Recreational Cannabis and its Effect on Opioids Demand

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Abstract

With many different countries attempting to legalize recreational cannabis, it has prompted many discussions on its potential effects. Especially, in the case of the United States, its potential impact on opioid demands. This study investigates whether recreational cannabis is a complement or substitute for opioids through economic analysis and and public health implications. A Difference-in-Differences (DiD) model is employed in the model for examining the impact of cannabis legalization on opioid prescription rates across selected U.S. states. The findings in this paper suggest that cannabis legalization is associated with a statistically significant decrease in opioid prescriptions, supporting the hypothesis that cannabis may act as a substitute. Given the complexity of the relationship, further analysis is required, given that the overall drug overdose rates have shown an upward trend post-legalization. The study also identifies data limitations and potential confounding factors, such as alcohol consumption which may influence the observed effects. These findings contribute to the ongoing policy debate regarding cannabis legalization and its role in addressing the opioid crisis while emphasizing the need for continued research into its long-term social and health impacts.

1 Introduction

1.1 Motivations

The legalization of recreational cannabis in various U.S. states has ignited many heated debates about the economic, health and social consequences. The main concern is the potential impact of cannabis legalization on opioid usage, given their similar medicinal properties and potential for abuse. While a handful of studies suggest that cannabis might act as a substitute for opioids, leading to a decrease in opioid abuse, others raise concerns about potential spillover effects.

This paper investigates the causal effect of cannabis legalization on the demand for opioid prescriptions. Specifically, I aimed to examine the impact of this relatively new legalization of recreational cannabis and if it has led to a reduction in opioid prescription rates.

The main goal of this analysis is to estimate the treatment effect of cannabis legalization on opioid prescriptions, represented by the coefficient of the DiD interaction term β in a Difference-in-Differences (DiD) model. The coefficient β reflects the differential change in opioid prescriptions between states that legalized cannabis and those that did not. To ensure robustness of the data, I account for potential confounding factor. A statistically significant β would provide evidence that cannabis legalization has a meaningful impact on opioid demand, with potential policy implications for addressing the opioid crisis.

1.2 History

Cannabis has a long and convoluted history, with its origin dating back to approximately 12,000 years ago (Lawler, 2019). The first record of its medical use dates back to 2800 BCE. The father of Chinese medicine, Emperor Shen Nung, documented its medical usage in his pharmacopoeia. (University of Sydney, n.d.). Evidence of cannabis consumption could also be found in various ancient civilizations, including Chinese, Greek, Roman, Indian, and Assyrian. Additionally, ancient Chinese civilizations had previously cultivated cannabis for its psychotropic effects (Crocq, 2020).

Over time, cannabis use expanded beyond traditional medicinal and ritualistic purposes. Developing into a substance that is now widely consumed for recreational use. According to the World Health Organization, cannabis is currently the most widely cultivated, trafficked, and abused illicit drug, accounting for almost half of all drug seizures worldwide. An alarming approximate of 147 million people, or 2.5% of the global population, are estimated to consume cannabis.

1.3 Types of Cannabis Consumption

With its extensive history, the methods for ingesting cannabis have evolved significantly. Cannabis products and now available in various forms. The most common form of consumption involves: inhalation, ingestion, and topical application. The method of inhalation includes smoking the cannabis component, with an additional alternative of including it in vaping devices. Ingestion refers to the consumption of cannabis-infused food products, edibles, or capsules. Other types of uses include topical applications, such as lotions, sprays, and pads, which allow absorption through the skin (University of California, n.d.).

With the growing prevalence of cannabis, its legalization for recreational use in various regions has sparked significant academic and policy discussions. Researchers have increasingly examined its economic and social implications, particularly in relation to other substances. This paper attempts to investigate whether recreational cannabis serves as a complement or a substitute for opioids, given that both substances can induce euphoria and provide pain relief.

