 to 21.4% in 2017, but increased from 21.4% in 2017 to 26.2% in 2018 among participants who ever used e-cigarettes. Regardless, reported marijuana vaping increased from 2016 to 2018 among high school students who accounted for the majority of marijuana vapers in the sample.

Table 3.1 Prevalence of Reported Marijuana Vaping in e-Cigarettes Among US Middle and High School Students by Characteristic and Year

	All Participants (N=58,736)			Participants Who Ever Used e-Cigarettes (N=24,827)		
	2016 (N= 20,675)	2017 (N= 17,872)	2018 (N= 20,189)	2016 (N= 5,217)	2017 (N= 8,930)	2018 (N= 10,680)
Characteristic						
No. Total	1,783	1,975	2,791	1,621	1,975	2,791
Weighted %	8.9	11.1	14.7	30.6	21.4	26.2
(95% CI)	(8.1-9.9)	(9.9-12.6)	(13.3-16.2)	(28.3-33.1)	(19.3-23.6)	(24.0-28.5)
School Level						
No. of Middle school	446	371	475	380	371	475
Weighted %	4.4	4.5	5.5	23.1	9.2	10.9
(95% CI)	(4.0-5.0)	(3.8-5.3)	(4.9-6.1)	(0.5-25.9)	(7.9-10.7)	(9.8-12.1)
No. of High school	1,327	1,582	2,289	1,232	1,582	2,289
Weighted %	12.4	16.1	21.7	33.3	29.4	35.9
(95% CI)	(10.9-14.2)	(15.2-17.0)	(20.8-22.7)	(31.4-35.2)	(27.9-31.0)	(34.5-37.3)

Table 3.1 Prevalence of Reported Marijuana Vaping in e-Cigarettes Among US Middle and High School Students by Characteristic and Year (continued)

Sex						
No. of Male	1,087	1,024	1,416	997	1,024	1,416
Weighted %	10.6	11.2	14.6	33.3	21.3	25.9
(95% CI)	(9.7-11.5)	(9.9-12.6)	(13.2-16.0)	(30.7-35.9)	(19.1-23.7)	(23.8-28.2)
No. of Female	682	926	1,343	612	926	1,343
Weighted %	7.2	10.9	14.7	27.2	21.2	26.3
(95% CI)	(6.0-8.6)	(9.4-12.6)	(13.0-16.5)	(23.6-31.3)	(18.8-23.9)	(23.7-29.2)
Race/ethnicity						
No. of White non-Hispanic	769	816	1,314	697	816	1,314
Weighted %	8.5	10.8	14.5	29.1	20.9	26.0
(95% CI)	(7.5-9.6)	(9.3-12.4)	(12.7-16.5)	(26.9-31.3)	(18.5-23.7)	(23.0-29.2)
No. of Other non-Hispanic	112	76	93	99	76	93
Weighted %	7.2	5.5	8.8	32.9	12.8	19.1
(95% CI)	(5.6-9.3)	(4.2-7.3)	(6.8-11.3)	(26.3-40.3)	(9.8-16.7)	(15.1-23.8)

Table 3.1 Prevalence of Reported Marijuana Vaping in e-Cigarettes Among US Middle and High School Students by Characteristic and Year (continued)

No. of Black non-Hispanic	250	339	273	217	339	273
Weighted %	8.4	10.5	11.6	32.8	19.7	21.6
(95% CI)	(7.2-9.7)	(9.2-12.0)	(9.5-14.0)	(28.5-37.3)	(17.3-22.5)	(18.0-25.7)
No. of Hispanic	588	674	1,006	551	674	1,006
Weighted %	10.8	14.1	18.4	32.4	25.4	30.6
(95% CI)	(9.0-12.9)	(12.2-16.1)	(16.3-20.7)	(28.4-36.6)	(22.6-28.5)	(27.5-34.0)
Current (Past 30 Days) use of e-cigarettes						
No. of No	1,166	1,257	1,371	1,008	1,257	1,371
Weighted %	6.1	7.4	8.1	26.3	15.3	16.5
(95% CI)	(5.5-6.9)	(6.6-8.2)	(7.1-9.3)	(23.6-29.2)	(14.0-16.8)	(14.6-18.6)
No. of Yes	582	680	1380	579	680	1,380
Weighted %	39.5	51.7	53.5	40.3	53.9	55.2
(95% CI)	(35.6-43.5)	(48.3-55.0)	(50.2-56.8)	(36.4-44.4)	(50.5-57.3)	(51.9-58.6)

Table 3.1 Prevalence of Reported Marijuana Vaping in e-Cigarettes Among US Middle and High School Students by Characteristic and Year (continued)

Current (past 30 days) use of tobacco products that were not e-cigarettes						
No. of No	981	1,067	1,600	834	1,067	1,600
Weighted %	5.3	6.7	9.6	22.6	13.8	18.4
(95% CI)	(4.7-6.0)	(5.8-7.8)	(8.5-10.8)	(20.4-24.9)	(12.2-15.7)	(16.5-20.6)
No. of Yes	799	906	1,186	785	906	1,186
Weighted %	38.4	51.4	56.0	46.9	60.5	64.2
(95% CI)	(33.8-43.3)	(48.4-54.4)	(52.3-59.6)	(42.3-51.6)	(57.3-63.7)	(61.4-66.9)

Table 3.1 Prevalence of Reported Marijuana Vaping in e-Cigarettes Among US Middle and High School Students by Characteristic and Year (continued)

Cohabiting with at least one tobacco user						
No. of No	726	841	1,167	633	841	1,167
Weighted %	6.0	7.6	10.5	27.8	15.9	20.5
(95% CI)	(5.3-6.7)	(6.4-9.0)	(9.1-12.1)	(25.0-30.7)	(13.6-18.4)	(18.1-23.1)
No. of Yes	905	978	1,404	848	978	1,404
Weighted %	13.0	16.8	20.8	31.7	28.4	33.3
(95% CI)	(11.4-14.8)	(15.0-18.7)	(19.0-22.8)	(29.0-34.6)	(25.8-31.2)	(30.6-36.1)

Table 3.1 Prevalence of Reported Marijuana Vaping in e-Cigarettes Among US Middle and High School Students by Characteristic and Year (continued)

Ever use e-cigarettes because e-cigarettes cost less compared to other tobacco products						
No. of No	1,695	1,883	2,641	1,535	1,883	2,641
Weighted %	8.5	10.7	14.2	29.8	20.7	25.5
(95% CI)	(7.7-9.5)	(9.5-12.0)	(12.8-15.7)	(27.3-32.3)	(18.7-22.8)	(23.4-27.8)
No. of Yes	83	75	126	81	75	126
Weighted %	61.3	71.8	62.7	61.1	76.2	68.8
(95% CI)	(52.1-69.8)	(61.4-80.3)	(53.5-71.1)	(51.8-69.6)	(65.9-84.2)	(59.6-76.7)

Table 3.1 Prevalence of Reported Marijuana Vaping in e-Cigarettes Among US Middle and High School Students by Characteristic and Year (continued)

Ever use e-cigarettes due to less perceived harmfulness associated with e-cigarette use than other tobacco use						
No. of No	1,547	1,710	2,323	1,388	1,710	2,323
Weighted %	8.0	9.9	12.9	30.4	19.7	24.0
(95% CI)	(7.2-9.0)	(8.9-11.1)	(11.6-14.3)	(27.7-33.2)	(17.9-21.6)	(21.9-26.3)
No. of Yes	231	248	444	228	248	444
Weighted %	31.0	42.4	47.4	32.1	44.3	49.1
(95% CI)	(26.8-35.5)	(37.5-47.4)	(43.4-51.5)	(27.9-36.6)	(39.3-49.5)	(45.0-53.1)

Table 3.1 Prevalence of Reported Marijuana Vaping in e-Cigarettes Among US Middle and High School Students by Characteristic and Year (continued)

Ever use e-cigarettes because flavored e-cigarettes are available						
No. of No	1,344	1,539	2,069	1,184	1,539	2,069
Weighted %	7.1	9.1	11.8	29.3	18.5	22.5
(95% CI)	(6.3-8.0)	(8.1-10.2)	(10.6-13.1)	(26.5-32.4)	(16.7-20.4)	(20.5-24.6)
No. of Yes	434	419	698	432	419	698
Weighted %	33.4	41.6	47.4	34.4	43.4	49.6
(95% CI)	(29.8-37.3)	(37.8-45.5)	(43.6-51.3)	(30.8-38.3)	(39.5-47.3)	(45.8-53.4)

3.5.1 Results among all participants

I estimated results among all participants using two models. The basic models (Table 3.2: models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time, although school type was correlated with time if there was repeated sampling. To account for the possible correlation between school type and time, I examined results by school type in the following sections. The full models (Table 3.2: models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors (i.e., current (past 30 days) use of e-cigarettes, current (past 30 days) use of tobacco products that were not e-cigarettes, cohabiting with at least one tobacco user, ever use e-cigarettes because e-cigarettes cost less compared to other tobacco products, ever use e-cigarettes due to less perceived harmfulness associated with e-cigarette use than other tobacco use, and ever use e-cigarettes because flavored e-cigarettes are available) that may be correlated with time. Results from the full models told us the association between additional factors and marijuana vaping but may not tell us the much about the trend because the effect of those time-variant factors may confound the effect of time. Thus, I mostly relied on the basic models to explain the trend.

