Determinants of Cannabis Risk Perception and Consumption Choices*

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Abstract

Throughout the past two decades, medical and recreational cannabis legalization policies have swept the United States. These rapid developments in cannabis legalization have introduced notable interstate variation in the availability of cannabis and, in turn, have coincided with changes in the consumption patterns and risk perceptions of Americans. In this paper, we use data from the National Survey on Drug Use and Health (NSDUH) and the American Community Survey (ACS) to consider whether medical or recreational legalization are associated with significant changes in state-level outcomes of past-month cannabis use, past-year cannabis use, or perceptions of great risk of smoking marijuana once a month. First, we conduct an exploratory data analysis of changes in the consumption and risk perception outcomes over time, reinforcing previous findings in the literature that cannabis consumption has increased considerably over the past two decades, while associated risk perceptions have fallen. Second, we analyze the associations between legalization policy, on one hand, and consumption and risk perception outcomes on the other, under three model specifications: an ordinary least squares (OLS) regression model with covariates alone, with one-way fixed effects by state, and with two-way fixed effects by state and year. We find that the associations between legalization policy and the outcomes of interest vary considerably across model specification and that – in the two-way fixed effects model – the state and year fixed effects together account for a substantial portion of the variation in consumption and risk perception outcomes. From the two-way fixed effects model, we also find that recreational legalization is unexpectedly associated with a small but statistically significant decrease in consumption, while legalization policy does not exhibit significant associations with risk perceptions.

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1 Introduction

The evolution of cannabis legalization throughout the past three decades has introduced notable interstate variation in the availability of cannabis to American consumers. Cannabis use is largely governed by state laws and, currently, 47 states permit the medical use of marijuana while 24 states allow for its recreational use by consumers (NCSL 2024). Conversely, according to the Centers for Disease Control and Prevention (2024), only three states – Idaho, Nebraska, and Kansas – offer no legal cannabis program whatsoever.

Medical and recreational legalization of cannabis are relatively recent phenomena: all legalization has occurred within the past two decades and the majority of recreational states have legalized cannabis within the past decade.[1] The economic and social implications are wide-ranging. The 2019 United Nations Drug Report finds that cannabis is the most widely used illicit drug under international control, with estimates suggesting that over 3.8% of the global adult population, or approximately 188 million adults worldwide, consume cannabis. Peacock et al. (2019) finds that cannabis users are also disproportionately concentrated in North America, as well as higher-income countries in Europe and Oceania. In the context of the U.S. market, a 2024 *Economist* article indicates that, based on data from the National Survey on Drug Use and Health (NSDUH), cannabis use has noticeably grown relative to the use of alcohol and cigarettes, with approximately one in 20 Americans consuming the drug on a daily basis.

Recent economic research confirms these findings.[2] Caulkins (2024) finds that, between 2008 and 2022, the per capita rate of reporting past-year use of cannabis increased by 120%, while days of use reported per capita increased by 218%. Moreover, in 2022, for the first time, the estimated number of "daily or near-daily" marijuana

[1]For a comprehensive discussion of historical United States cannabis legalization developments, see David V. Patton, "A History of United States Cannabis Law," *JL & Health* 34 (2020).

[2]For a more detailed literature review on the public health impacts of recreational marijuana legalization, see Wayne Hall and Michael Lynskey, "Evaluating the Public Health Impacts of Legalizing Recreational Cannabis Use in the United States," *Addiction* 111, no. 10 (2016): 1764–1773.

users (individuals who report using cannabis on at least 21 of the past 30 days) surpassed the analogous estimate for alcohol users.

In this paper, we consider how estimates of cannabis consumption and risk perceptions have changed over the course of the past two decades, during which the waves of medical and recreational legalization swept the United States. Specifically, we seek to answer the question: do changes in state legalization policies serve as useful predictors of state-level cannabis consumption and risk perception estimates? In particular, is there a quantifiable and significant impact of either medical or recreational legalization on cannabis consumption and risk perception estimates?

This analysis will build upon previous research in multiple respects. First, we analyze this question across all states and age groups, as well as taking into account a variety of state demographic features (contingent on data availability). While previous research has largely focused on adolescent risk perceptions,[3] we consider a wider scope of risk perceptions by utilizing state-level data collected from a representative sample of Americans. Second, we examine multiple metrics of consumption and risk perceptions, including monthly and yearly measures. Third, we utilize more recent data to update estimates of legalization impacts and, further, to observe whether trends stabilize in the years following legalization. Lastly, we compare the results of three distinct regression models − with covariates alone, with one-way fixed effects, and with two-way fixed effects − to assess whether results vary across model specification and to consider which models (if any) best capture variation in our selected outcome variables.

There are a few complementary questions that are addressed in this analysis. First, to what extent do estimates of cannabis consumption and risk perceptions parallel analogous outcomes for other substances, such as alcohol and cigarettes? Second, how do these estimates vary across other demographic variables, such as age group and geographic region? We briefly address both of these questions in

[3]See, for instance: Ashley A. Knapp et al., "Emerging Trends in Cannabis Administration Among Adolescent Cannabis Users," *Journal of Adolescent Health* 64, no. 4 (2019): 487–493.

Section 4.

The remainder of the paper proceeds as follows: Section 2 provides an overview of important theoretical and empirical literature that has examined the impact of cannabis legalization, and its relation to either consumption or risk perceptions. Section 3 describes the datasets utilized in the subsequent regression analysis, identifying their relevance to the question at hand alongside simplifying assumptions and potential limitations. Section 4 conducts a brief exploratory data analysis and highlights some of the key trends in cannabis consumption and risk perceptions over time. Section 5 presents various ordinary least squares (OLS) regression models with relevant covariates and fixed effects. Section 6 summarizes the key takeaways and suggests possible avenues for future research. The Appendix displays supplementary tables and regression estimates, in addition to providing the results of a few modified regressions intended to explore whether estimates are consistent across other model specifications.

2 Literature Review

Previous economic research has exploited legalization as a source of exogenous interstate variation, focusing in particular on the quantifiable market outcomes catalyzed by changes in cannabis policy. First and foremost, numerous studies have examined the impact of legalization on overall cannabis consumption. Smart et al. (2019), for instance, finds that medical cannabis laws contribute to an increase in adult, but not adolescent, cannabis use and notes that certain legalization provisions which are "associated with less regulated supply" may increase the prevalence of adult cannabis use disorders (CUDs). Recreational cannabis laws similarly exhibit a limited impact on the rate of adolescent cannabis use and a potential positive association with increases in consumption among college students. Zellers et al. (2023) considers a related question, seeking to estimate the effect of recreational legalization on cannabis use frequency across varying legal environments. Employing a longitudinal design that controls for age, sex, and previous cannabis use, they find that an approximately 24% increase in mean cannabis use frequency is attributable to legalization. Other research has focused on trends in consumption of certain demographic groups, such as adolescents. Notably, Mennis et al. (2023) investigates the association between recreational cannabis legalization and prevalence of adolescent cannabis use. Using a difference-in-difference model, the paper concludes that among adolescents and young adults alike, recreational legalization is often followed by a statistically significant increase in cannabis use.

Additionally, studies have explored the impacts on consumption of potentially complementary goods, including alcohol and cigarettes (Calvert et al. 2021), as well as considering consumption complementarities between cannabis and opioids (Shah et al. 2019), painkillers (Powell et al. 2018), and other prescription drugs (Tabarrok 2023). Literature reviews, though, have found mixed results regarding the economic relationships between these goods and the extent to which consumers view such product pairs as either substitutes or complements (Subbaraman 2016).

A notably smaller portion of the research has discussed the extent to which cannabis legalization has altered perceptions, across states and age groups, of the harm associated with usage of cannabis and other drugs. We summarize the findings of some key studies in this area. Felson et al. (2019) analyzes the liberalization of public opinion with respect to cannabis legalization and finds that this liberalization trend persists across gender, ethnic, educational, and religious demographics, though concludes that the legalization of cannabis has not prompted considerable attitude changes within states. Sarvet et al. (2018), in contrast, employs a piecewise linear model to examine changes in adolescent risk perception trends between 1991 and 2014, controlling for key demographic characteristics. The study finds that, irrespective of cannabis legalization policy, an "increase in adolescent marijuana use has not accompanied recent rapid decreases in marijuana risk perceptions." Mennis et al. (2023) explores a similar question, investigating whether associations among adolescent and young adult perceptions of risk of harm from cannabis use, prevalence of past-month cannabis use, and rate of CUD treatment admissions between 2008 and 2019 changed in the wake of cannabis legalization; the researchers utilize difference-in-difference models to measure the effect of legalization on these outcomes. This study concludes that, following recreational legalization, cannabis use is likely to increase among adolescents and young adults who do not associate cannabis consumption with higher risks of harm.

Overall, the literature exploring the associations of cannabis legalization on consumption and risk perceptions remains largely inconclusive; estimates of the causal effects, too, are accompanied by a large degree of variability across studies. Bahji et al. (2019) reinforces this conclusion, observing that there is an insufficient body of research dedicated to exploring the impacts of cannabis legalization and that the available studies remain "fairly heterogeneous in their findings."[4]

In sum, we observe three crucially related variables: consumption, risk perceptions, and legalization. As the literature above demonstrates, legalization policies have the potential to influence both consumption patterns and consumer risk perceptions alike. The aim of this paper, therefore, is to consider how state-level consumption and risk perceptions have changed over time and, specifically, whether recreational or medical legalization exhibit strong associations with either of these outcomes. It is particularly important, we think, to consider consumption and risk perception outcomes simultaneously, for they are far from being two distinct and independent outcomes. A consumer's choice to purchase and consume a substance is directly dependent on their perception of the risks associated with consumption. Meanwhile, a consumer's perception of the risk associated with a substance is also a function of their previous consumption patterns. Lundborg et al. (2002), for in-

[4]As a general note, we also point out that much of the literature on cannabis consumption and risk perceptions exclusively examines the extent to which the legalization of cannabis contributes to changes in *adolescent* outcomes.

stance, examines Swedish cross-sectional survey data on young individuals and finds that individuals with higher risk perceptions of alcohol are generally less likely to consume alcohol. In the context of cannabis consumption, Choi et al. (2024) finds a significant association between risk perceptions and cannabis consumption methods; users that report moderate or great risk perceptions are less likely to adopt multiple cannabis consumption methods, indicating that users with lower reported risk perceptions are more frequently exposed to the varying degrees of potential harm associated with multiple consumption methods.

3 Data

To conduct this analysis, we compile data from three distinct sources. The following subsections identify the data sources and highlight relevant documentation changes.