1.4 Legalization of Cannabis

In the election of 2012, Colorado and Washington took the lead and approved ballots in favor of legalizing the recreational use and sales of cannabis. With Colorado and Washington lighting the path, twenty-three other states followed in their footsteps, legalizing the drug in the next 11 years as public support rose drastically. However, cannabis is still illegal at the federal level (Davis Jr., Hansen, & Alas, 2024)

1.4.1 Regulatory Framework of the U.S. Cannabis Market

With the successful legalization of cannabis in several states in America, there has been significant interest among the policymakers and the public regarding the probable repercussions of this legal access (Rehm, Elton-Marshall, Sornpaisarn, & Manthey, 2019). Cannabis dispensaries have been established in these legal states, though the regulatory framework governing cannabis laws varies across jurisdictions. However, all cannabis dispensaries are required to obtain proper licensing (Davis Jr., Hansen, & Alas, 2024). These dispensaries operate as privately own firms which competes within the market.

A study conducted in Canada by Myran et al. (2022), found that a privately operated retail system in comparison to a government run retail system, was 4 times more likely to be accessible, resulting in 913% higher sales. Beyond the economic implications, these dispensaries play a role in reducing social stigmatization and mitigating the issue of criminalization. Vedelago et al. (2022) found that at the same price, legal cannabis is preferred to illegal purchases, reducing criminal offenses. According to Pew Research Center, public attitudes towards cannabis have became increasingly liberal in recent years, with growing recognition of its potential benefits.

CannabisMD Telemed (2025) asserts that THC has the potential to facilitate mental and emotional healing. Additionally, the euphoric effects associated with cannabis can enhance creativity, deepen experiences, and alter perceptions. Furthermore, cannabis withdrawal is generally non-dangerous compared to opioids, as cannabis is not physically addictive. Cannabis-induced euphoria can also be achieved in a relatively safer manner, reducing the risk of overdose commonly associated with opioid use. While cannabis offers potential therapeutic benefits, its relationship with opioid consumption remains an important area of study.

However, cannabis use is not without risks. As noted by Hassin, D. (2018), heavy cannabis users faces an increased likelihood of adverse health consequences, including vehicle crashing, respiratory distress, emergency department visits and psychiatric symptoms withdrawal and cannabis use disorder. The American Addiction Centre (2024), Dr. Florimbio highlights that approximately one in ten adults who consume cannabis develops a cannabis use disorder. Furthermore, cannabis abuse accounts for half of all substance abuse admissions among youth aged 12 to 17. The primary component responsible for its addictive properties and the difficulty of withdrawal is THC, which induces euphoria and stimulates increased dopamine levels. As reported by Carmen Pope (2024), common side effects of cannabis use include changes in blood pressure, elevated heart rate, dizziness or drowsiness, facial flushing, gastrointestinal disturbances, an increased risk of developing mood disorders, and some impairment of respiratory function.

Ultimately, the health and social outcomes of cannabis legalization remain uncertain, necessitating assessment to evaluate its broader effects.

1.5 Opioids - Oxycodone

According to the National Center for Health Statistics (June 2023), opioid overdose remains the leading cause of drug-related deaths. Oxycodone contributes to a large proportion of the opioids abused. Despite the introduction of a reformulated, less addictive version of OxyContin (which contains Oxycodone), overdose cases have continued to rise, with a notable 30% increase in 2017 (Hill. KP, 2019). Opioid intoxication is often characterized by rush of pleasure, and a sense of relaxation. However, the severe withdrawal symptoms typically result in a prolonged reluctance to initiate detoxification efforts (Crane, 2024).

1.5.1 Opioid Crisis

On October 26, 2017, President Trump declared the opioid crisis a Public Health Emergency, underscoring the severity of the situation in the United States. From 1999 to 2023, opioid-related deaths have increased tenfold. A significantly high dosage of opioids can induce euphoria, but it is also associated with extremely challenging physical withdrawal symptoms (Fergusson & Hopper, 2023). While the opioid crisis continues to be a significant issue, alternative treatments such as cannabis are being explored to address opioid use and abuse."

1.6 Comparative Analysis of Cannabis and Opioids

1.6.1 Medical Property

The medicinal properties of cannabis closely resemble those of opioids. Medical marijuana has been prescribed as an alternative treatment for pain management. Both substances can be administered via ingestion. A study by Cooper, Bedi, Ramesh, Comer, and Haney (2018), published in Neuropsychopharmacology, found that the combined use of cannabis and opioids resulted in greater pain reduction compared to opioids alone, providing evidence for the opioid-sparing effects of cannabis. An analysis by Vyas, LeBaron, and Gilson (2018), concluded that there is preliminary evidence supporting the use of medicinal cannabis, as it has been associated with a significant reduction in opioid abuse, cannabis abuse, overdose incidents, and lower healthcare costs.