Controlling for demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)), logistic results indicated that marijuana vaping among all participants increased from 9.0% (95% CI, 8.1%-9.8%) in 2016 to 11.1% (95% CI, 9.9%-12.3%) in 2017, and to 14.7% (95% CI, 13.6%-15.8%) in 2018 (Figure 3.1; Table 3.2). Being male was at 1.148 (95% CI, 1.064 - 1.239) times greater odds of marijuana vaping compared to being female. Compared to White non-Hispanic, Hispanic was at 1.390

(95% CI, 1.246 - 1.551) times greater odds of marijuana vaping, while other non-Hispanic was at 0.571 (95%, 0.463 - 0.704) times lower odds of marijuana vaping. High school participants were at 4.054 (95%, 3.621 - 4.539) times greater odds of marijuana vaping than middle school participants.

I also wanted to know if behavioral and environmental factors were associated with marijuana vaping. Therefore, I ran the logistic model while also controlling for those factors (i.e., current (past 30 days) use of e-cigarettes, current (past 30 days) use of tobacco products that were not e-cigarettes, cohabiting with at least one tobacco user, ever use e-cigarettes because e-cigarettes cost less compared to other tobacco products, ever use e-cigarettes due to less perceived harmfulness associated with e-cigarette use than other tobacco use, and ever use e-cigarettes because flavored e-cigarettes are available). Logistic results demonstrated that marijuana vaping among all participants increased from 2016 to 2018, albeit the effect sizes were slightly smaller than those of the basic logistic model (Table 3.2). The additional individual characteristics were all associated with an increase in the odds of marijuana vaping. Current use of e-cigarettes increased the odds of marijuana vaping by 3.912 (95% CI, 3.386 - 4.520). Current use of tobacco products that were not e-cigarettes increased the odds of marijuana vaping by 4.866 (95% CI, 4.314 - 5.488). Cohabiting with at least one tobacco user increased the odds of marijuana vaping by 1.491 (95% CI, 1.369 - 1.624). Those who ever used e-cigarettes because e-cigarettes cost less compared to other tobacco products were at 1.574 (95% CI, 1.076 - 2.303) times greater odds of marijuana vaping. Those who ever used e-cigarettes due to less perceived harmfulness associated with e-cigarette use than other tobacco use were at 1.344 (95% CI, 1.134 - 1.594) times greater odds of marijuana vaping. Moreover, those who ever used e-cigarettes because flavored e-cigarettes were available were at 2.245 (95% CI, 1.977 - 2.550) times greater odds of marijuana vaping.

However, this does not tell us much about the mechanism, because those demographic and individual characteristics were also associated with increased odds of e-cigarette use (Table 3.2). Moreover, the increased odds of e-cigarette use by most of those factors were much larger.

Figure 3.1 Marijuana Vaping among All Participants Controlling for Demographic Characteristics

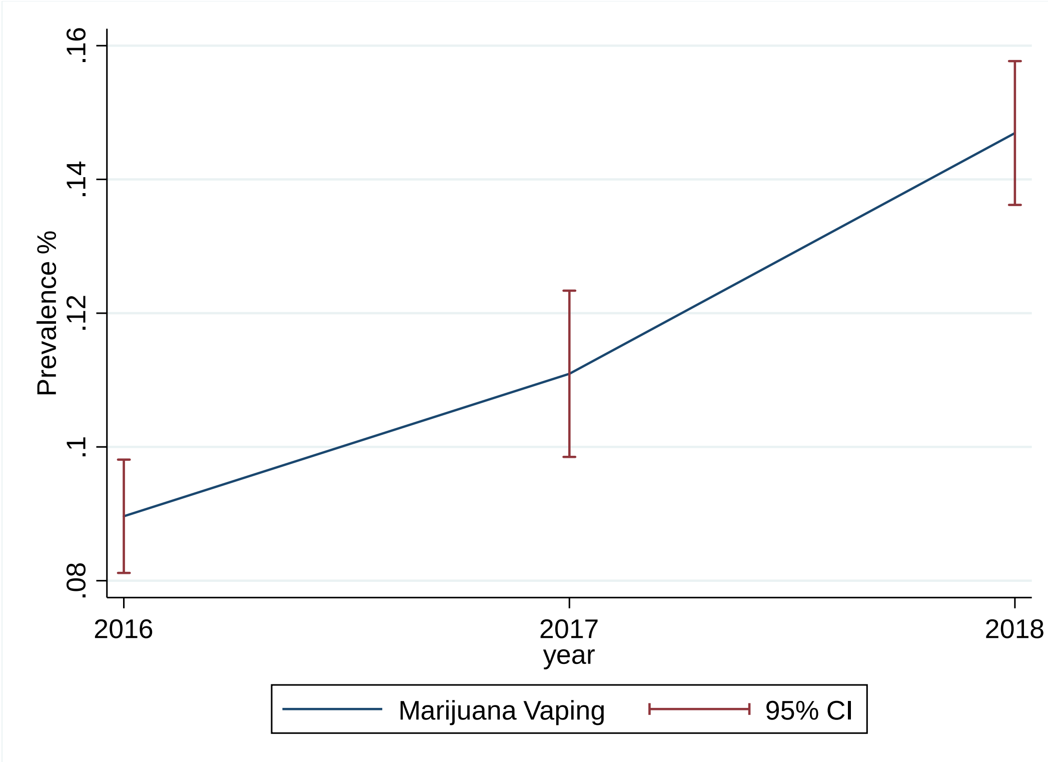

Table 3.2 Logistic Regression Results among All Participants

Marginal effects on odds ratio	(Model 1) Marijuana Vaping	(Model 2) Marijuana Vaping	(Model 3) Ever Use e-Cigarettes	(Model 4) Ever Use e-Cigarettes
Sex				
Female (reference)				
Male	**1.148*** (1.064 - 1.239)**	0.992 (0.905 - 1.086)	**1.118*** (1.065 - 1.173)**	1.031 (0.979 - 1.086)
Race/ethnicity				
White non-Hispanic (reference)				
Other non-Hispanic	**0.571*** (0.463 - 0.704)**	0.843 (0.682 - 1.043)	**0.676*** (0.588 - 0.778)**	**0.840** (0.730 - 0.966)**
Black non-Hispanic	0.917 (0.804 - 1.045)	**1.393*** (1.195 - 1.623)**	0.937 (0.853 - 1.029)	**1.165*** (1.047 - 1.295)**
Hispanic	**1.390*** (1.246 - 1.551)**	**1.883*** (1.654 - 2.143)**	**1.222*** (1.133 - 1.318)**	**1.367*** (1.271 - 1.469)**
School type				
Middle school (reference)				
High School	**4.054*** (3.621 - 4.539)**	**2.639*** (2.353 - 2.960)**	**1.689*** (1.540 - 1.852)**	**1.127*** (1.033 - 1.228)**
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**3.912*** (3.386 - 4.520)**		**21.170*** (16.463 - 27.222)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**4.866*** (4.314 - 5.488)**		**3.820*** (3.263 - 4.472)**

Table 3.2 Logistic Regression Results among All Participants (continued)

Cohabiting with at least one tobacco user				
No (reference)				
Yes		**1.491*** (1.369 - 1.624)**		**1.335*** (1.255 - 1.420)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		**1.574** (1.076 - 2.303)**		**3.024** (1.005 - 9.101)**
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		**1.344*** (1.134 - 1.594)**		**11.121*** (7.888 - 15.680)**
Ever use e-cigarettes because of flavor				
No (reference)				
Yes		**2.245*** (1.977 - 2.550)**		**20.188*** (15.252 - 26.721)**
Year				
2017 (reference)				
2016	**0.783*** (0.661 - 0.926)**	**0.676*** (0.565 - 0.810)**	**0.329*** (0.294 - 0.368)**	**0.227*** (0.205 - 0.251)**
2018	**1.401*** (1.195 - 1.642)**	**1.209** (1.007 - 1.451)**	**1.181*** (1.072 - 1.302)**	1.045 (0.955 - 1.144)
Constant	**0.042*** (0.036 - 0.049)**	**0.023*** (0.019 - 0.028)**	**0.745*** (0.680 - 0.816)**	**0.594*** (0.537 - 0.656)**
Observations	53,057	49,814	53,057	49,814

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

3.5.2 Results among participants who ever used e-cigarettes

Logistic results indicated that marijuana vaping among those who ever used e-cigarettes decreased from 27.9% (95% CI, 25.8%-30.0%) in 2016 to 22.1% (95% CI, 20.2%-24.0%) in 2017, but increased from 22.1% (95% CI, 20.2%-24.0%) in 2017 to 26.7% (95% CI, 25.0%-28.5%) in 2018, controlling for basic demographic characteristics (Figure 3.2; Table 3.3).