3.1 National Survey on Drug Use and Health (NSDUH)

3.1.1 Overview

Consumption and risk perception state-level data are drawn from the National Survey on Drug Use and Health (NSDUH), an annual survey of the civilian, non-institutionalized population aged 12 or older, sponsored by the Substance Abuse and Mental Health Services Administration (SAMHSA). Since 1971, the NSDUH has collected information on drug use, mental health, and other health-related behaviors from individuals residing in households, non-institutionalized group quarters, and civilians living on military bases. The data is collected through the administration of questionnaires to a representative sample of the population at their place of residence. The NSDUH survey data is one of the primary data sources utilized by researchers examining the impacts of cannabis legalization; indeed, many of the studies referenced in Section 2 identify NSDUH survey data as a key data source. See, for instance, Mennis et al. (2023), Powell et al. (2018), and Felson et al. (2019).

It is important to note, however, that the NSDUH has a cross-sectional design rather than a panel design, and therefore collects data from a new sample of the population each year. Thus, the reliability of the NSDUH data may be compromised by the typical shortcomings of survey data − such as question revisions, response bias, and unrepresentative sampling − as well as by the structure of cross-sectional survey designs, which renders researchers unable to control for how the specific characteristics and behaviors of the respondents evolve over time.

3.1.2 Small Area Estimation (SAE) Dataset

For the purposes of this paper, we focus on the Small Area Estimation (SAE) dataset, a public compilation of state small area outcomes from the NSDUH by survey year, outcome, state, and age group (SAMHSA). The SAE dataset does not report all data from the NSDUH, but instead contains selected outcomes for a limited number of substance use, mental health, and risk perception measures between 1999 and 2019. Also, note that the outcomes are not reported for the 2001–2002 annual interval due to changes in data collection that occurred in 2002.

The NSDUH also releases annual national reports, which provide detailed nationally representative data that include more granular consumption and risk perception outcomes. However, in order to maintain confidentiality, the public national reports eliminate identifying information, such as the census region, state, and other geographical identifiers. The SAE dataset, in contrast, aggregates the raw individual-level data and reports estimates for a considerably smaller collection of outcomes. Thus, there is an important tradeoff to exclusively focusing our analysis on the SAE dataset: while the data enables us to more accurately compare *state-level* consumption and risk outcomes, it obscures heterogeneity in individual-level determinants of these trends in outcomes. Given that much of the existing research on cannabis consumption has already explored individual demographic determinants of cannabis consumption, we aim to expand the scope of findings by considering similar questions at the state level.[5] This is accomplished by extracting our outcome variables from the SAE dataset. We recommend, though, that future studies delve deeper into these questions by examining state-level outcomes with the granular restricted-access datasets.

3.1.3 Variables of Interest

Among the selected state-level variables reported in the SAE dataset, the key outcome variables for this report are marijuana use in the past month, marijuana use in the past year, and perceptions of great risk of smoking marijuana once a month. Notably, the dataset also includes analogous consumption and risk perception outcome variables for other substances, such as alcohol and cigarettes. These state level estimates − which form the foundation of the following analysis − are benchmarked small area estimates (BSAE) based on the hierarchical Bayes estimation approach and reported as proportions for interpretability.[6] Other important variables in the SAE dataset record the name of the state,[7] the year,[8] and the age group corresponding to data entries.[9]

The dataset utilized for this analysis, then, includes estimates for each of the outcome variables across all states and years; specifically, for a given outcome variable, there are 19 yearly reported estimates per state-age group category, yielding approximately 969 estimates for each age group across all years. Importantly, due to methodological redesign, the SAE dataset does not report risk perception estimates

[5] See for example: Callaghan, Russell C., Marcos Sanches, Claire Benny, Tim Stockwell, Adam Sherk, and Stephen J. Kish. "Who consumes most of the cannabis in Canada? Profiles of cannabis consumption by quantity." Drug and alcohol dependence 205 (2019): 107587; Chiu, Vivian, Wayne Hall, Gary Chan, Leanne Hides, and Janni Leung. "A systematic review of trends in US attitudes toward cannabis legalization." Substance Use & Misuse 57, no. 7 (2022): 1052-1061.

[6] For a more detailed description of how the data estimates are produced, refer to Section A.2 of the "2011-2012 NSDUH: Guide to State Tables and Summary of Small Area Estimation Methodology."

[7] This location variable identifies all 50 states, 4 broader geographic regions, and the District of Columbia.

[8] The year ranges from 1999 to 2019.

[9] The age groups are reported in specific intervals: individuals aged 12 or older, 12 to 17, 18 to 25, 26 or older, 18 or older, or 12 to 20.

for 2015.[10]

3.2 American Community Survey (ACS)

In order to control for characteristics of given states, we use state-level covariates from the American Community Survey (ACS), an ongoing survey conducted by the U.S. Census Bureau that collects detailed demographic, social, economic, and housing information from a sample of U.S. households on an annual basis. Full implementation of the ACS began in 2005, so the data collected on state-level characteristics is confined to the interval from 2005 to 2019. We use the following state-level covariates from the ACS: total overall population, total populations corresponding to each age interval, total White (non-Hispanic) population, total Black population, total population living in poverty, total civilian employed population 16 years and over, total population of high school graduates between the ages of 25 and 64, total population with a Bachelor's degree or higher between the ages of 25 and 64, and the median income.

3.3 Legalization Timeline

Recall that one of the primary research questions of this paper is to examine whether we can identify a strong association between a state's medical or recreational legalization of cannabis, on one hand, and its consumption and risk perception estimates, on the other. Therefore, we construct a dataset that codifies on an annual basis whether a state has implemented either medical or recreational legalization of cannabis. The constructed timeline consists of two dummy variables: a medical legalization dummy variable and a recreational legalization dummy variable that are both "0" prior to (and including) the year of passage of the relevant legalization legislation and "1" in the following years.

[10]This omission in the data will be evident in the tables and plots displayed in subsequent sections.

There are a few relevant limitations to this approach. First, the passage of legislation is by no means equivalent to the effective implementation of legalization; lags between the formal institution of policies and their practical manifestations warrant an examination of the time delay between legalization and the adjustment of state economies. Second, though we codify medical and recreational legalization using two binary variables, this conceals finer variations between state policies.[11] In Section 6, we reiterate how these shortcomings could present avenues for future research exploration.

4 Exploratory Data Analysis

We begin by conducting a basic exploratory data analysis of the outcomes of interest in the SAE dataset. The results enable us to confirm some of the findings of the broader literature that examines how consumption and risk perceptions have changed over time, as well as by region, substance, and age group.

4.1 Summary Statistics

Table 1, Table 2, and Table 3 depict summary statistics of monthly cannabis consumption, yearly cannabis consumption, and risk perception estimates respectively. The reported statistics are calculated by grouping all states on a yearly basis and then calculating the unweighted annual mean, median, and standard deviation for each outcome across the widest available age range, or 12+.

[11] Consider, for instance, that nine states allow for the use of "low THC, high cannabidiol" products as either a legal defense or for specific limited medical reasons. These programs, however, do not fall under the category of comprehensive medical cannabis programs. Finer codifications of state legalization policies may be represented with categorical variables that take on more than simply two values. For more detail on interstate variation and statutory language, see: National Conference of State Legislatures, *State Medical Cannabis Laws.*

Year	Mean	Median	Std. Dev
2005	0.062	0.059	0.013
2006	0.063	0.058	0.014
2007	0.062	0.057	0.015
2008	0.063	0.058	0.016
2009	0.066	0.060	0.018
2010	0.070	0.061	0.021
2011	0.070	0.063	0.022
2012	0.073	0.065	0.023
2013	0.076	0.069	0.025
2014	0.082	0.075	0.026
2015	0.086	0.078	0.027
2016	0.090	0.078	0.032
2017	0.098	0.082	0.036
2018	0.105	0.089	0.036
2019	0.112	0.101	0.036

Table 1: Monthly Consumption Summary Statistics

Year	Mean	Median	Std. Dev
2005	0.107	0.102	0.019
2006	0.106	0.102	0.021
2007	0.105	0.100	0.021
2008	0.105	0.102	0.022
2009	0.110	0.105	0.022
2010	0.116	0.107	0.027
2011	0.117	0.108	0.029
2012	0.122	0.111	0.031
2013	0.128	0.116	0.034
2014	0.134	0.122	0.034
2015	0.138	0.126	0.036
2016	0.141	0.129	0.040
2017	0.152	0.137	0.044
2018	0.162	0.143	0.046
2019	0.173	0.158	0.047

Table 2: Yearly Consumption Summary Statistics

In Table 1 and Table 2, we observe that the mean monthly and yearly cannabis consumption estimates have increased substantially between 2005 and 2019. While on average an estimated 6.2% of individuals above the age of 12 consumed cannabis on a monthly basis in 2005, over 11% were estimated monthly users in 2019. Similarly, the estimated mean percentage of yearly users of cannabis across all states jumped from approximately 10.7% in 2005 to 17.3% in 2019. The median estimates follow similar trends, increasing by 4.2% and 5.6% for monthly and yearly consumption respectively. Finally, the standard deviations of both monthly and yearly estimates tend to increase throughout the 15-year range, suggesting that the variation or spread of consumption between states has widened over time.

Year	Mean	Median	Std. Dev
2005	0.381	0.390	0.053
2006	0.379	0.386	0.055
2007	0.379	0.389	0.056
2008	0.368	0.370	0.052
2009	0.347	0.348	0.052
2010	0.326	0.330	0.054
2011	0.313	0.319	0.051
2012	0.301	0.302	0.049
2013	0.282	0.286	0.051
2014	0.260	0.265	0.049
2016	0.265	0.272	0.051
2017	0.250	0.251	0.048
2018	0.236	0.246	0.046
2019	0.223	0.226	0.044

Table 3: Risk Perceptions Summary Statistics

In contrast, the mean risk perception estimates, shown in Table 3, have decreased significantly over time, falling from 38.1% in 2005 to 22.3% in 2019. The median has dropped sharply as well, from 39.0% in 2005 to 22.6% in 2019. To put these numbers in context, the noticeable downwards trend indicates that the average proportion of individuals, aross all states, who perceive that there is a great associated risk from monthly cannabis consumption has fallen dramatically. The standard deviation remains relatively consistent across all years, though falls slightly in the most recent reported data.

To extend these findings visually, we provide boxplots of monthly cannabis consumption, yearly cannabis consumption, and risk perceptions over time. Similarly to the summary statistics, these boxplots are created by grouping all states within each year and then boxplotting the resultant outcome vectors. Observe that each boxplot provides a visual representation of the corresponding dataset's distribution. The middle line represents the median of the data, while the box itself ranges from the first quartile of the data to the third quartile. The lower "whisker", or dotted line, corresponds to the smallest data point greater than the first quartile minus the Interquartile Range (IQR) scaled by 1.5. The upper whisker corresponds to the largest data point below the third quartile plus 1.5 times the IQR. The points beyond the whiskers represent outliers under this IQR method.

These figures reinforce our findings from the previous tables. First, monthly and yearly consumption estimates have gradually increased over time, as evidenced by upwards-trending boxplots; the total spread of the boxplots also seems to increase over the 15-year period, suggesting a trend towards greater within-year variation. Second, there are many right-tail outliers among the consumption estimates grouped by year, suggesting that certain states exhibit significantly above-average consumption proportions. Third, risk perception estimates have fallen over time, along with the within-year variation of risk estimates; by 2019, the risk perception estimates across all states are contained within a notably smaller range than, say, in 2005. Indeed, relative to the boxplots of consumption estimates, we observe far fewer outliers within the risk perception boxplots.