1.6.2 Euphoria Property

In addition to its medical applications, the recreational use of cannabis allows consumers to experience sensations of pleasure similar to those produced by opioids. Opioids bind to opioid receptors in the brain, triggering a surge of dopamine that reinforces pleasurable sensations, contributing to their high potential for addiction (SAMHSA, 2021). Similarly, cannabis stimulates dopamine release but through a different biochemical pathway. Cannabis-induced euphoria is primarily attributed to tetrahydrocannabinol (THC), cannabidiol (CBD), and terpenes. THC interacts with the brain's endogenous cannabinoid system, which influences dopamine activity and alters mood (SAMHSA). Additionally, cannabis contains a complex formulation of compounds such as caryophyllene, terpinolene, myrcene, and limonene, which contribute to its psychological effects, including enhanced relaxation, reduced anxiety, and an overall sense of well-being.

1.6.3 Correlation of Prices

The similarity in the medicinal and recreational properties of cannabis and opioids suggests that they may act as substitutes. To assess whether cannabis and opioids act as substitutes, we estimate the following simple linear regression model:

$$\text{Opioid Prices}_i = \beta_0 + \beta_1 \cdot \text{Nominal Sales of Marijuana}_i + \varepsilon_i \tag{1}$$

where:

- Opioid Prices_i is the dependent variable representing the nominal price of oxycodone in the United States.
- $\text{Nominal Sales of Cannabis}_i$ is the independent variable, capturing the total dollar value of recreational Cannabis sold in the United States.
- β_0 is the intercept term, representing the expected price of oxycodone when marijuana sales are zero.
- β_1 measures the marginal effect of marijuana sales on opioid prices — i.e., how much opioid prices change for a one-unit increase in marijuana sales.
- ε_i is the error term capturing unobserved factors affecting opioid prices.

The small positive coefficient of β_1 suggests a potential substitution effect between opioids and cannabis. However, the large p-value of 0.20 and low explanatory power of the model ($R^2 = 0.035$) indicates that this relationship is not statistically significant at the 95% confidence level.

Variable	**Estimate**	**Std. Error**	**t value**	**Pr(>$\|t\|$)**
Intercept	93.38	21.47	4.349	0.00245
Nominal Sales of Marijuana	$1.670e^{-08}$	$1.200e^{-08}$	1.391	0.20157
Model Statistics:				
Multiple R-squared		0.03549		
Adjusted R-squared		-0.08508		

Table 1: Regression Results: Price of Oxycodone on Nominal Sales of Marijuana

To more accurately assess the relationship, a more detailed model, such as a Difference-in-Differences (DID) approach, is needed. This model would help control for fixed state effects, as well as account for inflation and income effects.

2 Literature Review

2.1 Medical Cannabis and Opioids

There exists a body of literature related to the current topic of interest. The most relevant and similar paper is a study conducted by Bachhuber, M. A., Saloner, B., Cunningham, C. O., and Barry, C. L. in 2014. This paper examines the correlation between medical cannabis laws and opioid analgesic overdose rates, which aligns with my current research interests. The study utilizes a regression model, including state and fixed effects, and found significantly lower opioid overdose and mortality rates in states with medical cannabis laws.

The second relevant study is by Ponnapalli, Grando, Murcko, and Wertheim (2018), which examines the impact of prescription drug monitoring programs. By controlling for fixed effects, they found that states with medical marijuana laws experienced fewer opioid overdose deaths than states without such laws. Both studies concluded that medical cannabis laws at the state level were associated with a decrease in the rate of opioid prescriptions and overdoses.

The third relevant study is by Lucas and Walsh (2017). This study surveyed patients enrolled in the Marijuana for Medical Access Regulations program and found that an astonishing 63% of patients (273) had substituted medical cannabis for prescription drugs, with opioids accounting for 30% of these substitutions. A similar study by James M. Corroon Jr., Laurie K. Mischley, and Michelle Sexton (2017) utilized a different approach, a cross-sectional study and epidemiological survey, to examine the effect of medical cannabis as a substitute for prescription drugs. Similarly, 46% of respondents reported substituting cannabis for prescription drugs, with opioids being the most common class of drugs substituted. Substitution of cannabis for opioids was 2.5 times more frequent than substitution for anxiolytics.