Compared to the effect sizes of both demographic characteristics and behavioral and environmental factors among all participants, the effect sizes among those who ever used e-cigarettes were generally smaller (Table 3.3). Additionally, considering e-cigarettes as harmless was no longer significantly associated with marijuana vaping among those who ever used e-cigarettes. This might suggest that those characteristics were more of determinants to those who chose to use e-cigarette devices than to those who chose to use marijuana in e-cigarette devices.

Figure 3.2 Marijuana Vaping among Those Who Ever Used e-Cigarettes Controlling for Demographic Characteristics

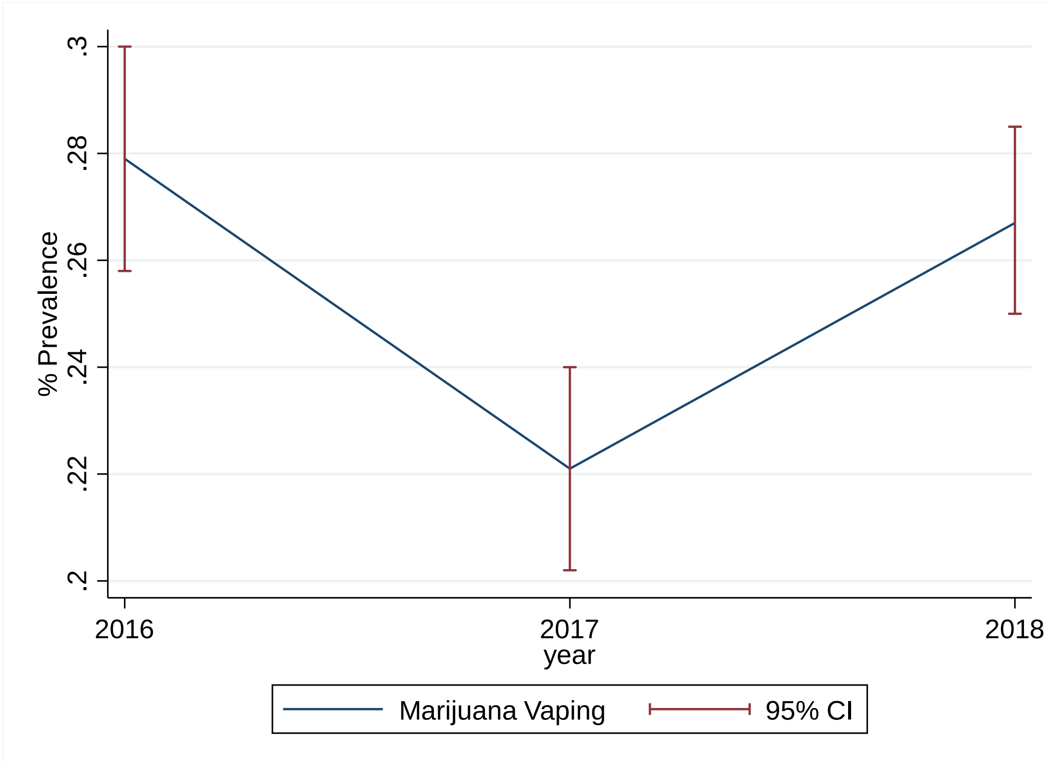

Table 3.3 Logistic Regression Results among Participants Who Ever Used e-Cigarettes

Marginal effects on odds ratio	(Model 1) Marijuana Vaping	(Model 2) Marijuana Vaping
Sex		
Female (reference)		
Male	**1.087**** **(1.006 - 1.175)**	0.962 (0.878 - 1.054)
Race/ethnicity		
White non-Hispanic (reference)		
Other non-Hispanic	**0.702***** **(0.565 - 0.872)**	0.902 (0.721 - 1.127)
Black non-Hispanic	1.015 (0.887 - 1.162)	**1.434***** **(1.225 - 1.678)**
Hispanic	**1.352***** **(1.212 - 1.508)**	**1.793***** **(1.573 - 2.042)**
School type		
Middle school (reference)		
High School	**3.620***** **(3.211 - 4.081)**	**2.645***** **(2.350 - 2.976)**
Current (past 30 days) use of e-cigarettes		
No (reference)		
Yes		**2.289***** **(1.996 - 2.626)**
Current (past 30 days) use of tobacco products that were not e-cigarettes		
No (reference)		
Yes		**3.625***** **(3.224 - 4.076)**
Cohabiting with at least one tobacco user		
No (reference)		
Yes		**1.340***** **(1.227 - 1.464)**
Ever use e-cigarettes because e-cigarettes cost less		
No (reference)		
Yes		**1.707***** **(1.244 - 2.341)**

Table 3.3 Logistic Regression Results among Participants Who Ever Used e-Cigarettes (continued)

Ever use e-cigarettes due to less perceived harmfulness		
No (reference)		
Yes		1.090 (0.940 - 1.263)
Ever use e-cigarettes because of flavor		
No (reference)		
Yes		**1.440***** **(1.284 - 1.615)**
Year		
2017 (reference)		
2016	**1.390***** **(1.182 - 1.634)**	0.957 (0.781 - 1.174)
2018	**1.305***** **(1.122 - 1.518)**	**1.216**** **(1.019 - 1.451)**
Constant	**0.100***** **(0.086 - 0.118)**	**0.059***** **(0.049 - 0.071)**
Observations	23,602	21,853

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

3.5.3 Results by school type

3.5.3.1 Among all participants

Logistic results indicated that marijuana vaping among all high school participants increased from 12.4% (95% CI, 10.9%-13.8%) in 2016 to 16.0% (95% CI, 14.1%-17.9%) in 2017, and to 21.7% (95% CI, 20.1%-23.3%) in 2018, controlling for basic demographic characteristics (Figure 3.3; Table 3.4). On the other hand, changes in marijuana vaping among all middle school participants were not significant from 2016 to 2018, controlling for basic demographic characteristics. When controlling for additional behavioral and environmental factors, marijuana vaping among all high school participants had similar increases, while marijuana vaping among all middle school participants still did not change significantly. Interestingly, demographic characteristics and behavioral and environmental factors had larger effects on the odds of marijuana vaping among all middle school participants than among all high school participants.