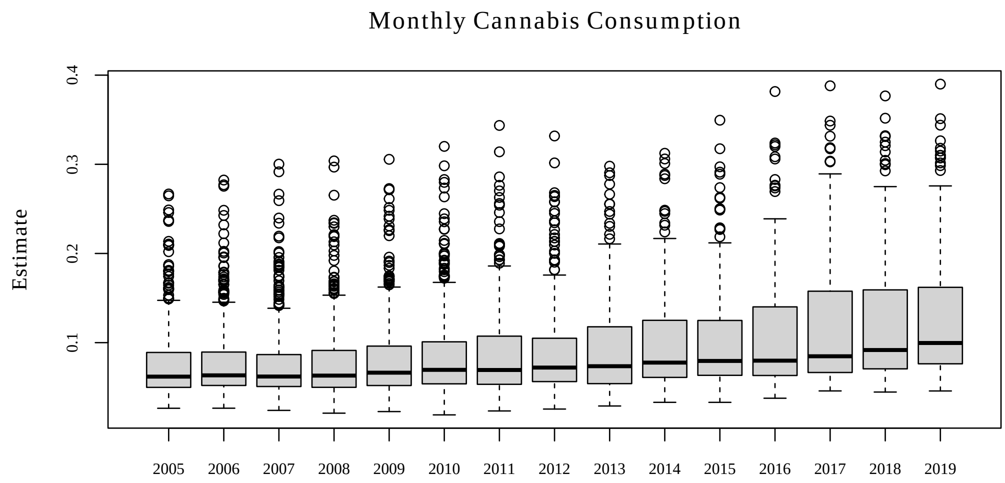

Figure 1: Boxplots of Monthly Cannabis Consumption Over Time

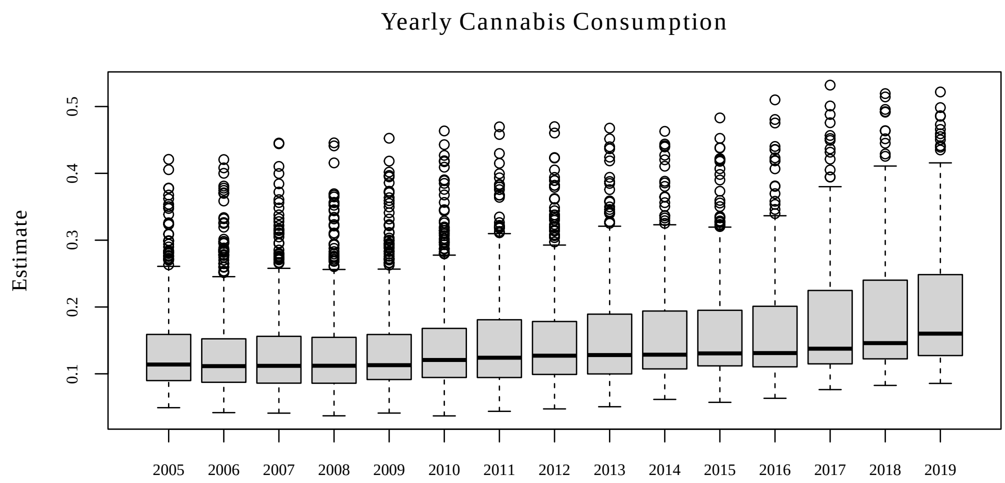

Figure 2: Boxplots of Yearly Cannabis Consumption Over Time

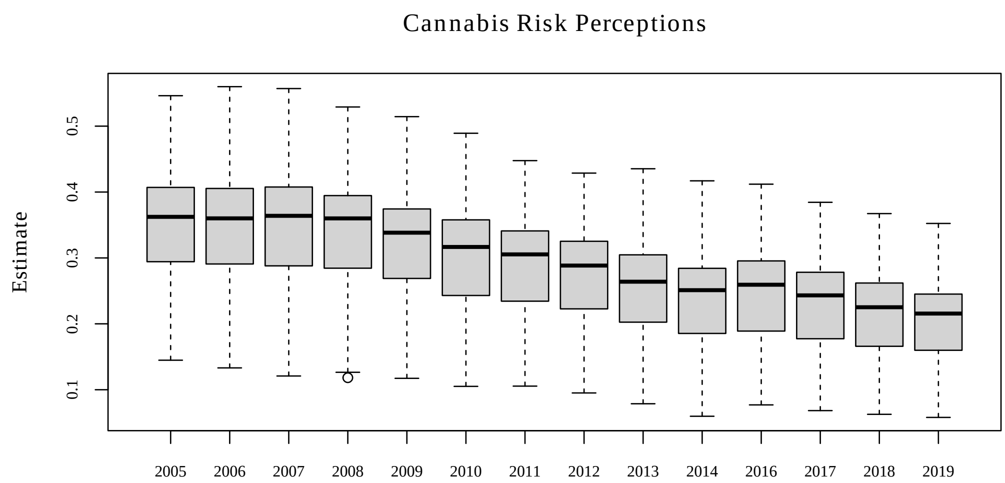

Figure 3: Boxplots of Cannabis Risk Perceptions Over Time

4.2 Comparative Analysis

Figures 4 through 11 depict absolute and indexed estimates of monthly consumption, yearly consumption, and risk perceptions over time, by various groupings: region, substance, and age group. The absolute plots (on the left) show raw reported estimates between 2005 and 2019, while the indexed plots (on the right) show these same estimates indexed to 100 in 2005.

4.2.1 Across Regions

Figure 4, Figure 5, and Figure 6 display the three outcome variable estimates over time by region. The region groupings are the Northeast,[12] the Midwest,[13] the South,[14] the West,[15] and the National aggregate.[16]

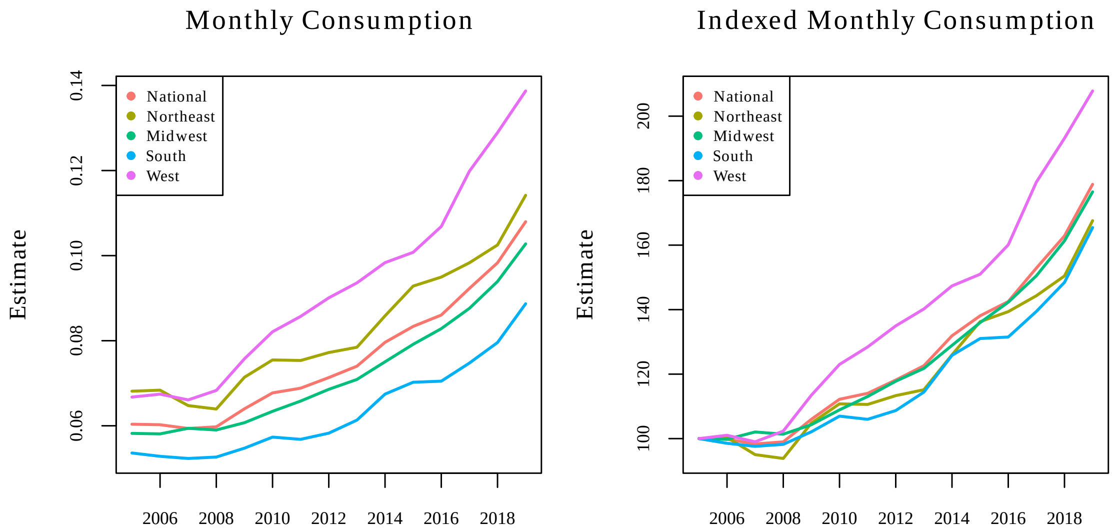

Figure 4: Monthly Cannabis Consumption Over Time by Region

[12]The Northeast consists of estimates collected from Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.

[13]The Midwest consists of estimates collected from Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

[14]The South consists of estimates collected from Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia.

[15]The West consists of estimates collected from Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

[16]The National aggregate represents the survey's outcome estimate for the entire United States in a given year.

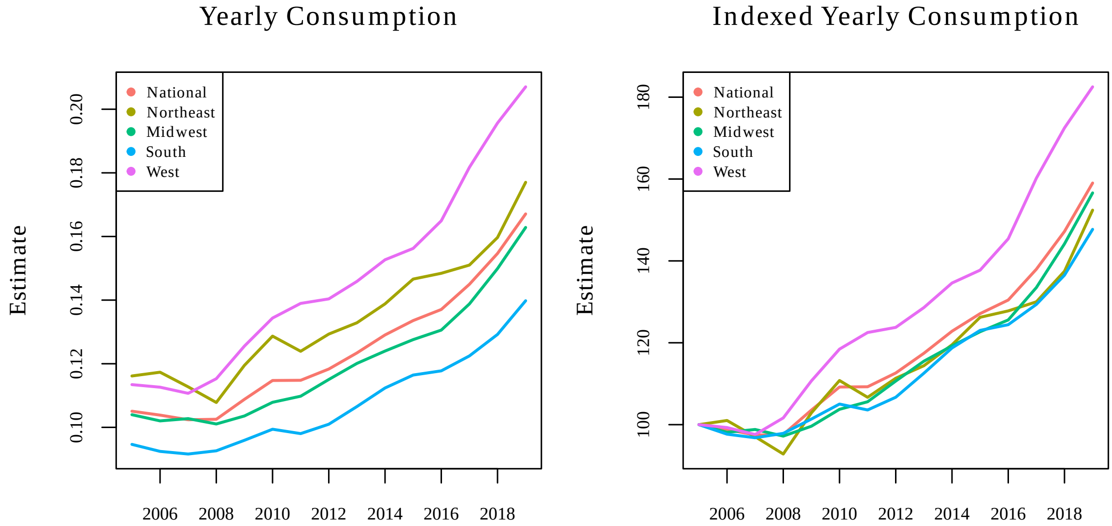

Figure 5: Yearly Cannabis Consumption Over Time by Region

In Figure 4 and Figure 5, the absolute monthly and yearly consumption estimates by region follow similar trends. The West boasts the highest consumption estimates throughout most of the 15-year period, while the South consistently reports the lowest; the Northeast and the Midwest, in that order, are typically somewhere in between the extreme regional estimates. We also observe that the spread of consumption estimates increases over time: the Western and Southern regions, for instance, exhibit considerably larger differences in consumption estimates during later years than during the early 2000s. According to these survey estimates, as of 2019 an estimated 10.8% of Americans consume cannabis on a monthly basis and approximately 16.7% do so on an annual basis.[17] In contrast, the analogous estimates for 2005 are 6.0% and 10.5%.

The indexed plots similarly shed light on how consumption estimates have grown rapidly across all regions. Consumption growth rates in the West, in particular, have outpaced those of other regions, which have separately exhibited similar growth rates. Prior to 2008, the increases in consumption were somewhat negligible relative to the 2005 benchmark, with the largest gains observed in more recent years.