The findings of these studies appear applicable to my current study and models, allowing us to anticipate a negative relationship between the legalization of recreational marijuana and the demand for opioid prescriptions. However, this paper distinguishes itself by focusing on the recent legalization of recreational cannabis (as opposed to medical cannabis) and its impact on the demand for prescription opioids, particularly opioids. Furthermore, the studies mentioned above did not account for the dual usage of cannabis, which addresses the medical aspect of its use.

2.2 Cannabis and Other Substitutes

The next relevant study I would like to emphasize is the paper by Weinberger et al.(2004), which used a difference-in-differences approach to examine the impact of cannabis legalization on disparities in the use of cigarettes and cannabis. Given that the relationship between cigarettes and cannabis was unclear, the DID model allowed for a more definitive investigation into the potential relationship. The DID coefficient was found to be positive, indicating that these products were complements and were co-used. This study provides a foundation for building a similar model to study the relationship between recreational cannabis and opioid prescriptions.

2.3 Pain Specific Substitution

While most body of literature focuses on the general substitution of medical cannabis for other alternatives, the study by Beohnke, Litinas & Clauw (2016), surveryed medical cannabis dispensary patients and found that 64% consumers replaced opioids for medical cannabis to manage chronic pain. This study reported similar findings to Lucas et al. (2016), in which 80% of participants substituted cannabis for prescription drugs to treat chronic pain, citing reduced severity of side effects and improved symptom management. However, substitution of cannabis for antidepressants did not produce statistically significant results. It was also mentioned that the median weekly cannabis consumption was 14grams, a relatively low quantity well below the treshold of abuse. Additionally, the study found a 25% reduction mean annual opioid overdoze rates in the states that allowed medical cannabis.

These body of research underscores the importance of the motivation behind the substitution. While this paper does not explore these specific reasons in detail, it highlights a potential avenue for future research.

3 Methodology

This study begins by distinguishing between medical and recreational cannabis, as the effects may differ depending on the intended use. According to Dr Woodcock (2024), medical cannabis is state-regulated ans specifically intended for medical purposes. In contrast, recreational cannabis refers to the legislations permitting the purchase of cannabis products by individuals over the age of 21, regardless of their intended usage.

3.1 Data Collection

This study examines the market trends in the United States from 2013 to 2023 to assess the impact of cannabis legalization on the demand for opioid prescriptions.

The treatment group consists of four states—Alaska, Arizona, Colorado, and Maine—that each legalized the recreational use of cannabis at different times. Specifically, Alaska legalized cannabis in 2015, Arizona in 2020 (with retail sales beginning in 2021), Colorado in 2014, and Maine in 2016. However, state-reported retail sales data for Maine are only available starting from 2019 onward.

The control group is composed of four states—Wyoming, Texas, Nebraska, and New Hampshire—that have not legalized recreational cannabis during the study period. The control state for Arizona is Texas, selected for its comparable geographic and economic characteristics. Wyoming serves as the control for Alaska, given their comparable geographical features. Nebraska is chosen as the control for Colorado due to geographic similarities, while New Hampshire is the control for Maine, based on shared geographical and demographic attributes.

Opioid prescription data for the study were sourced from the ARCOS (Automation of Reports and Consolidated Orders System) database, which provides comprehensive information on drug distribution and prescription patterns.[1]. The opioid prescription data were then adjusted to account for per capita figures, expressed in a similar manner to the cannabis sales data. Meanwhile, data on nominal marijuana sales were obtained from official government agencies of the respective states as well as from Statista[2][3][4][5]. Most websites provided quarterly reports of nominal cannabis sales, which were later adjusted to derive annual figures, as quarterly data for Colorado were unavailable. This adjustment ensures that all data are expressed in consistent units.The relevant prices for cannabis were obtained from CannabisBenchmarks, which monitors the wholesale cannabis market.[6].

In contrast, data on the price of oxycodone was less readily available, with information sourced from less authoritative platforms, such as SingleCare[7]—a pharmaceutical application—and ClinCalc[8]—which provides data on drug sales.