Figure 3.3 Marijuana Vaping among All Participants by School Type Controlling for Demographic Characteristics

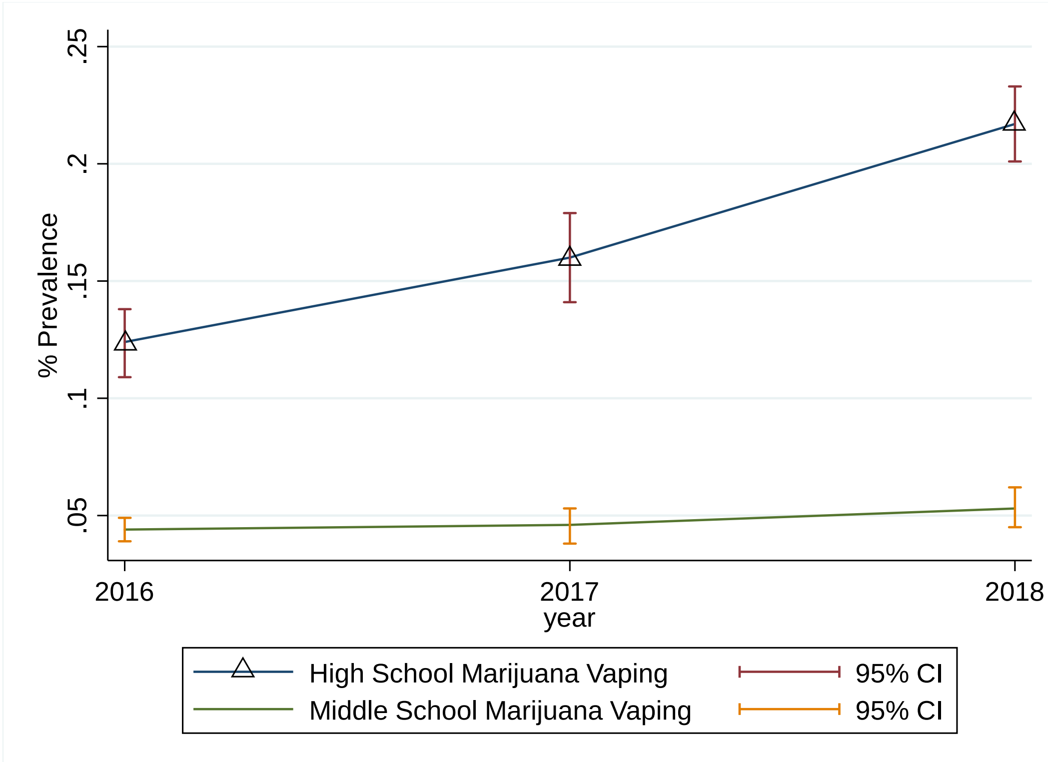

Table 3.4 Logistic Results among All Participants by School Type

Marginal effects on odds ratio	(Model 1) Marijuana Vaping Middle School	(Model 2) Marijuana Vaping Middle School	(Model 3) Marijuana Vaping High School	(Model 4) Marijuana Vaping High School
Sex				
Female (reference)				
Male	**1.427*** (1.183 - 1.722)**	**1.309** (1.043 - 1.643)**	**1.088** (1.000 - 1.185)**	0.929 (0.840 - 1.028)
Race/ethnicity				
White non-Hispanic (reference)				
Other non-Hispanic	0.775 (0.499 - 1.203)	0.802 (0.513 - 1.254)	**0.535*** (0.424 - 0.676)**	0.820* (0.648 - 1.039)
Black non-Hispanic	**1.748*** (1.352 - 2.261)**	**2.051*** (1.568 - 2.683)**	**0.773*** (0.671 - 0.889)**	**1.208** (1.021 - 1.429)**
Hispanic	**2.204*** (1.811 - 2.681)**	**2.249*** (1.810 - 2.796)**	**1.239*** (1.100 - 1.397)**	**1.740*** (1.508 - 2.008)**
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**4.747*** (3.408 - 6.613)**		**3.638*** (3.095 - 4.278)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**7.810*** (5.873 - 10.385)**		**4.422*** (3.895 - 5.020)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		**1.942*** (1.605 - 2.351)**		**1.370*** (1.242 - 1.512)**

Table 3.4 Logistic Results among All Participants by School Type (continued)

Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		**6.794*** (1.683 - 27.437)**		1.361 (0.938 - 1.973)
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		**2.669*** (1.693 - 4.210)**		**1.204** (1.017 - 1.425)**
Ever use e-cigarettes because of flavor				
No (reference)				
Yes		**2.256*** (1.643 - 3.099)**		**2.171*** (1.889 - 2.495)**
Year				
2017 (reference)				
2016	0.968 (0.782 - 1.199)	0.810 (0.612 - 1.072)	**0.740*** (0.608 - 0.899)**	**0.640*** (0.523 - 0.783)**
2018	1.177 (0.922 - 1.501)	1.120 (0.844 - 1.486)	**1.457*** (1.230 - 1.725)**	**1.236** (1.020 - 1.497)**
Constant	**0.028*** (0.022 - 0.037)**	**0.012*** (0.009 - 0.017)**	**0.183*** (0.158 - 0.213)**	**0.073*** (0.062 - 0.086)**
Observations	23,272	21,689	29,785	28,125

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

3.5.3.2 Among those who ever used e-cigarettes

Marijuana vaping among all high school participants increased from 2017 to 2018 regardless of model. Marijuana vaping among all middle school participants decreased from 2016 to 2017 and 2018, controlling for basic demographic characteristics (Table 3.5). When controlling for behavioral and environmental factors, changes in marijuana vaping among all middle school students became insignificant. The signs of effects of the behavioral and environmental factors on the odds of marijuana vaping among those who ever used e-cigarettes were consistent with the signs of effects among all participants. However, considering e-cigarettes as harmless was no longer significantly associated with marijuana vaping among high school participants who ever used e-cigarettes.

Table 3.5 Logistic Results among Those Who Ever Used e-Cigarettes by School Type

Marginal effects on odds ratio	(Model 1) Marijuana Vaping Middle School	(Model 2) Marijuana Vaping Middle School	(Model 3) Marijuana Vaping High School	(Model 4) Marijuana Vaping High School
Sex				
Female (reference)				
Male	**1.257** (1.024 - 1.541)**	1.146 (0.898 - 1.463)	1.044 (0.954 - 1.142)	0.925 (0.835 - 1.025)
Race/ethnicity				
White non-Hispanic (reference)				
Other non-Hispanic	0.904 (0.569 - 1.436)	0.873 (0.547 - 1.393)	**0.662*** (0.520 - 0.842)**	0.871 (0.680 - 1.116)
Black non-Hispanic	**1.482*** (1.155 - 1.902)**	**1.839*** (1.375 - 2.461)**	0.905 (0.781 - 1.048)	**1.293*** (1.087 - 1.539)**
Hispanic	**1.893*** (1.520 - 2.356)**	**2.103*** (1.648 - 2.685)**	**1.222*** (1.083 - 1.378)**	**1.648*** (1.425 - 1.906)**
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**2.654*** (1.920 - 3.669)**		**2.119*** (1.821 - 2.465)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**6.129*** (4.655 - 8.068)**		**3.261*** (2.876 - 3.697)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		**1.718*** (1.412 - 2.092)**		**1.230*** (1.114 - 1.359)**

Table 3.5 Logistic Results among Those Who Ever Used e-Cigarettes by School Type (continued)

Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		**7.822*** (2.365 - 25.866)**		**1.465** (1.079 - 1.988)**
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		**1.867*** (1.232 - 2.829)**		0.997 (0.861 - 1.154)
Ever use e-cigarettes because of flavor				
No (reference)				
Yes		**1.494*** (1.137 - 1.963)**		**1.388*** (1.225 - 1.573)**
Year				
2017 (reference)				
2016	**2.761*** (2.194 - 3.474)**	1.329* (0.952 - 1.856)	1.175* (0.977 - 1.412)	0.866 (0.692 - 1.083)
2018	1.145 (0.897 - 1.461)	1.130 (0.857 - 1.490)	**1.349*** (1.149 - 1.585)**	**1.248** (1.036 - 1.502)**
Constant	**0.070*** (0.055 - 0.090)**	**0.033*** (0.024 - 0.046)**	**0.398*** (0.345 - 0.459)**	**0.189*** (0.161 - 0.222)**
Observations	8,692	7,981	14,910	13,872

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

3.5.4 Results by race, gender and school

3.5.4.1 Among White non-Hispanic

The odds of marijuana vaping mainly increased among high-school non-Hispanic White (Tables 3.6&3.7). The basic models (Table 3.7: models 1&3) demonstrated that the odds of marijuana vaping among high-school white non-Hispanic female participants increased from 2016 to 2018 and the odds of marijuana vaping among high-school white non-Hispanic male participants increased from 2017 to 2018. E-cigarette use because of flavors was associated with increased odds of marijuana vaping among both high-school white non-Hispanic male and female participants; and the effect size was larger for the female participants. E-cigarette use due to its less cost was associated with very substantially increased odds of marijuana vaping among middle-school white non-Hispanic female participants.