[17] Note that the estimates here differ from those in Tables 1–3 because the latter are calculated using a simple unweighted average, in contrast to the SAE estimates.

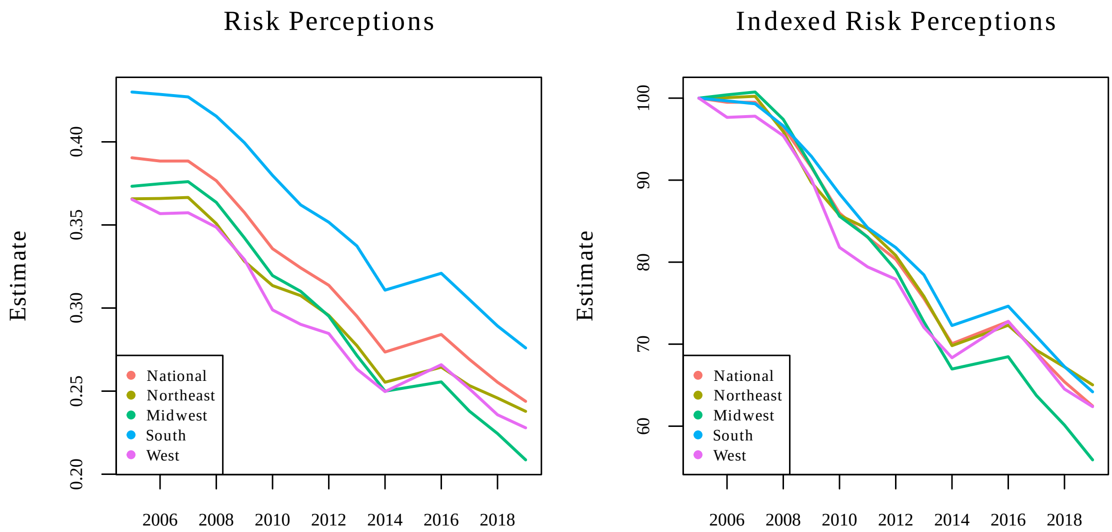

Figure 6: Risk Perceptions Over Time by Region

In contrast to the consumption trends, risk perception estimates follow a downwards trajectory over time across all regions. The South exhibits the highest absolute risk perception estimates across all years, while the Midwest experiences the largest proportional drop in risk perception estimates since 2005. From 2005 to 2019, the percentage of Americans that perceive a great associated risk to monthly consumption of cannabis falls from 39.0% to 24.4%.

4.2.2 Across Substances

Figure 7 and Figure 8 depict consumption and risk perception estimates over time for selected substances (specifically, alcohol, cigarettes, and cannabis). By inspection, monthly consumption of alcohol has remained relatively constant between 2005 and 2019, while cigarette consumption has gradually fallen and cannabis consumption has gradually risen; this is particularly evident in the indexed plot, which demonstrates the divergence of growth rates between consumption of the three substances. While cannabis consumption has grown the most rapidly during this period, as of 2019 it still lags behind analogous estimates for alcohol and cigarette consumption.

Conversely, the percentage of Americans who associate great risk with monthly consumption of cannabis has fallen since 2005. Risk perceptions of alcohol have somewhat increased, while risk perceptions of cigarettes have not changed significantly.[18] In sum, we observe that cannabis has exhibited rapid changes in consumption and risk perception estimates relative to other commonly consumed substances.

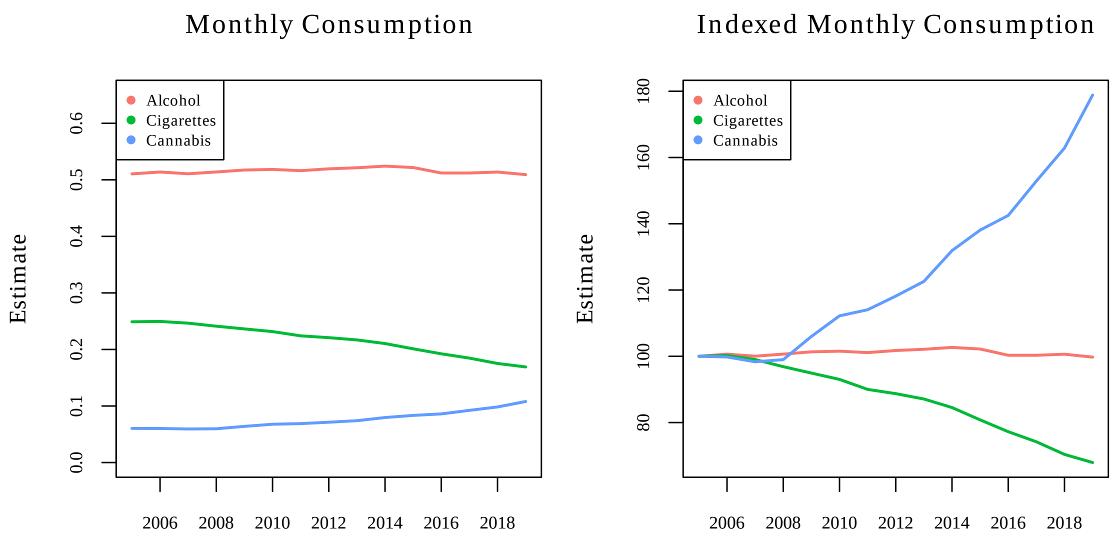

Figure 7: Monthly Consumption Over Time by Substance

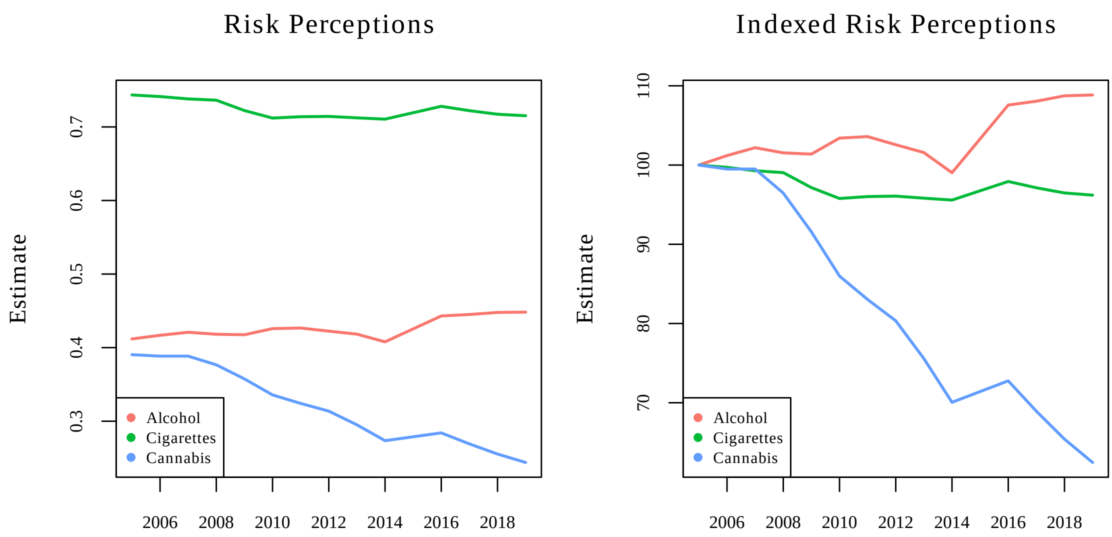

Figure 8: Risk Perceptions Over Time by Substance

[18]Note that the risk perception estimate for alcohol represents perceptions of great risk from consuming five or more drinks of an alcoholic beverage once or twice a week, and for cigarettes represents perceptions of great risk from smoking one or more packs of cigarettes per day.

4.2.3 Across Age Groups

Figure 9, Figure 10, and Figure 11 display the outcomes of interest over time, by age group. Note that the age groups reported in the SAE dataset are not standard age intervals and, therefore, are principally helpful for examining consumption and risk perception trends among adolescents (ages 12 through 17) and young adults (ages 18 through 25).