It is important to highlight that the overall average prices of oxycodone and cannabis were utilized instead of state-specific prices due to the absence of state-level data, resulting in a generalization. However, this approach still provides a reasonable estimation for examining the correlation between prices at the national level. Additionally, it allows the expression of oxycodone in terms of nominal sales, ensuring consistency in units.

[1] https://www.deadiversion.usdoj.gov/arcos/retail_drug_summary/arcos-drug-summary-reports.html
[2] https://www.statista.com/statistics/586198/medical-recreational-marijuana-sales-colorado/ (Colorado)
[3] https://www.commerce.alaska.gov/web/AMCO (Alaska)
[4] https://www.azdhs.gov (Arizona)
[5] https://www.maine.gov/revenue/taxes/tax-policy-office/sales-tax-reports (Maine)
[6] https://www.cannabisbenchmarks.com/wholesale-market-observer/9-years-of-cannabis-wholesale-price-history/
[7] https://www.singlecare.com/prescription/oxycodone-acetaminophen?q=Oxycodone-Acetaminophen%20(Endocet)
[8] https://clincalc.com/Drugstats/Drugs/Oxycodone

3.2 Data Categorization

The data is split into four main catergories:

- Prescription Oxycodone Nominal Sales Data (OXY)
- Cannabis Nominal Sales Data (MAJ)
- Location (8 States)
- CPI (CPI)

3.2.1 Prescription Oxycodone Nominal Sales Data

This category comprises of 8 datasets corresponding to the nominal sales of oxycodone in each states over the years. These datasets are labeled with each state's name accompanying "_oxy".

3.2.2 Cannabis Nominal Sales Data

This category consists of sales data of cannabis for states that legalized recreational cannabis during the study period. These datasets are labeled with each state's name followed by "_maj" to indicate marijuana-related sales. The nominal sales figures are then adjusted for inflation using the Consumer Price Index (CPI) dataset to ensure comparability over time and across states.

The opioid price data, used in conjunction with the cannabis sales data, is derived from the Automated Reports and Consolidated Ordering System (ARCOS) maintained by the U.S. Drug Enforcement Administration (DEA). ARCOS tracks the legal distribution of controlled substances, such as oxycodone, from manufacturers to retail-level outlets like pharmacies and hospitals. These opioids are prescribed for legitimate medical purposes, requiring individuals to obtain them through licensed healthcare providers.

However, despite the controlled and legal distribution, there is widespread concern over opioid misuse and abuse. A significant portion of the legally prescribed opioids end up being used non-medically, contributing to the ongoing opioid crisis. This makes the analysis of cannabis and opioid interactions particularly relevant, as cannabis is sometimes viewed as a potential substitute for opioids in pain management or recreational contexts. The analysis aims to shed light on whether increased access to recreational cannabis correlates with changes in the demand for prescription opioids, potentially offering insights into policy and public health outcomes.

3.2.3 Data Cleaning Process

The data cleaning process was performed using the R programming. The initial step involve splitting the data into two main categories: opioid sales and cannabis sales. The data is then converted into the long format to facilitate easier econometric analysis. Both data set were then merged by year and state using left joined, forming the final dataset to be utilized in the analysis.

3.3 Difference-in-Differences Model: Cannabis Legalization and Opioid Prescriptions

This paper employs a *Difference-in-Differences (DiD)* model to estimate the causal effect of recreational cannabis legalization on the demand for opioid prescriptions. A significant proportion of individuals who misuse opioids acquire them through legitimate prescriptions. Therefore, the volume of opioid prescriptions is used as a proxy for demand. By comparing changes in prescription levels across states that did and did not legalize recreational cannabis—before and after the legalization event—the DiD framework isolates the effect of legalization from other time-varying trends.

The baseline DiD model is specified as follows:

$$\text{oxy\_adj}_{it} = \beta_0 + \beta_1 \text{treated}_i + \beta_2 \text{post}_t + \beta_3 (\text{treated}_i \times \text{post}_t) + \epsilon_{it} \tag{2}$$

where:

- oxy_adj_{it} is the inflation-adjusted level series volume of opioid prescriptions per capita in state i at time t. It serves as a proxy for opioid demand.
- treated_i is a binary variable equal to 1 if state i is in the treatment group (i.e., legalized recreational cannabis during the study period), and 0 otherwise.
- post_t is a binary variable equal to 1 for time periods after cannabis legalization in the treated states, and 0 for periods before.
- $\text{treated}_i \times \text{post}_t$ is the interaction term. The coefficient β_3 on this term captures the average treatment effect of cannabis legalization on opioid prescriptions.
- ϵ_{it} is the error term.