Table 3.6 Logistic Results among Middle School White non-Hispanic

Marginal effects on odds ratio	(Model 1) Middle School White non-Hispanic Male	(Model 2) Middle School White non-Hispanic Male	(Model 3) Middle School White non-Hispanic Female	(Model 4) Middle School White non-Hispanic Female
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**5.289*** (3.167 - 8.833)**		**7.528*** (3.339 - 16.972)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**7.074*** (4.543 - 11.015)**		**8.179*** (4.044 - 16.545)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		**2.124*** (1.421 - 3.175)**		**1.914** (1.054 - 3.475)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		**5.790** (1.260 - 26.602)**		**193.257*** (8.933 - 4,180.881)**
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		**2.290** (1.139 - 4.606)**		1.780 (0.547 - 5.790)

Table 3.6 Logistic Results among Middle School White non-Hispanic (continued)

Ever use e-cigarettes because of flavor				
No (reference)				
Yes		1.695 (0.833 - 3.448)		**2.619** (1.058 - 6.485)**
Year				
2017 (reference)				
2016	1.184 (0.764 - 1.835)	1.115 (0.662 - 1.878)	0.804 (0.411 - 1.571)	0.860 (0.413 - 1.788)
2018	1.191 (0.749 - 1.895)	1.141 (0.670 - 1.942)	1.441 (0.740 - 2.804)	1.450 (0.716 - 2.935)
Constant	**0.039*** (0.027 - 0.055)**	**0.014*** (0.009 - 0.021)**	**0.027*** (0.015 - 0.048)**	**0.010*** (0.005 - 0.020)**
Observations	5,549	5,212	5,574	5,322

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for time. The full models (models 2 &4) controlled for additional behavioral and environmental factors that may be correlated with time.

Table 3.7 Logistic Results among High School White non-Hispanic

Marginal effects on odds ratio	(Model 1) High School White non-Hispanic Male	(Model 2) High School White non-Hispanic Male	(Model 3) High School White non-Hispanic Female	(Model 4) High School White non-Hispanic Female
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**3.827*** (3.019 - 4.852)**		**3.726*** (2.869 - 4.841)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**4.692*** (3.736 - 5.892)**		**3.823*** (2.935 - 4.980)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		**1.390*** (1.144 - 1.688)**		**1.340*** (1.095 - 1.639)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		1.703* (0.972 - 2.984)		1.246 (0.562 - 2.762)
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		1.307* (0.987 - 1.731)		1.138 (0.832 - 1.558)

Table 3.7 Logistic Results among High School White non-Hispanic (continued)

Ever use e-cigarettes because of flavor				
No (reference)				
Yes		**1.544*** (1.195 - 1.996)**		**2.512*** (1.975 - 3.196)**
Year				
2017 (reference)				
2016	0.876 (0.694 - 1.107)	0.745* (0.540 - 1.027)	**0.599*** (0.451 - 0.795)**	**0.553*** (0.408 - 0.749)**
2018	**1.415*** (1.169 - 1.712)**	1.095 (0.821 - 1.461)	**1.511*** (1.173 - 1.948)**	1.167 (0.869 - 1.568)
Constant	**0.192*** (0.164 - 0.224)**	**0.066*** (0.052 - 0.083)**	**0.191*** (0.157 - 0.232)**	**0.081*** (0.064 - 0.102)**
Observations	7,418	7,041	7,267	7,005

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for time. The full models (models 2 &4) controlled for additional behavioral and environmental factors that may be correlated with time.

3.5.4.2 Among other non-Hispanic

The odds of marijuana vaping increased among other non-Hispanic male participants from 2017 to 2018 (Tables 3.8&3.9). Those high-school other non-Hispanic female participants who used e-cigarettes because of less perceived harmfulness were at greater odds of vaping marijuana.

Table 3.8 Logistic Results among Middle School other non-Hispanic

Marginal effects on odds ratio	(Model 1) Middle School Other non-Hispanic Male	(Model 2) Middle School Other non-Hispanic Male	(Model 3) Middle School Other non-Hispanic Female	(Model 4) Middle School Other non-Hispanic Female
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		4.311 (0.522 - 35.625)		4.768 (0.619 - 36.751)
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**13.028** (1.323 - 128.252)**		**8.097** (1.411 - 46.485)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		**8.308*** (2.745 - 25.143)**		**8.254*** (1.788 - 38.101)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		10.197 (0.148 - 704.080)		Omitted
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		0.619 (0.021 - 18.155)		0.101 (0.006 - 1.810)

Table 3.8 Logistic Results among Middle School other non-Hispanic (continued)

Ever use e-cigarettes because of flavor				
No (reference)				
Yes		3.196 (0.467 - 21.876)		1.586 (0.288 - 8.744)
Year				
2017 (reference)				
2016	4.462* (0.977 - 20.381)	2.192 (0.247 - 19.477)	1.154 (0.288 - 4.626)	1.009 (0.161 - 6.308)
2018	**5.321** (1.232 - 22.973)**	3.681 (0.716 - 18.926)	1.338 (0.304 - 5.894)	1.791 (0.241 - 13.282)
Constant	**0.010*** (0.003 - 0.038)**	**0.002*** (0.000 - 0.022)**	**0.016*** (0.006 - 0.044)**	**0.003*** (0.000 - 0.020)**
Observations	909	840	796	746

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for time. The full models (models 2 &4) controlled for additional behavioral and environmental factors that may be correlated with time.

Table 3.9 Logistic Results among High School other non-Hispanic

Marginal effects on odds ratio	(Model 1) High School Other non-Hispanic Male	(Model 2) High School Other non-Hispanic Male	(Model 3) High School Other non-Hispanic Female	(Model 4) High School Other non-Hispanic Female
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**11.773*** (4.799 - 28.882)**		**2.792** (1.160 - 6.719)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**6.981*** (2.980 - 16.357)**		**7.888*** (3.560 - 17.476)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		1.105 (0.607 - 2.009)		**1.948** (1.003 - 3.782)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		0.298 (0.029 - 3.095)		1.168 (0.242 - 5.635)
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		0.740 (0.177 - 3.103)		**4.716** (1.057 - 21.031)**
Ever use e-cigarettes because of flavor				
No (reference)				
Yes		2.424 (0.700 - 8.389)		2.707* (0.988 - 7.415)

Table 3.9 Logistic Results among High School other non-Hispanic (continued)

Year				
2017 (reference)				
2016	1.404 (0.762 - 2.588)	1.419 (0.715 - 2.816)	1.069 (0.415 - 2.752)	0.821 (0.353 - 1.909)
2018	**1.972** (1.027 - 3.784)**	1.256 (0.577 - 2.735)	0.869 (0.306 - 2.466)	0.587 (0.244 - 1.412)
Constant	**0.101*** (0.060 - 0.170)**	**0.045*** (0.024 - 0.087)**	**0.076*** (0.036 - 0.159)**	**0.034*** (0.017 - 0.068)**
Observations	1,049	982	947	917

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for time. The full models (models 2 &4) controlled for additional behavioral and environmental factors that may be correlated with time.

3.5.4.3 Among Black

The odds of marijuana vaping increased among high-school black female participants from 2016 to 2017 (Tables 3.10&3.11). Both middle-school black male and female participants who used e-cigarettes due to less perceived harmfulness were at greater odds of marijuana vaping.

Table 3.10 Logistic Results among Middle School Black

Marginal effects on odds ratio	(Model 1) Middle School Black Male	(Model 2) Middle School Black Male	(Model 3) Middle School Black Female	(Model 4) Middle School Black Female
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**13.691*** (4.205 - 44.576)**		2.380 (0.547 - 10.352)
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**9.882*** (3.149 - 31.008)**		**4.883*** (1.544 - 15.440)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		**2.875*** (1.613 - 5.124)**		1.578 (0.876 - 2.840)
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		11.449 (0.150 - 876.376)		Omitted
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		**6.199*** (1.575 - 24.398)**		**14.520*** (4.007 - 52.618)**

Table 3.10 Logistic Results among Middle School Black (continued)

Ever use e-cigarettes because of flavor				
No (reference)				
Yes		0.686 (0.200 - 2.351)		**4.089***** **(1.706 - 9.802)**
Year				
2017 (reference)				
2016	1.345 (0.674 - 2.681)	0.988 (0.440 - 2.221)	0.785 (0.414 - 1.490)	0.879 (0.452 - 1.710)
2018	1.166 (0.609 - 2.234)	1.062 (0.438 - 2.571)	0.598 (0.300 - 1.190)	0.807 (0.363 - 1.794)
Constant	**0.069***** **(0.045 - 0.106)**	**0.024***** **(0.013 - 0.046)**	**0.059***** **(0.037 - 0.093)**	**0.026***** **(0.013 - 0.049)**
Observations	1,779	1,594	1,854	1,704

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for time. The full models (models 2 &4) controlled for additional behavioral and environmental factors that may be correlated with time.