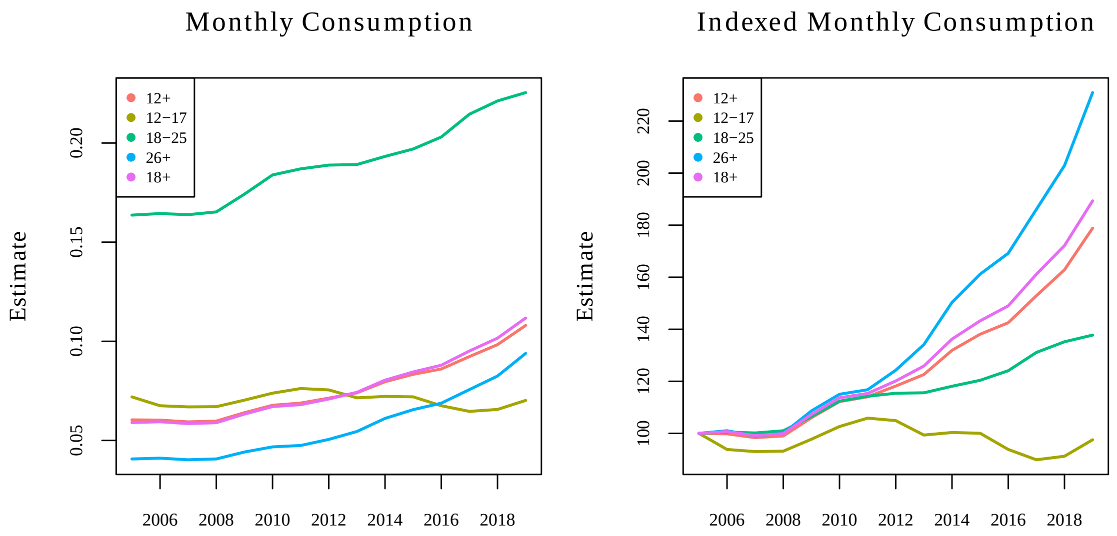

Figure 9: Monthly Cannabis Consumption Over Time by Age Group

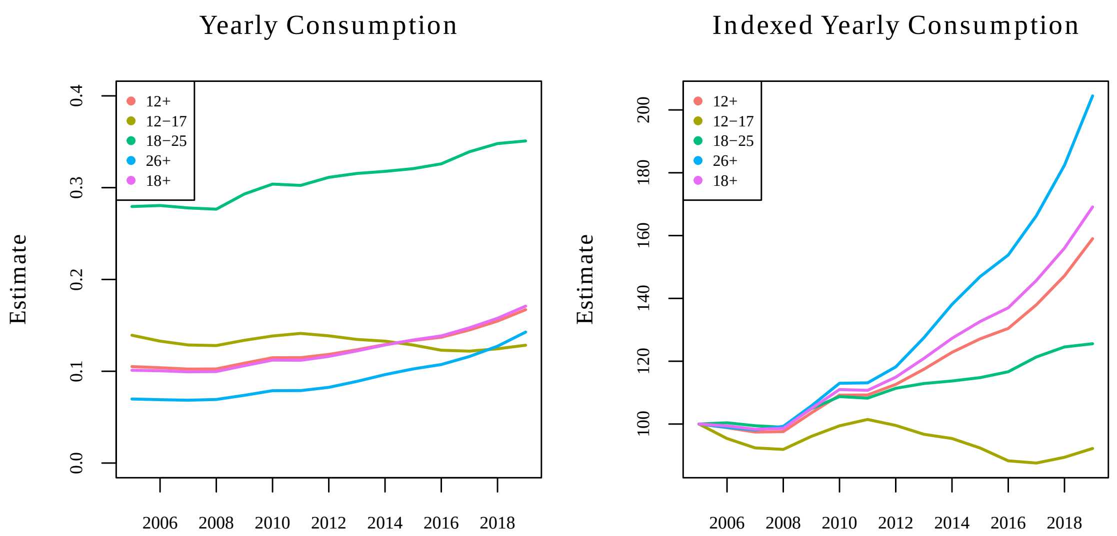

Figure 10: Yearly Cannabis Consumption Over Time by Age Group

Consumption estimates are consistently the largest for individuals between 18 and 25 years of age, with monthly consumption increasing from 16.4% to 22.5% and yearly consumption increasing from 27.9% to 35.1% between 2005 and 2019. In contrast, for adolescents between 12 and 17 years of age, yearly consumption estimates have fallen slightly from 13.9% in 2005 to 12.8% in 2019. From the indexed series, we find that consumption estimates among users older than 26 years of age have exhibited the fastest rates of growth. Adolescent consumption has, on the other hand, exhibited negligible or negative changes since 2005.

Risk perception estimates across age intervals have exhibited relatively similar declines over time, though the drop in risk associated with monthly cannabis consumption among individuals between the ages of 18 and 25 is by far the greatest (proportionally). The key takeaway, then, is that between 2005 and 2019 we observe a significant *increase* in young adult cannabis consumption alongside a simultaneous *decrease* in young adult risk perceptions of cannabis. Finally, we observe slight increases in risk perception estimates between 2014 and 2016, which are also evident in Figure 6.[19]

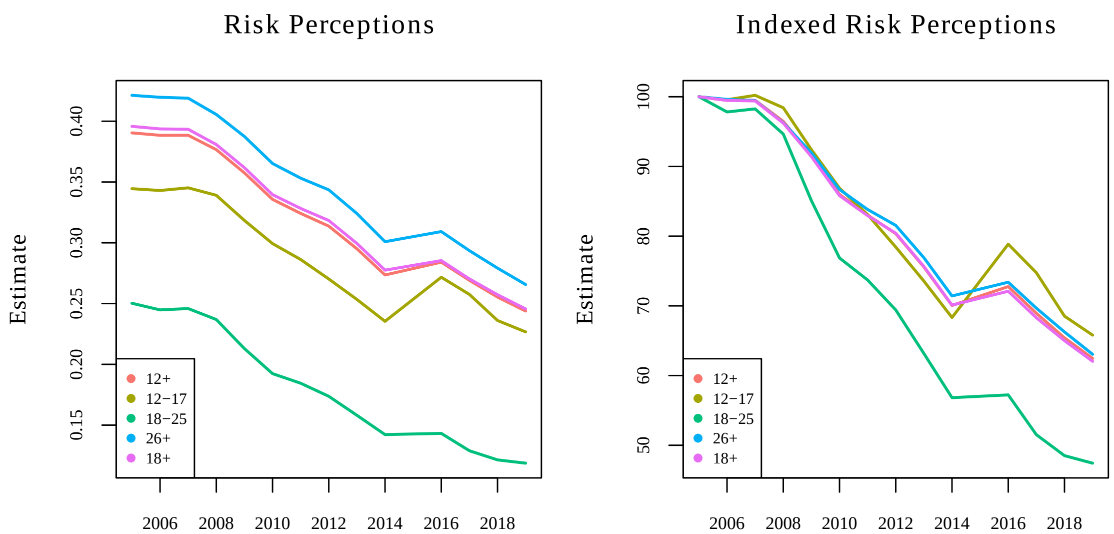

Figure 11: Risk Perceptions Over Time by Age Group

[19]It is unclear to what extent this sudden jump is attributable to the fact that risk perception data are omitted in 2015.

4.3 A Simple Regression

To conclude this section, we present the results of three simple OLS regressions that reinforce the previous observational findings. We regress each of the outcomes of interest – scaled by 100 for interpretability as a percentage rather than a proportion – on a time index explanatory variable. This time index regressor is defined as the number of years since 2005 (which takes on a value of 0 in 2005 and corresponding positive values for years following 2005). The choice to index the explanatory year variable at 2005 stems from two observations: first, 2005 is the first year of the time series and second, indexing the year to 2005 will render the intercept estimates more meaningful in context.[20] Thus, our intercept parameters represent the estimated consumption or risk perception measurements in 2005, while the slope parameters represent the estimated change in consumption or risk perception measurements for each subsequent year.

The regression results are shown graphically in Figure 12, and the corresponding tables are included in the Appendix. Note that the plotted points are the reported outcome estimates, and the lower and upper error bars are determined by the lower and upper bound estimates also included in the SAE dataset.[21] From the regression slopes, we find that monthly and yearly consumption percentages among Americans are predicted to increase by .328% and 0.429% for each year following 2005. The percentage of Americans that associate great risk with monthly consumption of cannabis is predicted to fall by approximately 1.13% each year during the 15-year period. Each of the slope and intercept coefficients are significant at the 1% level and the regressions boast R^2 values that exceed 0.90, as shown in the Appendix. These results support the observations in Sections 4.1 and 4.2 that cannabis consumption and risk perceptions among Americans have changed over the past two decades.

[20] If we regress the scaled outcomes on the raw (un-indexed) year variable, then the intercept will represent the predicted estimate at year 0. Not only is such an estimate irrelevant in the context of cannabis legalization, but it is also an example of extreme linear extrapolation.

[21] These bounds correspond to the 95% lower and upper Bayesian confidence intervals associated with the point estimate.

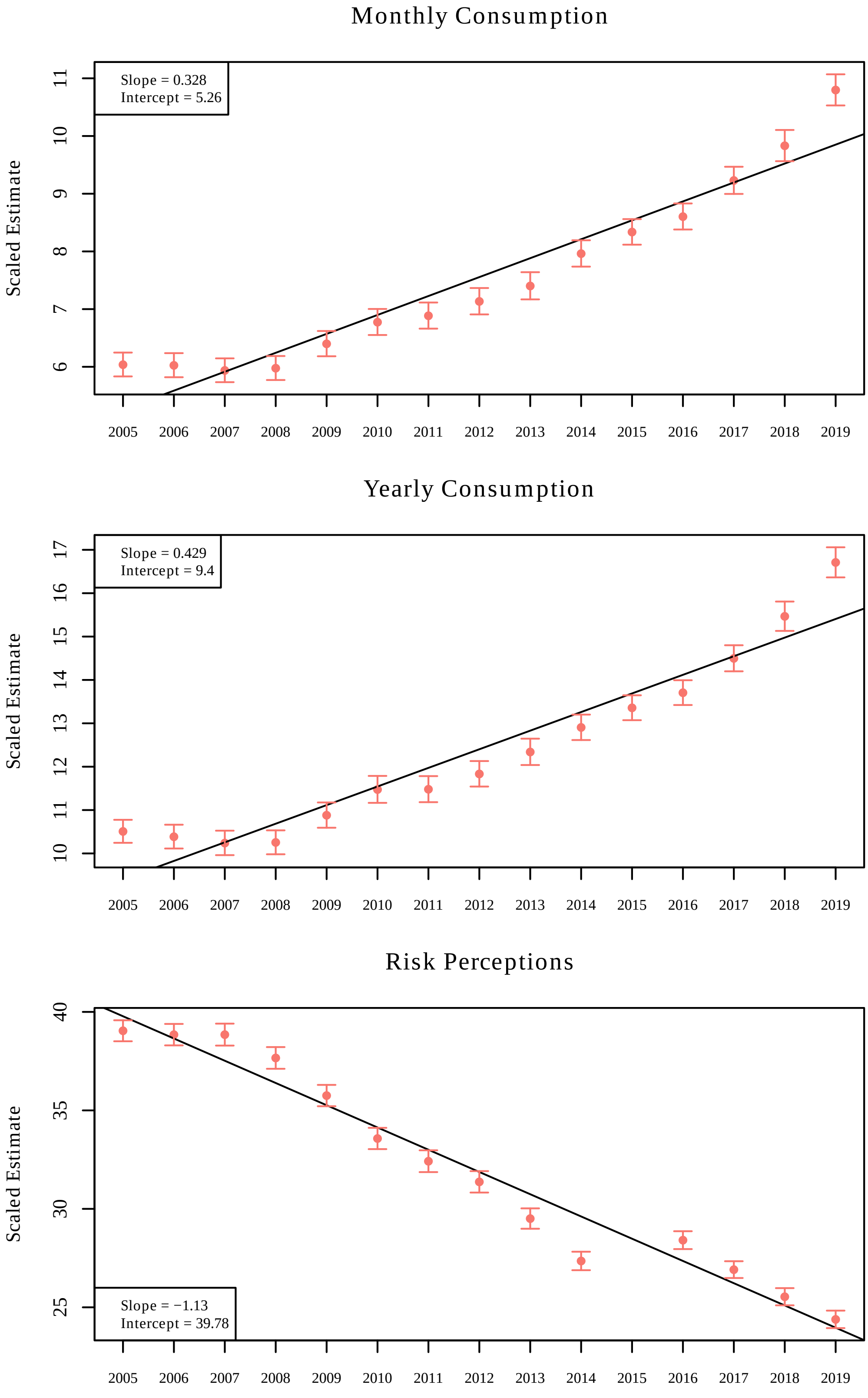

Figure 12: Simple OLS Regression Plots

5 Regression Models

In Section 5, we detail the regression analysis. In Section 5.1, we motivate the construction of the three models. In Sections 5.2, 5.3, and 5.4, we present the estimated regression results for the monthly cannabis consumption, the yearly cannabis consumption, and the risk perception outcomes. In Section 5.5, we identify the key takeaways from this analysis and provide possible explanations for a few of the more counterintuitive findings.

5.1 Model Construction

We begin by constructing a set of regressors to model state variation in consumption and risk perception outcomes. Our regressor selection is motivated largely by previous empirical findings. Jeffers et al. (2021), for example, examines sociodemographic characteristics associated with the prevalence and frequency of cannabis use among American adults. The study finds that higher frequency cannabis use is more commonly observed among respondents with low socioeconomic status, and is simultaneously associated with younger ages, lower educational attainment, and Black racial identification. Pacek et al. (2015) considers a similar question for cannabis risk perceptions, analyzing demographic differences in perceived risk of regular cannabis use between 2002 and 2012. Controlling for confounding sources of variation, the study concludes that certain demographic characteristics – female sex, non-White racial identification, age exceeding 50 years, and family income between \$20,000 and \$49,999 – are associated with increased odds of perceived great risk of regular cannabis use. Conversely, adolescent and young adult age ranges, educational attainment above the high school level, total family income exceeding \$75,000, and previous yearly cannabis usage are strong predictors of decreased odds of perceived great risk.