The main goal of this model is to estimate β_3, which reflects the difference in outcomes for treated states *after* legalization, relative to the pre-legalization period and to states that did not legalize cannabis. This model controls for:

- Time-invariant differences across states (e.g., baseline health policies, demographic structures).
- Common time shocks affecting all states (e.g., national health campaigns, federal regulations).

By accounting for these confounding factors, the DiD framework allows for a more credible estimation of the causal impact of recreational cannabis legalization on opioid prescription behavior.

3.4 Enhanced Difference-in-Differences Model with Fixed Effects

An enhanced version of the Difference-in-Differences (DiD) model is considered to control for potential unobserved heterogeneity across states and over time. This modified specification incorporates both *state fixed effects* and *year fixed effects* to account for systematic, time-invariant differences between states, as well as national trends or shocks common to all states.

State fixed effects (α_i) control for persistent characteristics such as geography, historical opioid usage patterns, baseline health policies, or demographic structure. Year fixed effects (γ_t) capture national-level changes, such as federal regulation shifts or economic cycles. Additionally, the model includes state-level income as a control variable to account for economic disparities across regions.

The enhanced DiD model is specified as follows:

$$\text{oxy\_adj}_{it} = \alpha_i + \gamma_t + \beta(\text{treated}_i \times \text{post}_t) + \delta \text{state\_income}_i + \epsilon_{it} \tag{3}$$

where:

- oxy_adj_{it}: Inflation-adjusted opioid prescriptions per capita in state i at time t.
- α_i: State fixed effects.
- γ_t: Year fixed effects.
- $(\text{treated}_i \times \text{post}_t)$: DiD interaction term capturing the causal impact of cannabis legalization.
- state_income_i: Average income level in state i, included as a time-varying control.
- ϵ_{it}: Error term.

The main purpose of estimating the coefficient β is to quantify the causal effect of cannabis legalization on opioid prescriptions. Specifically, β represents the differential change in opioid prescription volumes between the treatment group (states that legalized cannabis) and the control group (states that did not legalize cannabis), after accounting for both observed and unobserved factors that could vary across states and time. A significant β would indicate that cannabis legalization has a measurable effect on opioid prescription demand, either increasing or decreasing it.

This model provides a more robust estimation of the treatment effect by controlling for both observed and unobserved confounding factors.

To further validate the identification strategy, a parallel trends analysis will be conducted using only pre-treatment data. This step checks whether the treatment and control groups exhibited similar trends in opioid prescription rates before the legalization of recreational cannabis. If the trends are parallel, it supports the key DiD assumption that, absent treatment, both groups would have followed similar trajectories over time.

4 Result

Having outlined the empirical strategy and data sources, we now present the results of the analysis. Specifically, we begin by examining the estimates of the treatment effect of cannabis legalization on the demand for opioid prescriptions, as captured by the Difference-in-Differences (DiD) model. In addition to the basic model, we also discuss the results from the enhanced model that controls for fixed state effects and state income effects. To further bolster the credibility of the findings, we first test the parallel trends assumption to ensure that the pre-treatment trends of the treatment and control states were similar.

The following section presents the results of these analyses, starting with the basic DiD model and subsequently incorporating the enhanced model.

4.1 Basic DiD

Variable	**Estimate**	**Std. Error**	**t value**	**Pr(>$\|t\|$)**
`(Intercept)`	0.042125	0.003292	12.79644	¡ 2.2e-16***
`did`	-0.012009	0.008504	-1.41219	0.16155
`treated`	-0.016069	0.006775	-2.37186	0.01996*
Model Statistics:				
RMSE		0.023994		
Adjusted R-squared		0.160049		

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*
Note: 1 variable removed due to collinearity (post)