Table 3.11 Logistic Results among High School Black

Marginal effects on odds ratio	(Model 1) High School Black Male	(Model 2) High School Black Male	(Model 3) High School Black Female	(Model 4) High School Black Female
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**2.470**** **(1.242 - 4.912)**		**2.016**** **(1.077 - 3.775)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**4.991***** **(3.379 - 7.372)**		**4.020***** **(2.709 - 5.966)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		1.384* (0.993 - 1.930)		**1.716***** **(1.217 - 2.419)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		1.946 (0.229 - 16.547)		0.748 (0.093 - 6.017)
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		1.735 (0.755 - 3.986)		0.951 (0.313 - 2.895)

Table 3.11 Logistic Results among High School Black (continued)

Ever use e-cigarettes because of flavor				
No (reference)				
Yes		**2.105** (1.076 - 4.118)**		**3.205*** (1.687 - 6.090)**
Year				
2017 (reference)				
2016	1.101 (0.813 - 1.489)	0.948 (0.651 - 1.380)	**0.367*** (0.250 - 0.539)**	**0.295*** (0.189 - 0.462)**
2018	1.329 (0.926 - 1.906)	1.296 (0.818 - 2.054)	1.151 (0.817 - 1.623)	0.908 (0.625 - 1.320)
Constant	**0.143*** (0.115 - 0.179)**	**0.077*** (0.057 - 0.104)**	**0.179*** (0.142 - 0.226)**	**0.105*** (0.080 - 0.138)**
Observations	2,333	2,126	2,416	2,288

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for time. The full models (models 2 &4) controlled for additional behavioral and environmental factors that may be correlated with time.

3.5.4.4 Among Hispanic

The odds of marijuana vaping increased among middle-school Hispanic female participants from 2016 to 2017 (Table 3.12). Both high-school Hispanic female and male participants had been increasingly more likely to vape marijuana from 2016 to 2018 after controlling for demographic characteristics and behavioral and environmental factors (Table 3.13: models 2&4), although the basic models (Table 3.13: models 1&3) demonstrated the odds of marijuana vaping only increased among high-school Hispanic female participants from 2017 to 2018. Both middle-school and high-school Hispanic female participants who used e-cigarettes due to its flavors were at greater odds of marijuana vaping.

Table 3.12 Logistic Results among Middle School Hispanic

Marginal effects on odds ratio	(Model 1) Middle School Hispanic Male	(Model 2) Middle School Hispanic Male	(Model 3) Middle School Hispanic Female	(Model 4) Middle School Hispanic Female
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**4.669*** (2.849 - 7.652)**		**2.886*** (1.433 - 5.810)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**7.861*** (4.619 - 13.378)**		**12.093*** (6.472 - 22.595)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		**2.072*** (1.375 - 3.124)**		1.232 (0.786 - 1.933)
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		1.640 (0.421 - 6.395)		3.031 (0.481 - 19.090)
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		2.030* (0.922 - 4.468)		**2.620** (1.234 - 5.562)**
Ever use e-cigarettes because of flavor				
No (reference)				
Yes		1.757 (0.827 - 3.730)		**3.349*** (1.764 - 6.359)**

Table 3.12 Logistic Results among Middle School Hispanic (continued)

Year				
2017 (reference)				
2016	1.024 (0.656 - 1.598)	0.961 (0.557 - 1.661)	**0.606** (0.379 - 0.970)**	**0.369*** (0.215 - 0.633)**
2018	1.240 (0.829 - 1.857)	1.317 (0.808 - 2.145)	1.002 (0.644 - 1.560)	0.845 (0.498 - 1.434)
Constant	**0.080*** (0.058 - 0.110)**	**0.032*** (0.020 - 0.052)**	**0.084*** (0.060 - 0.117)**	**0.047*** (0.029 - 0.074)**
Observations	3,365	3,047	3,446	3,223

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for time. The full models (models 2 &4) controlled for additional behavioral and environmental factors that may be correlated with time.

Table 3.13 Logistic Results among High School Hispanic

Marginal effects on odds ratio	(Model 1) High School Hispanic Male	(Model 2) High School Hispanic Male	(Model 3) High School Hispanic Female	(Model 4) High School Hispanic Female
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**3.738*** (2.707 - 5.161)**		**3.570*** (2.567 - 4.966)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**4.979*** (3.655 - 6.782)**		**4.027*** (2.970 - 5.460)**
Cohabiting with at least one tobacco user				
No (reference)				
Yes		1.209* (0.967 - 1.513)		**1.434*** (1.169 - 1.758)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		1.415 (0.441 - 4.542)		1.364 (0.542 - 3.432)
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		1.097 (0.692 - 1.738)		1.221 (0.722 - 2.064)

Table 3.13 Logistic Results among High School Hispanic (continued)

Ever use e-cigarettes because of flavor				
No (reference)				
Yes		**2.136*** (1.465 - 3.114)**		**2.913*** (2.108 - 4.024)**
Year				
2017 (reference)				
2016	0.761 (0.538 - 1.077)	**0.688** (0.483 - 0.978)**	0.684 (0.434 - 1.078)	**0.578** (0.372 - 0.899)**
2018	1.380* (0.982 - 1.938)	**1.514** (1.066 - 2.150)**	**1.722*** (1.297 - 2.285)**	**1.740*** (1.295 - 2.337)**
Constant	**0.241*** (0.181 - 0.321)**	**0.106*** (0.079 - 0.141)**	**0.225*** (0.182 - 0.277)**	**0.112*** (0.090 - 0.139)**
Observations	4,110	3,745	4,245	4,021

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for time. The full models (models 2 &4) controlled for additional behavioral and environmental factors that may be correlated with time.

3.5.5 Results by reason of e-cigarette use

3.5.5.1 E-cigarette use due to or not due to flavors

The odds of marijuana vaping continuously increased among those who did not report flavors as one of the reasons for using e-cigarettes from 2016 to 2018 (Table 3.14). The odds of marijuana vaping only increased among those who reported flavors as one of the reasons for using e-cigarettes from 2016 to 2017 and the increase in the odds was smaller compared to the increased in the odds among those who did not report flavors as one of the reasons for using e-cigarettes. Male participants who did not report flavors as one of the reasons for using e-cigarettes were at greater odds of marijuana vaping compared to the female counterparts in the basic model (Table 3.14: model 3). Other non-Hispanic participants who did not report flavors as one of the reasons for using e-cigarettes were at lower odds of marijuana vaping compared to the white non-Hispanic counterparts in the basic model (Table 3.14: model 3).

Table 3.14 Logistic results by reason of e-cigarette use—flavors

Marginal effects on odds ratio	(Model 1) Marijuana Vaping (e-Cigarette Use due to Flavors)	(Model 2) Marijuana Vaping (e-Cigarette Use due to Flavors)	(Model 3) Marijuana Vaping (e-Cigarette Use **NOT** due to Flavors)	(Model 4) Marijuana Vaping (e-Cigarette Use **NOT** due to Flavors)
Sex				
Female (reference)				
Male	0.876	0.777***	1.254***	1.054
	(0.740 - 1.037)	(0.647 - 0.933)	(1.156 - 1.359)	(0.955 - 1.164)
Race/ethnicity				
White non-Hispanic (reference)				
Other non-Hispanic	0.868	0.995	0.586***	0.823*
	(0.549 - 1.372)	(0.612 - 1.617)	(0.471 - 0.729)	(0.659 - 1.027)
Black non-Hispanic	0.916	1.214	1.040	1.420***
	(0.646 - 1.300)	(0.838 - 1.757)	(0.905 - 1.196)	(1.208 - 1.671)
Hispanic	1.254**	1.562***	1.460***	1.918***
	(1.037 - 1.515)	(1.262 - 1.933)	(1.294 - 1.647)	(1.667 - 2.208)
School type				
Middle school (reference)				
High School	1.617***	1.542***	4.004***	2.771***
	(1.314 - 1.990)	(1.233 - 1.927)	(3.554 - 4.511)	(2.452 - 3.131)
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		1.968***		5.155***
		(1.614 - 2.400)		(4.386 - 6.059)
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		2.950***		5.419***
		(2.390 - 3.642)		(4.741 - 6.195)
Cohabiting with at least one tobacco user				
No (reference)				
Yes		1.117		1.523***
		(0.920 - 1.355)		(1.393 - 1.664)