In line with these observations, we use state-level ACS data to construct variables of urbanicity, population demographic features, educational attainment, poverty rates, and key economic outcomes (such as income and employment). First, we determine the population density by dividing the total state population by the state area, measured in square kilometers.[22] Second, we find the proportion of "young" individuals (between 15 and 24 years of age) in each state, by dividing the relevant age interval population totals by the total state population. Third, the White and Black population proportions are established by dividing the total number of White and Black individuals, respectively, by the total state population. Fourth, we create proxies for high school and college degree rates by dividing the total number of high school and college graduates (between the ages of 25 and 64) by the total state population within this age interval. Fifth, the poverty rate is defined to be the total population below the poverty threshold as a proportion of the total state population. Sixth, we calculate the civilian employment rate as the proportion of the total state population that is classified as both civilian and employed. Lastly, the median state income is pulled directly from the ACS data, without subsequent transformations.

Therefore, the final set of state-level covariates for our regression analysis consists of: the population density in hundreds of people per square kilometer, the proportion of "young" individuals, the proportion of White individuals, the proportion of Black individuals, educational indices of high school and college attainment, the poverty rate, the civilian employment rate, and the median income in thousands of dollars. Summary statistics of these variables (across all years and states) are displayed in Section 8.2 of the Appendix.

Importantly, the set of regressors that we use in the regressions below consists of these covariates along with the recreational legalization and medical legalization dummy variables introduced in Section 3.3. For reference, Section 8.3 of the Appendix includes a table of medical and recreational legalization years by state. The relevant outcomes, of course, are the annual SAE estimates of monthly cannabis

[22] Note that we use a cartographic boundary shapefile from the U.S. Census Bureau to determine state area.

consumption, yearly cannabis consumption, and perceptions of great risk of consuming cannabis on a monthly basis; recall that each of these outcomes – representing proportions of the total state population – fall on a scale of 0 to 1.

In the following subsections, for each outcome of interest, we perform three regressions. Let i and t denote the state and year, respectively. The first model, represented by Equation (1), is a standard OLS regression,

$$Y_{it} = X_{it}\beta + \epsilon_{it} \tag{1}$$

where Y is the consumption or risk perception outcome, X is the vector of regressors, β is the vector of coefficients, and ϵ is the corresponding error term. We assume that the zero conditional mean assumption holds, or $E[\epsilon|X] = 0$. The second model is a one-way fixed effects regression model, shown in Equation (2),

$$Y_{it} = X_{it}\beta + \alpha_i + \epsilon_{it} \tag{2}$$

where α_i is now the state fixed effect that controls for time-invariant differences across states. The third model is a two-way fixed effects regression model, shown in Equation (3),

$$Y_{it} = X_{it}\beta + \alpha_i + \lambda_t + \epsilon_{it} \tag{3}$$

where the additional term λ_t is the year fixed effect that controls for unobserved time-varying factors that are common across all states.

5.2 Monthly Consumption

Table 4 reports the results from the three regression models for the monthly cannabis consumption outcome.[23] For Model (1), we estimate coefficients that are statisti-

[23]Note that the state and time fixed effects for Model (2) and Model (3) are displayed in Section 8.4 of the Appendix. This is also the case for the subsequent regressions involving yearly cannabis

cally significant at the 1% significance level for almost all of the regressors, except for the college degree attainment index (with a corresponding coefficient that is significant at the 5% level) and the civilian employment rate (with an insignificant coefficient). In particular, the coefficients on both the medical and recreational legalization dummy variables differ statistically from 0, though they are also small in magnitude relative to a handful of the other reported coefficients. The model suggests, rather counterintuitively, that medical and recreational legalization are associated with respective 1.8% and 3.9% declines in the proportions of individuals in a given state that report monthly cannabis consumption. Note, however, that these estimates do not take into account fixed effects because Model (1) does not control for state and time confounders; the results therefore suggest that states adopting legalization simply have lower consumption on average.[24]

Model (2), which incorporates state fixed effects, similarly reports statistically significant coefficients for many of the variables, including the population density, the median income, the proportion of Black individuals, the index of college degree attainment, and the civilian employment rate. The indicator of medical legalization exhibits a positive but insignificant association with monthly consumption, while recreational legalization is associated with an expected 2.2% decrease in monthly cannabis consumption.[25] Finally, in Model (3), after taking into account both time-invariant effects within states and time-varying effects across states, we observe statistically significant coefficients for the proportion of White individuals, the proportion of Black individuals, the poverty rate, and the civilian employment rate; the coefficients are particularly large in magnitude for these latter three variables. Moreover, medical legalization and recreational legalization are associated with a significant 0.8% increase and 2.0% decrease in monthly cannabis consumption, re-

consumption and risk perceptions.

[24]Notably, Model (1) exhibits an R^2 of 0.717, suggesting that the selected regressors explain a considerable portion of the variation in the monthly cannabis consumption outcome.

[25]The overall R^2 is 0.945 and the within R^2 is 0.815, which demonstrates that the model exhibits a relatively accurate overall fit and that the selected regressors explain a reasonably substantial amount of variation in monthly consumption after controlling for state fixed effects.

Table 4: Monthly Consumption Regressions

	Dependent variable:		
	BSAE		
	No Fixed Effects	One-Way	Two-Way
	(1)	(2)	(3)
pop_density	−0.004***	−0.070***	−0.017
	(0.001)	(0.024)	(0.023)
median_income	0.002***	0.002***	0.0002
	(0.0003)	(0.0003)	(0.0005)
young_prop	0.358***	−0.366**	0.229
	(0.130)	(0.145)	(0.160)
white_prop	0.112***	0.130**	0.140***
	(0.023)	(0.054)	(0.050)
black_prop	−0.073***	0.879***	0.481**
	(0.024)	(0.210)	(0.195)
pov_rate	0.431***	0.103	−0.216**
	(0.086)	(0.086)	(0.106)
hs_rate	0.238***	0.164**	0.005
	(0.047)	(0.077)	(0.093)
ba_rate	0.115**	0.539***	0.018
	(0.049)	(0.103)	(0.119)
civemp_rate	−0.021	−0.311***	−0.294***
	(0.084)	(0.082)	(0.106)
med_dummy	−0.018***	0.004	0.008***
	(0.002)	(0.002)	(0.002)
rec_dummy	−0.039***	−0.022***	−0.020***
	(0.003)	(0.002)	(0.002)
Constant	−0.258***		
	(0.056)		
Observations	360	360	360
R^2	0.717	0.945	0.958
Adjusted R^2	0.708	0.795	0.241
Within R^2		0.815	0.343
F Statistic	80.271***	129.950***	14.732***
Note:			*p<0.1; **p<0.05; ***p<0.01

spectively. The overall R^2 of the two-way fixed effects model is 0.958, while the remaining within R^2 is merely 0.343. This suggests that, first, the state and year fixed effects explain a relatively large proportion of the variation in monthly cannabis consumption and that, second, the selected regressors (including the indicators of medical and recreational legalization) explain a somewhat limited amount of the additional variation in the outcome variable within each state over time.

Thus, we observe that all three models report a statistically significant *negative* coefficient for the recreational legalization dummy variable, suggesting that recreational legalization is predicted to yield declines in monthly cannabis consumption – even after controlling for state and year fixed effects. Given that recreational legalization is likely to expand reliable access to cannabis, we are skeptical about the robustness of this result. In Section 5.5, we discuss possible interpretations of these counterintuitive results in further detail.

5.3 Yearly Consumption

Table 5 reports the regression results for prediction of yearly cannabis consumption. We unsurprisingly observe that the significance and magnitudes of the slope coefficients are somewhat similar to those in Table 4, for monthly consumption.[26] Model (1) reports statistically significant coefficients on almost all of the selected regressors, though the reported coefficients are largest in magnitude for the proportion of young individuals, the poverty rate, and the index of high school attainment. Before controlling for fixed effects, we find that medical and recreational legalization are expected to coincide with corresponding 2.1% and 5.0% decreases in yearly consumption.

The fixed effects models yield distinct results. First, after controlling for state fixed effects, Model (2) suggests that medical legalization is not an important predictor of yearly consumption, while recreational legalization is associated with a

[26]Recall that, in Section 4, our exploratory data analysis plots suggest that monthly and yearly cannabis consumption have followed similar trends between 2005 and 2019.

Table 5: Yearly Consumption Regressions

	Dependent variable:		
	BSAE		
	No Fixed Effects	One-Way	Two-Way
	(1)	(2)	(3)
pop_density	-0.005^{***}	-0.106^{***}	-0.037
	(0.001)	(0.029)	(0.027)
median_income	0.003^{***}	0.002^{***}	0.001
	(0.0003)	(0.0004)	(0.001)
young_prop	0.444^{***}	-0.473^{***}	0.247
	(0.159)	(0.175)	(0.189)
white_prop	0.141^{***}	0.155^{**}	0.165^{***}
	(0.028)	(0.065)	(0.059)
black_prop	-0.090^{***}	1.089^{***}	0.609^{***}
	(0.029)	(0.253)	(0.231)
pov_rate	0.543^{***}	0.173^{*}	-0.355^{***}
	(0.105)	(0.104)	(0.125)
hs_rate	0.276^{***}	0.181^{*}	-0.034
	(0.057)	(0.093)	(0.110)
ba_rate	0.128^{**}	0.647^{***}	-0.062
	(0.060)	(0.124)	(0.141)
civemp_rate	-0.038	-0.371^{***}	-0.331^{***}
	(0.103)	(0.099)	(0.126)
med_dummy	-0.021^{***}	0.004	0.010^{***}
	(0.003)	(0.003)	(0.003)
rec_dummy	-0.050^{***}	-0.028^{***}	-0.026^{***}
	(0.004)	(0.003)	(0.003)
Constant	-0.288^{***}		
	(0.068)		
Observations	360	360	360
R^2	0.727	0.953	0.966
Adjusted R^2	0.719	0.812	0.304
Within R^2		0.830	0.397
F Statistic	84.396^{***}	144.273^{***}	18.623^{***}
Note:			*p<0.1; **p<0.05; ***p<0.01

statistically significant 2.8% decline in yearly consumption. As in Table 4, the poverty rate also appears to become a less important predictor of variation in yearly consumption after we incorporate state fixed effects. Second, after controlling for both state and year fixed effects, Model (3) reports statistically significant coefficients on the proportion of White individuals, the proportion of Black individuals, the poverty rate, and the civilian employment rate. The coefficients on medical and recreational legalization – both significant at the 1% level – indicate that the two policies are associated with a corresponding 1.0% increase and 2.6% decrease in yearly cannabis consumption.