Table 2: Regression Results for the DiD Model

The coefficient of the DiD variable represents the difference in the outcome between the treated (legalized) and control groups (non-legalized) following the legalization of cannabis. The negative coefficient of -0.012009 suggests that, on average, the legalization of cannabis is associated with a decrease in opioid prescriptions. However, this result is not statistically significant at the conventional 5% significance level, as the p-value is 0.161. Additionally, the low R^2 value suggest that the model is fitted poorly, not adequately explain the variations observed in the data. Given that the basic DiD model did not yield statistically significant results, an enhance model including fixed effects could improve the model's performance. The inclusion of state and income fixed effects allows us to control for time-invariant state characteristics and state-specific income variations that could be influencing opioid prescriptions. By accounting for these additional factors, we can expect that the fixed effects model may provide a more accurate estimate of the causal impact of cannabis legalization on opioid prescriptions. Therefore, we proceed to analyze the results from the fixed effects model to see if it improves both the statistical significance and model fit.

4.2 Fixed State Effect and Income DiD

Upon estimation of the model, the results obtained are presented in the following table:

Variable	**Estimate**	**Std. Error**	**t value**	**Pr(>$\lvert t\rvert$)**
`did`	-0.006447138	0.001899180	-3.39470	0.014591*
`state_income`	-0.000000325	0.000000101	-3.21566	0.018237*
Model Statistics:				
RMSE		0.009981		
Adjusted R-squared		0.737739		
Within R-squared		0.168801		
*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*				
Note: 2 variables removed due to collinearity (treated, post)				

Table 3: Regression Results for the DiD Model with Fixed Effects

The coefficient for the DiD variable represents the Difference-in-Differences estimator, which measures the change in outcomes for the treatment states relative to the control states. The negative coefficient of -0.006447138 implies that, after controlling for other variables, the legalization of recreational cannabis is associated with a reduction in opioid prescriptions. After accounting for the fixed effects, unlike the basic DiD model which yielded insignificant results, the p-value of 0.014591 indicates that the result is statistically significant at the 5Furthermore, a reduction in the Root Mean Squared Error (RMSE) relative to the basic DiD model suggests an improvement in the model's specification, which can be attributed to the inclusion of fixed state and income effects. The adjusted R^2 of 73.77% indicates that the model explains approximately 73.77% of the variation in the dependent variable, while mitigating concerns about potential overfitting.

The significant results from the fixed effects model suggest that cannabis and opioids may be substitutes in the context of recreational cannabis legalization. This study is the first to suggest a negative association between the legalization of recreational cannabis and the prescriptions of oxycodone. The negative coefficient of the DiD variable indicates that, on average, cannabis legalization is associated with a decrease by 0.006447138 opioid prescriptions. Specifically, the coefficient of the interaction term suggests that, on average, legalizing cannabis is associated with a reduction of approximately 0.0064 opioid prescriptions per capita in the treatment states relative to the control states. This finding supports the hypothesis that individuals may turn to cannabis as an alternative to opioids, potentially due to its pain-relieving properties. However, checking for parallel trend and robustness checks are needed to confirm this relationship and explore other factors that could be influencing the substitution effect.

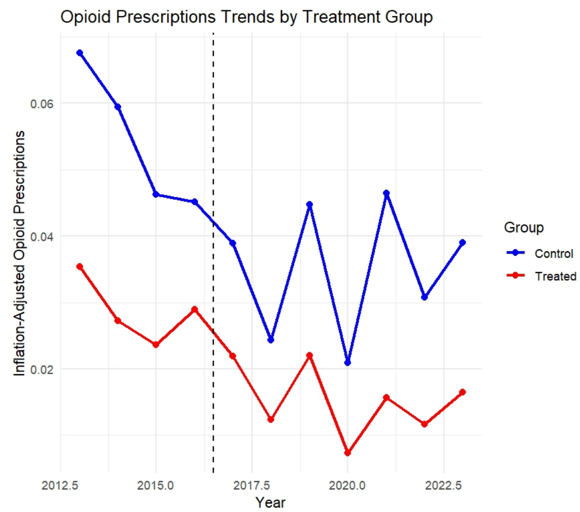

Figure 1: Parallel Trend

4.3 Parallel Trend

The nominal sales of opioids in the treatment group were plotted against those in the control group to assess whether the pre-treatment sales trends were similar, providing insight into the validity of the parallel trends assumption before and after the legalization of cannabis.

Based on the combined parallel trend graph (Figure 1), there appears to be a similar trend between both groups. However, a regression analysis is necessary to formally test whether this trend holds statistically significant.