Table 3.14 Logistic results by reason of e-cigarette use—flavors (continued)

Year				
2017 (reference)				
2016	0.716**	0.617***	0.762***	0.709***
	(0.536 - 0.957)	(0.463 - 0.821)	(0.638 - 0.909)	(0.591 - 0.850)
2018	1.277*	1.106	1.356***	1.252**
	(0.963 - 1.694)	(0.821 - 1.489)	(1.162 - 1.584)	(1.050 - 1.492)
Constant	0.480***	0.237***	0.032***	0.019***
	(0.354 - 0.650)	(0.163 - 0.345)	(0.027 - 0.037)	(0.016 - 0.023)
Observations	3,743	3,478	49,094	46,336

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

3.5.5.2 E-cigarette use due to or not due to less cost

The odds of marijuana vaping consistently increased among those who did not report less cost as one of the reasons for using e-cigarettes from 2016 to 2018 (Table 3.15). Male participants who did not report less cost as one of the reasons for using e-cigarettes were at greater odds of marijuana vaping compared to the female counterparts in the basic model (Table 3.15: model 3). Other non-Hispanic participants who did not report less cost as one of the reasons for using e-cigarettes were at lower odds of marijuana vaping compared to the white non-Hispanic counterparts in the basic model (Table 3.15: model 3). Hispanic participants who did not report less cost as one of the reasons for using e-cigarettes were at greater odds of marijuana vaping compared to the white non-Hispanic counterparts in both models (Table 3.15: models 3&4).

Table 3.15 Logistic results by reason of e-cigarette use—less cost

Marginal effects on odds ratio	(Model 1) Marijuana Vaping (e-Cigarette Use due to Less Cost)	(Model 2) Marijuana Vaping (e-Cigarette Use due to Less Cost)	(Model 3) Marijuana Vaping (e-Cigarette Use **NOT** due to Less Cost)	(Model 4) Marijuana Vaping (e-Cigarette Use **NOT** due to Less Cost)
Sex				
Female (reference)				
Male	0.916 (0.545 - 1.538)	0.964 (0.526 - 1.769)	**1.137*** (1.051 - 1.229)**	0.972 (0.886 - 1.066)
Race/ethnicity				
White non-Hispanic (reference)				
Other non-Hispanic	0.510 (0.177 - 1.474)	0.577 (0.190 - 1.754)	**0.561*** (0.454 - 0.695)**	0.835* (0.678 - 1.029)
Black non-Hispanic	0.841 (0.422 - 1.677)	0.963 (0.372 - 2.494)	0.933 (0.814 - 1.069)	**1.354*** (1.158 - 1.584)**
Hispanic	1.141 (0.691 - 1.885)	1.083 (0.624 - 1.881)	**1.406*** (1.255 - 1.574)**	**1.904*** (1.669 - 2.173)**
School type				
Middle school (reference)				
High School	0.593 (0.296 - 1.189)	**0.355** (0.161 - 0.783)**	**4.075*** (3.641 - 4.561)**	**2.799*** (2.494 - 3.141)**
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**3.296*** (1.672 - 6.497)**		**5.133*** (4.464 - 5.902)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		1.819* (0.961 - 3.440)		**4.989*** (4.423 - 5.627)**

Table 3.15 Logistic results by reason of e-cigarette use—less cost (continued)

Cohabiting with at least one tobacco user				
No (reference)				
Yes		1.581 (0.850 - 2.940)		**1.494*** (1.370 - 1.629)**
Year				
2017 (reference)				
2016	0.573* (0.301 - 1.089)	**0.417** (0.209 - 0.829)**	**0.779*** (0.659 - 0.922)**	**0.701*** (0.586 - 0.837)**
2018	0.686 (0.364 - 1.290)	0.500* (0.230 - 1.086)	**1.413*** (1.208 - 1.652)**	**1.245** (1.040 - 1.491)**
Constant	**4.382*** (1.784 - 10.764)**	1.541 (0.456 - 5.205)	**0.040*** (0.034 - 0.046)**	**0.023*** (0.019 - 0.028)**
Observations	437	379	52,400	49,435

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

3.5.5.3 E-cigarette use due to or not due to less harmfulness

The odds of marijuana vaping consistently increased among those who did not report less harmfulness as one of the reasons for using e-cigarettes from 2016 to 2018 (Table 3.16). Male participants who did not report less harmfulness as one of the reasons for using e-cigarettes were at greater odds of marijuana vaping compared to the female counterparts in the basic model (Table 3.16: model 3). Other non-Hispanic participants who did not report less harmfulness as one of the reasons for using e-cigarettes were at lower odds of marijuana vaping compared to the white non-Hispanic counterparts in the basic model (Table 3.16: model 3).

Table 3.16 Logistic results by reason of e-cigarette use—less harmfulness

Marginal effects on odds ratio	(Model 1) Marijuana Vaping (e-Cigarette Use due to Less Harmfulness)	(Model 2) Marijuana Vaping (e-Cigarette Use due to Less Harmfulness)	(Model 3) Marijuana Vaping (e-Cigarette Use **NOT** due to Less Harmfulness)	(Model 4) Marijuana Vaping (e-Cigarette Use **NOT** due to Less Harmfulness)
Sex				
Female (reference)				
Male	0.997	0.899	1.127***	0.983
	(0.799 - 1.245)	(0.709 - 1.140)	(1.038 - 1.224)	(0.892 - 1.083)
Race/ethnicity				
White non-Hispanic (reference)				
Other non-Hispanic	0.982	1.037	0.572***	0.837
	(0.571 - 1.690)	(0.560 - 1.922)	(0.461 - 0.710)	(0.671 - 1.044)
Black non-Hispanic	1.234	1.523	0.974	1.357***
	(0.793 - 1.919)	(0.894 - 2.596)	(0.850 - 1.116)	(1.156 - 1.593)
Hispanic	1.193	1.416***	1.441***	1.932***
	(0.940 - 1.514)	(1.097 - 1.827)	(1.282 - 1.619)	(1.689 - 2.210)
School type				
Middle school (reference)				
High School	1.472***	1.196	4.098***	2.874***
	(1.102 - 1.965)	(0.878 - 1.630)	(3.637 - 4.616)	(2.545 - 3.246)
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		2.038***		5.233***
		(1.582 - 2.624)		(4.541 - 6.031)
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		2.464***		5.441***
		(1.949 - 3.116)		(4.778 - 6.196)
Cohabiting with at least one tobacco user				
No (reference)				
Yes		1.089		1.530***
		(0.879 - 1.351)		(1.397 - 1.675)

Table 3.16 Logistic results by reason of e-cigarette use—less harmfulness (continued)

Year				
2017 (reference)				
2016	0.619**	0.518***	0.794***	0.721***
	(0.414 - 0.924)	(0.339 - 0.793)	(0.671 - 0.940)	(0.604 - 0.859)
2018	1.217	1.047	1.379***	1.243**
	(0.825 - 1.795)	(0.690 - 1.587)	(1.185 - 1.605)	(1.041 - 1.485)
Constant	0.506***	0.290***	0.036***	0.021***
	(0.323 - 0.792)	(0.172 - 0.487)	(0.031 - 0.043)	(0.017 - 0.025)
Observations	2,291	2,121	50,546	47,693

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

3.6 Robustness checks

First, considering the inconsistency in questions regarding marijuana and e-cigarette use from 2016 to 2017 and 2018, I conducted logistic regression analyses just including data from 2017 and 2018 NYTSs (Table 3.17). Second, I used linear probability models to estimate the effects on the probability of marijuana vaping (Table 3.18). Those results were consistent with the main logistic results.