5.4 Risk Perceptions

Table 6 displays the regression results for the cannabis risk perception outcome. Model (1) reports statistically significant coefficients at the 1% significance level for most of the regressors, including the medical and recreational legalization indicators. Specifically, the model suggests that medical legalization is associated with a 3.6% increase in the proportion of individuals who associate great risk with the monthly consumption of cannabis, while recreational legalization is associated with an analogous 2.7% increase. After controlling for state fixed effects, Model (2) yields statistically significant coefficients of particularly high magnitude for the proportion of young individuals, the proportion of Black individuals, the poverty rate, and the index of college degree attainment. Under this one-way fixed effects model, medical legalization is expected to coincide with a 1.8% increase in risk perceptions, significant at the 1% level. Conversely, recreational legalization does not exhibit a statistically significant association with risk perceptions. In line with the findings regarding the consumption regression models, it appears that the model explains a substantial portion of the total variation in risk perceptions and that, after incorporating state fixed effects, the selected regressors remain valuable predictors of remaining variation.

Table 6: Risk Perception Regressions

	Dependent variable:		
	BSAE		
	No Fixed Effects	One-Way	Two-Way
	(1)	(2)	(3)
pop_density	0.018***	0.154***	0.006
	(0.002)	(0.047)	(0.030)
median_income	−0.007***	−0.004***	0.003***
	(0.001)	(0.001)	(0.001)
young_prop	−0.341	0.778***	−0.012
	(0.242)	(0.283)	(0.210)
white_prop	−0.513***	−0.078	−0.097
	(0.042)	(0.106)	(0.066)
black_prop	−0.071	−1.172***	−0.334
	(0.044)	(0.411)	(0.258)
pov_rate	−1.235***	−1.261***	0.336**
	(0.160)	(0.170)	(0.141)
hs_rate	−0.243***	−0.014	−0.114
	(0.087)	(0.154)	(0.127)
ba_rate	−0.167*	−1.108***	−0.141
	(0.092)	(0.200)	(0.158)
civemp_rate	0.314**	0.693***	0.225
	(0.156)	(0.162)	(0.143)
med_dummy	0.036***	0.018***	0.002
	(0.004)	(0.005)	(0.003)
rec_dummy	0.027***	0.006	−0.003
	(0.006)	(0.005)	(0.003)
Constant	1.226***		
	(0.104)		
Observations	336	336	336
R^2	0.777	0.968	0.989
Adjusted R^2	0.769	0.848	0.052
Within R^2		0.863	0.185
F Statistic	102.516***	172.659***	5.952***
Note:			*p<0.1; **p<0.05; ***p<0.01

Lastly, Model (3) reports statistically significant coefficients only for the median income and the poverty rate, suggesting that a $1,000 increase in the median income or a 1% increase in the poverty rate are associated with corresponding 0.3% and 33.6% increases in risk perception estimates. Notably, neither of the medical or recreational legalization indicator slopes are significant. The two-way fixed effects model, then, suggests that after controlling for state and year fixed effects, medical and recreational legalization are not significantly associated with changes in risk perception estimates.

5.5 Results

We briefly summarize the key findings of the previous regression analysis. Model (1), or the standard OLS regression, reports that medical and recreational legalization are associated with statistically significant declines in monthly and yearly cannabis consumption, ranging between 1.0% and 5.0%, with higher magnitude declines corresponding to recreational legalization. With respect to risk perception estimates, Model (1) finds that medical and recreational legalization are expected to yield 3.6% and 2.7% increases in cannabis risk perception – estimates derived from slope coefficients that are significant at the 1% level. The coefficients reported in Model (1), however, are likely biased by unobserved heterogeneity across all states or, in other words, state-specific characteristics that do not vary over time. Model (1), which seeks to predict variation in outcomes with a common intercept across all states, therefore overlooks differences between states that compromise the reliability of pooled estimates.

Model (2), then, remedies this shortcoming by incorporating one-way state fixed effects, effectively controlling for the time-invariant differences across states. The Model (2) regression results indicate that medical legalization is not significantly associated with changes in monthly or yearly consumption, in contrast to recreational legalization which is associated with significant 2.2% and 2.8% declines in monthly consumption and yearly consumption, respectively. Meanwhile, we find that under this model medical legalization, on one hand, is associated with a significant 1.8% increase in risk perception estimates and recreational legalization, on the other, does not produce any significant change in risk perceptions. Of course, the slope estimates from the one-way fixed effects model – that does not incorporate year fixed effects – may be biased by trends over time that are common across all states.

Finally, in Model (3), we control for both unobserved heterogeneity across states (state fixed effects) and trends across time common to all states (year fixed effects). This two-way fixed effects model reports statistically significant associations between medical and recreational legalization and the two consumption outcomes. Specifically, medical legalization is associated with 0.8% and 1.0% increases in monthly and yearly consumption, while recreational legalization is associated with 2.0% and 2.6% declines in monthly and yearly consumption. We do not find, though, that indicators of legalization are significantly related to the risk perception outcome under Model (3).

Crucially, the significant negative associations between the recreational legalization indicator and the consumption estimates are counterintuitive, for recreational legalization tends to improve access to cannabis for potential users. There are multiple possible explanations for these results,[27] but we suspect that these negative coefficients arise in the two-way fixed effects model because the fixed effects themselves account for a large proportion of the variation in cannabis consumption. Indeed, if the increase in cannabis consumption is a common nationwide trend across all states, then this development will likely be reflected in the common year fixed effects parameters (rather than in the legalization indicator coefficient).

To consider the validity of this hypothesis, we inspect the tables of the fixed effects (included in Section 8.4 of the Appendix) which shed light on the trends in consumption across states and years. In line with our speculations, we note that the

[27] In Section 6.2, we discuss possible limitations of this regression analysis that may also contribute to the counterintuitive findings.

year fixed effects from the two-way regressions suggest that substantial increases in consumption are common *across all states* during this time period. The year fixed effect for the two-way monthly consumption model, for instance, increases considerably between 2008 and 2019, from 0.111 to 0.169. For yearly consumption as well, the year fixed effect increases from 0.175 in 2008 to 0.248 in 2019. These results indicate at least to some extent that the general upwards trend in monthly and yearly cannabis consumption is reflected in the year fixed effects, rather than in the legalization indicator slope coefficients. A comparison of overall R^2 and within R^2 to some extent also reinforces our hypothesis. Recall that, for the two-way fixed effects model, the relatively low within R^2 suggests that after state and year fixed effects are taken into account, the selected state-level covariates and legalization indicators explain a limited proportion of the remaining variation in consumption.[28]

Either way, it is important to note that the final regression results do not imply that recreational legalization leads to decreases in monthly or yearly consumption estimates. Rather, we find that after controlling for time-invariant differences between states and time-varying factors common across all states, recreational legalization is associated with declines in state-level consumption.

Following these counterintuitive findings, we explore a few additional renditions of the two-way fixed effects model, the results of which are displayed in Section 8.5 of the Appendix. First, we regress the consumption and risk perception outcomes on the medical and recreational legalization dummy variables alone (without any ACS covariates). Second, we regress the outcomes on the medical legalization indicator and the ACS covariates (without the recreational legalization indicator). Third, we regress the outcomes on the recreational legalization indicator and the ACS covariates (without the medical legalization indicator). In general, the slope estimates on both legalization indicator variables do not differ noticeably from the original two-way effects regression slopes in either sign, magnitude, or significance.

[28]The within R^2 statistic is even smaller for the two-way effects model of risk perceptions.

6 Conclusions

6.1 Key Takeaways

The regression analysis yields findings that vary considerably by model specification. To briefly summarize, the two-way fixed effects model – which is the most compelling in that it controls for both state and year fixed effects – suggests that medical legalization is associated with a small and statistically significant increase in consumption, while recreational legalization is associated with a small and statistically significant decrease in consumption. In contrast, under this model, legalization policy shows no significant association with risk perceptions.

6.2 Limitations

There are, however, a number of limitations to this regression analysis which must be considered before placing too much weight on the estimates from Section 5. First, the SAE dataset presents inherent constraints due to the limited number of reported consumption and risk perception outcomes, in addition to the periodic omission of data due to methodological survey changes.[29] Second, recall that the legalization indicator variables codify the implementation of legalization policies in a simple manner, assigning a value of "0" to the variable prior to the passage of legalization legislation and a value of "1" following its passage. Legalization policies, however, are not only characterized by more subtle variations within the broad categories of "legalized" versus "non-legalized", but also likely exhibit time lags before effective implementation. The basic dummy regressors used in this analysis may therefore insufficiently capture variation in legalization policies. Also, given that all states with recreational legalization have also adopted medical legalization policies,[30] it may be sensible to interpet the recreational legalization slope estimates as additive

[29]Note, in particular, that the 2020 and 2021 data are not comparable to prior years due to changes in methodology necessitated by the COVID-19 pandemic.

[30]See Section 8.3 of the Appendix.

impacts on top of the effects of medical legalization – rather than as independent associations with consumption and risk perception outcomes. Third, our regression models may fall prey to issues of overfitting[31] or multicollinearity based upon the selection of ACS covariates; indeed, high correlations between trends in legalization and other covariates may bias the estimated slope coefficients. Lastly, by the nature of the approach adopted in this paper – which focuses on changes in consumption and risk perceptions at the state-level – our regression results provide limited insight into how legalization influences individual behavior over time or how the influences on outcomes differ across demographics.

6.3 Future Research

Additionally, there are many possible avenues for future research. Extending the applications of the proposed regression models, future studies should consider to what extent legalization has different impacts on consumption and risk perception outcomes among adolescents and young adults, or within specific geographic regions of the U.S. Moreover, researchers should examine whether replacing cannabis with other substances, such as alcohol or cigarettes, yields similar relationships between the selected covariates and the outcomes of interest. Based upon the observations in Section 4, we suspect that the parameter estimates would vary across different age groups, geographic regions, and substances.

In order to build upon the proposed regression models, subsequent analyses should first seek to refine the variable codification of legalization policies by, for instance, incorporating factor variables that are not confined to the binary dummy variable format; such regressions should also explore whether lagged legalization variables serve as better predictors of outcomes due to implementation delays. Second, future regression models can consider incorporating "spillover" effects between neighboring states that implement legalization policies; specifically, does the extent

[31] Consider the very high R^2 values, for instance, especially in the one-way effects and two-way effects models.

of medical or recreational legalization *across* the United States impact cannabis consumption or risk outcomes *within* given states? Third, modified two-way fixed effects models can incorporate state-specific linear time trends such that each state has its own natural linear trend, thereby allowing for a weaker form of the parallel trends assumption. Fourth, we suggest investigating whether there exist alternative data sources that can facilitate an extension of this analysis beyond 2019 – given that methodology changes necessitated by the COVID-19 pandemic have rendered subsequent estimates incomparable.

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8 Appendix

8.1 A Simple Regression

Table 7: A Simple Regression

	Dependent variable:		
	BSAE_scaled		
	Monthly Consumption	Yearly Consumption	Risk Perception
	(1)	(2)	(3)
Indexed Year	0.328***	0.429***	−1.130***
	(0.027)	(0.037)	(0.065)
Constant	5.259***	9.398***	39.779***
	(0.220)	(0.303)	(0.525)
Observations	15	15	14
R^2	0.920	0.912	0.962
Adjusted R^2	0.914	0.906	0.959
Note:			*p<0.1; **p<0.05; ***p<0.01

8.2 ACS Covariate Summary Statistics

Table 8: ACS Covariate Summary Statistics

Variable	Mean	Std. Dev
Median Income	53,281.660	11,394.140
White Pop.	0.767	0.135
Black Pop.	0.111	0.108
Poverty Rate	0.140	0.053
Young Prop.	0.139	0.009
HS Rate	0.280	0.043
BA Rate	0.307	0.065
Civic Emp. Rate	0.473	0.041
Pop. Density	144.339	487.823

8.3 Legalization Timeline

Table 9: Legalization Years

State	Medical	Recreational
Alabama	2021	NA
Alaska	1998	2014
Arizona	2010	2020
Arkansas	2016	NA
California	1996	2016
Colorado	2000	2012
Connecticut	2012	2021
Delaware	2011	2023
Florida	2016	NA
Georgia	NA	NA
Hawaii	2000	NA
Idaho	NA	NA
Illinois	2013	2019
Indiana	NA	NA
Iowa	NA	NA
Kansas	NA	NA
Kentucky	2023	NA
Louisiana	2015	NA
Maine	1999	2016
Maryland	2003	2022
Massachusetts	2012	2016
Michigan	2008	2018
Minnesota	2014	2023
Mississippi	2022	NA
Missouri	2018	2022
Montana	2004	2020
Nebraska	NA	NA
Nevada	2000	2016
New Hampshire	2013	NA
New Jersey	2010	2021
New Mexico	2007	2021
New York	2014	2021
North Carolina	NA	NA
North Dakota	2016	NA
Ohio	2016	2023
Oklahoma	2018	NA
Oregon	1998	2014
Pennsylvania	2016	NA
Rhode Island	2006	2022
South Carolina	NA	NA
South Dakota	2021	NA
Tennessee	NA	NA
Texas	2015	NA
Utah	2018	NA
Vermont	2004	2018
Virginia	2021	2021

Washington	1998	2012
West Virginia	2017	NA
Wisconsin	NA	NA
Wyoming	NA	NA

8.4 Fixed Effect Parameters

8.4.1 Monthly Consumption

Table 10: One-Way Fixed Effects

Unit	FixedEffect
Alaska	−0.110
Arizona	−0.138
California	−0.104
Colorado	−0.158
Connecticut	−0.078
Delaware	−0.201
Illinois	−0.215
Maine	−0.111
Maryland	−0.280
Massachusetts	−0.034
Michigan	−0.185
Minnesota	−0.190
Missouri	−0.209
Montana	−0.102
Nevada	−0.146
New Jersey	−0.020
New Mexico	−0.097
New York	−0.174
Ohio	−0.160
Oregon	−0.106
Rhode Island	0.080
Vermont	−0.102
Virginia	−0.296
Washington	−0.134

Table 11: Two-Way State Fixed Effects

Unit	FixedEffect
Alaska	0.112
Arizona	0.059
California	0.097
Colorado	0.100
Connecticut	0.083
Delaware	0.016
Illinois	0.027

Maine	0.099
Maryland	−0.002
Massachusetts	0.116
Michigan	0.036
Minnesota	0.050
Missouri	0.015
Montana	0.103
Nevada	0.063
New Jersey	0.081
New Mexico	0.096
New York	0.056
Ohio	0.030
Oregon	0.109
Rhode Island	0.153
Vermont	0.123
Virginia	−0.011
Washington	0.092

Table 12: Two-Way Year Fixed Effects

Unit	FixedEffect
2005	0.112
2006	0.110
2007	0.109
2008	0.111
2009	0.112
2010	0.119
2011	0.123
2012	0.128
2013	0.133
2014	0.139
2015	0.144
2016	0.147
2017	0.157
2018	0.163
2019	0.169

8.4.2 Yearly Consumption

Table 13: One-Way Fixed Effects

Unit	FixedEffect
Alaska	−0.102
Arizona	−0.138
California	−0.083
Colorado	−0.159
Connecticut	−0.008

Delaware	−0.181
Illinois	−0.220
Maine	−0.104
Maryland	−0.276
Massachusetts	0.052
Michigan	−0.186
Minnesota	−0.197
Missouri	−0.219
Montana	−0.098
Nevada	−0.149
New Jersey	0.089
New Mexico	−0.089
New York	−0.155
Ohio	−0.145
Oregon	−0.095
Rhode Island	0.190
Vermont	−0.092
Virginia	−0.321
Washington	−0.128

Table 14: Two-Way State Fixed Effects

Unit	FixedEffect
Alaska	0.182
Arizona	0.129
California	0.182
Colorado	0.180
Connecticut	0.199
Delaware	0.097
Illinois	0.096
Maine	0.176
Maryland	0.070
Massachusetts	0.247
Michigan	0.107
Minnesota	0.116
Missouri	0.080
Montana	0.180
Nevada	0.125
New Jersey	0.214
New Mexico	0.179
New York	0.147
Ohio	0.109
Oregon	0.194
Rhode Island	0.291
Vermont	0.208
Virginia	0.045
Washington	0.167

Table 15: Two-Way Year Fixed Effects

Unit	FixedEffect
2005	0.182
2006	0.178
2007	0.175
2008	0.175
2009	0.178
2010	0.191
2011	0.198
2012	0.203
2013	0.212
2014	0.216
2015	0.218
2016	0.219
2017	0.231
2018	0.240
2019	0.248

8.4.3 Risk Perceptions

Table 16: One-Way Fixed Effects

Unit	FixedEffect
Alaska	0.604
Arizona	0.691
California	0.668
Colorado	0.696
Connecticut	0.430
Delaware	0.648
Illinois	0.746
Maine	0.558
Maryland	0.787
Massachusetts	0.348
Michigan	0.693
Minnesota	0.652
Missouri	0.713
Montana	0.603
Nevada	0.663
New Jersey	0.307
New Mexico	0.700
New York	0.702
Ohio	0.597
Oregon	0.616
Rhode Island	0.202
Vermont	0.568
Virginia	0.834
Washington	0.624

Table 17: Two-Way State Fixed Effects

Unit	FixedEffect
Alaska	0.135
Arizona	0.268
California	0.225
Colorado	0.176
Connecticut	0.219
Delaware	0.300
Illinois	0.291
Maine	0.217
Maryland	0.289
Massachusetts	0.161
Michigan	0.274
Minnesota	0.208
Missouri	0.314
Montana	0.236
Nevada	0.252
New Jersey	0.268
New Mexico	0.280
New York	0.282
Ohio	0.299
Oregon	0.179
Rhode Island	0.199
Vermont	0.193
Virginia	0.287
Washington	0.160

Table 18: Two-Way Year Fixed Effects

Unit	FixedEffect
2005	0.135
2006	0.125
2007	0.119
2008	0.101
2009	0.088
2010	0.065
2011	0.050
2012	0.035
2013	0.013
2014	−0.010
2016	−0.012
2017	−0.032
2018	−0.049
2019	−0.067

8.5 Supplementary Fixed Effects Regressions

Table 19: Monthly Consumption Regressions

	Dependent variable:		
	BSAE		
	No Covariates	Medical Only	Recreational Only
	(1)	(2)	(3)
pop_density		-0.014	-0.031
		(0.020)	(0.023)
median_income		0.0003	0.001
		(0.0003)	(0.0005)
young_prop		0.149	0.192
		(0.140)	(0.163)
white_prop		0.038	0.103^{**}
		(0.047)	(0.050)
black_prop		0.034	0.345^{*}
		(0.169)	(0.197)
pov_rate		0.114	-0.252^{**}
		(0.087)	(0.108)
hs_rate		0.088	0.012
		(0.081)	(0.095)
ba_rate		0.205^{**}	-0.019
		(0.096)	(0.121)
civemp_rate		0.016	-0.375^{***}
		(0.093)	(0.106)
med_dummy	0.008^{***}	0.008^{***}	
	(0.002)	(0.002)	
rec_dummy	-0.019^{***}		-0.022^{***}
	(0.002)		(0.002)
Observations	360	585	360
R^2	0.280	0.058	0.310
Adjusted R^2	0.192	-0.053	0.206
F Statistic	62.228^{***}	3.240^{***}	14.010^{***}
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 20: Yearly Consumption Regressions

	Dependent variable:		
	BSAE		
	No Covariates	Medical Only	Recreational Only
	(1)	(2)	(3)
pop_density		−0.032	−0.053*
		(0.024)	(0.027)
median_income		0.001*	0.001**
		(0.0004)	(0.001)
young_prop		0.170	0.205
		(0.166)	(0.193)
white_prop		0.031	0.123**
		(0.055)	(0.059)
black_prop		0.019	0.454*
		(0.201)	(0.232)
pov_rate		0.078	−0.396***
		(0.104)	(0.128)
hs_rate		0.077	−0.027
		(0.096)	(0.112)
ba_rate		0.182	−0.105
		(0.114)	(0.143)
civemp_rate		0.055	−0.424***
		(0.110)	(0.126)
med_dummy	0.010***	0.011***	
	(0.002)	(0.002)	
rec_dummy	−0.026***		−0.028***
	(0.003)		(0.003)
Observations	360	585	360
R^2	0.322	0.075	0.369
Adjusted R^2	0.240	−0.035	0.274
F Statistic	76.039***	4.246***	18.245***
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 21: Risk Perception Regressions

	Dependent variable:		
	BSAE		
	No Covariates	Medical Only	Recreational Only
	(1)	(2)	(3)
pop_density		0.055**	0.002
		(0.027)	(0.030)
median_income		0.002***	0.003***
		(0.0005)	(0.001)
young_prop		−0.289	−0.021
		(0.182)	(0.209)
white_prop		0.018	−0.106*
		(0.061)	(0.064)
black_prop		−0.370*	−0.366
		(0.220)	(0.254)
pov_rate		0.416***	0.328**
		(0.114)	(0.140)
hs_rate		0.163	−0.111
		(0.109)	(0.127)
ba_rate		0.157	−0.150
		(0.127)	(0.157)
civemp_rate		0.481***	0.206
		(0.123)	(0.140)
med_dummy	0.003	0.004*	
	(0.003)	(0.002)	
rec_dummy	−0.007**		−0.004
	(0.003)		(0.003)
Observations	336	546	336
R^2	0.025	0.196	0.184
Adjusted R^2	−0.100	0.095	0.054
F Statistic	3.831**	11.794***	6.504***
Note:			*p<0.1; **p<0.05; ***p<0.01