Table 3.17 Logistic results from 2017 to 2018

Marginal effects on odds ratio	(Model 1) Marijuana Vaping Among All Participants	(Model 2) Marijuana Vaping Among All Participants	(Model 3) Marijuana Vaping Among Ever Use e-Cigarettes	(Model 4) Marijuana Vaping Among Ever Use e-Cigarettes
Sex				
Female (reference)				
Male	1.021 (0.946 - 1.103)	**0.870** (0.782 - 0.967)**	1.012 (0.934 - 1.096)	**0.875** (0.787 - 0.972)**
Race/ethnicity				
White non-Hispanic (reference)				
Other non-Hispanic	**0.491*** (0.378 - 0.637)**	**0.728** (0.562 - 0.944)**	**0.586*** (0.456 - 0.754)**	0.780* (0.600 - 1.013)
Black non-Hispanic	0.887 (0.758 - 1.038)	**1.456*** (1.211 - 1.750)**	0.945 (0.814 - 1.097)	**1.476*** (1.228 - 1.772)**
Hispanic	**1.414*** (1.244 - 1.609)**	**2.068*** (1.777 - 2.406)**	**1.386*** (1.216 - 1.580)**	**1.964*** (1.679 - 2.298)**
School type				
Middle school (reference)				
High School	**4.539*** (3.949 - 5.218)**	**2.909*** (2.522 - 3.354)**	**4.455*** (3.896 - 5.094)**	**2.984*** (2.596 - 3.431)**
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**4.493*** (3.755 - 5.377)**		**2.760*** (2.340 - 3.256)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**5.039*** (4.366 - 5.815)**		**4.181*** (3.630 - 4.814)**

Table 3.17 Logistic results from 2017 to 2018 (continued)

Cohabiting with at least one tobacco user				
No (reference)				
Yes		**1.493*** (1.345 - 1.658)**		**1.422*** (1.281 - 1.579)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		1.505 (0.880 - 2.572)		**1.707** (1.086 - 2.681)**
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		**1.448*** (1.166 - 1.798)**		1.195* (0.984 - 1.452)
Ever use e-cigarettes because of flavor				
No (reference)				
Yes		**2.205*** (1.901 - 2.558)**		**1.569*** (1.373 - 1.794)**
Year				
2017 (reference)				
2018	**1.402*** (1.195 - 1.644)**	1.192* (0.989 - 1.436)	**1.306*** (1.123 - 1.519)**	1.190* (0.987 - 1.436)
Constant	**0.041*** (0.034 - 0.049)**	**0.021*** (0.017 - 0.026)**	**0.089*** (0.075 - 0.106)**	**0.048*** (0.039 - 0.059)**
Observations	34,059	31,983	18,617	17,289

Notes: Boldface indicates statistical significant at p<0.05 (* p<0.1; ** p<0.05; *** p<0.01). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

Table 3.18 Linear Probability Results

Marginal effects	(1) Marijuana Vaping Among All Participants	(2) Marijuana Vaping Among All Participants	(3) Marijuana Vaping Among Ever Use e-Cigarettes	(4) Marijuana Vaping Among Ever Use e-Cigarettes
Sex				
Female (reference)				
Male	**0.013*** (0.006 - 0.021)**	-0.002 (-0.009 - 0.005)	**0.014** (0.000 - 0.028)**	-0.007 (-0.021 - 0.007)
Race/ethnicity				
White non-Hispanic (reference)				
Other non-Hispanic	**-0.044*** (-0.059 - -0.029)**	-0.008 (-0.019 - 0.004)	**-0.056*** (-0.088 - -0.024)**	-0.012 (-0.040 - 0.016)
Black non-Hispanic	-0.008 (-0.020 - 0.004)	**0.020*** (0.009 - 0.031)**	0.003 (-0.019 - 0.025)	**0.050*** (0.028 - 0.072)**
Hispanic	**0.034*** (0.022 - 0.046)**	**0.046*** (0.035 - 0.057)**	**0.054*** (0.034 - 0.075)**	**0.086*** (0.066 - 0.106)**
School type				
Middle school (reference)				
High School	**0.119*** (0.108 - 0.130)**	**0.054*** (0.047 - 0.062)**	**0.208*** (0.190 - 0.225)**	**0.125*** (0.110 - 0.140)**
Current (past 30 days) use of e-cigarettes				
No (reference)				
Yes		**0.226*** (0.200 - 0.253)**		**0.160*** (0.132 - 0.188)**
Current (past 30 days) use of tobacco products that were not e-cigarettes				
No (reference)				
Yes		**0.253*** (0.229 - 0.278)**		**0.272*** (0.246 - 0.298)**

Table 3.18 Linear Probability Results (continued)

Cohabiting with at least one tobacco user				
No (reference)				
Yes		**0.026*** (0.019 - 0.033)**		**0.041*** (0.028 - 0.055)**
Ever use e-cigarettes because e-cigarettes cost less				
No (reference)				
Yes		**0.118*** (0.055 - 0.182)**		**0.119*** (0.060 - 0.179)**
Ever use e-cigarettes due to less perceived harmfulness				
No (reference)				
Yes		**0.042*** (0.014 - 0.070)**		0.014 (-0.014 - 0.043)
Ever use e-cigarettes because of flavor				
No (reference)				
Yes		**0.113*** (0.091 - 0.135)**		**0.066*** (0.043 - 0.088)**
Year				
2017 (reference)				
2016	**-0.021*** (-0.037 - -0.006)**	**-0.026*** (-0.039 - -0.013)**	**0.059*** (0.030 - 0.088)**	-0.015 (-0.048 - 0.017)
2018	**0.036*** (0.019 - 0.053)**	**0.016** (0.001 - 0.031)**	**0.045*** (0.020 - 0.071)**	**0.028** (0.003 - 0.053)**
Constant	**0.031*** (0.020 - 0.043)**	0.004 (-0.006 - 0.014)	**0.070*** (0.051 - 0.090)**	0.016* (-0.002 - 0.035)
Observations	53,057	49,814	23,602	21,853
R-squared	0.043	0.237	0.061	0.191

Notes: Boldface indicates statistical significant at $p<0.05$ (* $p<0.1$; ** $p<0.05$; *** $p<0.01$). 95% CIs presented in parentheses are clustered at the state level. The basic models (models 1&3) controlled for basic demographic characteristics (i.e., sex, race/ethnicity and school level (middle/high)) that were not correlated with time. The full models (models 2 &4) controlled for both basic demographic characteristics and additional behavioral and environmental factors that may be correlated with time.

3.7 Conclusions

Overall, marijuana vaping increased among high school students but not among middle school from 2016 to 2018. Being male was at greater odds of marijuana vaping. Compared to White non-Hispanic, Hispanic was at greater odds of marijuana vaping, while other non-Hispanic was at lower odds of marijuana vaping. High school students were at greater odds of marijuana vaping than middle school students. The odds of marijuana vaping increased among high-school Hispanic female and among other non-Hispanic male from 2017 to 2018. The odds of marijuana vaping increased among high-school black female and among middle-school Hispanic female from 2016 to 2017. Both high-school Hispanic female and male had been increasingly more likely to vape marijuana from 2016 to 2018 after controlling for behavioral and environmental factors.

The odds of marijuana vaping continuously increased among those who did not report flavors as one of the reasons of using e-cigarettes from 2016 to 2018, among those who did not report less cost as one of the reasons of using e-cigarettes from 2016 to 2018, and among those who did not report less harmfulness as one of the reasons of using e-cigarettes from 2016 to 2018.

My study has the following limitations.[20] First, the inconsistency in questions related to marijuana from 2016 to 2017 and 2018 could lead to biased results from 2016 to 2017 and 2018. Second, 2019 NYTS is available but does not include a question regarding marijuana vaping. Long-term studies are warrantied as this study only covers year 2016, 2017 and 2018.

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[20] Although I only discuss marijuana vaping in this paper, other substances, including nicotine, can also be used in e-cigarette devices.

E-cigarette policy may need to focus on the increase in marijuana vaping among Black and Hispanic female students, and Hispanic students in general. Banning flavored e-cigarettes may not reduce marijuana vaping among youth. Lower cost and less perceived harmfulness associated with e-cigarette use may not be associated with the trend of marijuana vaping among youth.

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Paper 3: Marijuana Use in E-Cigarettes among U.S. Youth

Publications and Working Papers

Wu, Y., & **Wen, J.** (2014). Fear of crime among Chinese immigrants in Metro-Detroit. *Crime, Law and Social Change*, *61*(5), 495-515. doi:10.1007/s10611-014-9513-y

Day, A., Riebschleger, J., & **Wen, J.** (2018, Spring). The utilization of pre-college programming in increasing college access and retention rates of foster care youth: Results from the Fostering Academics Mentoring Excellence (FAME) Program. *New Directions for Community Colleges, 181*. 39-47. doi: 10.1002/cc.20290.

Wen, J., Wen, H., Butler, J.S., & Talbert, J. “The Impact of Medical and Recreational Marijuana Laws on Opioid Prescribing in Employer-Sponsored Health Insurance.” *Health Economics*, in revision.

Wen, J. “Legalizing Marijuana in the Digital Age: State Compliance in Twitter Advertising.”

Conference Presentations

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