Variable	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
`year`	-0.008025	0.003394	-2.36406	0.050042
`treated:year`	0.005742	0.003508	1.63687	0.145669
Model Statistics:				
Residual standard error	0.007314 on 32 degrees of freedom			
Multiple R-squared	0.654			
Adjusted R-squared	0.925564			
Within R-squared	0.496481			
*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*				

Table 4: OLS Estimation Results with Treatment and Parallel Trend Variables

From Table 4, the treated:year coefficient, which measures the interaction between treatment and year, is not statistically significant at the 5% level, with a p-value of 0.1457. This suggests that, on average, cannabis legalization in the treated states does not have a significant impact on opioid sales post-legalization.

The year coefficient is marginally significant at the 5% level, with a negative sign. This indicates a slight decrease in opioid sales over time. However, it should be noted that the effect is relatively small and only marginally significant. This suggests that the effect is negligible.

The parallel trends assumption is a crucial aspect of the Difference-in-Differences (DiD) approach.

Based on the parallel trends check, it can be concluded that the DiD model is valid. The lack of a statistically significant interaction between the treated and year variables, along with the consistency of trends observed in the treated and control states prior to cannabis legalization, suggests that the treatment and control groups would have followed similar trajectories in opioid sales in the absence of legalization. This supports the validity of the DiD model and reinforces the model and allow for confidence in the estimated effects of cannabis legalization on opioid sales.

4.4 Robustness Checks

A study by Kerr, Levy, Bae, Boustead, and Martins (2023) found significant results between alcohol use and oxycodone consumption. Patrick et al. (2018) found that nearly all cannabis users also used alcohol. It could be inferred that alcohol may be a confounding factor, potentially accounting for the decline in oxycodone consumption, thus obscuring the causal effect between recreational cannabis legalization and opioid prescriptions.

It is therefore necessary to disentangle the effect of alcohol to ensure the robustness of the results. Country-level alcohol nominal sales were obtained from Statista[9] with the absence of data in 2023. Due to the limitation in obtaining state-level data, country-level aggregated data was used instead. While this compromises precision, it provides a reasonable proxy for accounting for the role of alcohol in the analysis, allowing for a broader understanding of its potential confounding effect. The alcohol-inclusive DiD Model is as follows:

$$\text{oxy\_adj}_{it} = \alpha_i + \gamma_t + \beta \text{did}_{it} + \delta \text{state\_income}_{it} + \lambda \text{alcohol}_t + \epsilon_{it} \tag{4}$$

- α_i: State fixed effects.
- γ_t: Year fixed effects.
- $\beta(\text{treated}_i \times \text{post}_t)$: Difference-in-Differences (DiD) interaction term
- $\delta\text{state\_income}_i$: Controls for state-level income.
- $\lambda\text{alcohol}_t$: Controls for alcohol sales at the country level.
- ϵ_{it}: The error term.

The following results were obtained after estimating the Difference-in-Differences (DiD) model in R:

Variable	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
`did`	-0.0062253564	0.0025238784	-2.466583	0.048683 *
`state_income`	-0.0000003705	0.0000001545	-2.398794	0.053383 .
`Alcohol`	0.0000000208	0.0000000349	0.595635	0.573185
Model Statistics:				
RMSE		0.009569		
Adjusted R-squared		0.712451		
Within R-squared		0.140212		
*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*				

Table 5: Regression Results for the Alcohol-Inclusive DiD Model

[9] https://www.statista.com/statistics/207936/us-total-alcoholic-beverages-sales-since-1990/

It can be observed that the Alcohol-Inclusive Model produced results very similar to those of the Enhanced DiD model. This suggests that the interaction variable, DiD, did not change significantly between the model with and without alcohol. The results are largely consistent, with only a minor change in the coefficient of DiD (-0.006447138 vs. -0.0062253564). Therefore, it can be concluded that alcohol is unlikely to be a confounding variable, thereby enhancing the credibility of establishing a causal relationship between recreational cannabis consumption and opioid prescriptions. Therefore, the robustness of the model is maintained with the addition of alcohol as a control.

5 Discussion

5.1 Policy Implications

This paper presents the first significant evidence of a decrease in opioid prescriptions following the legalization of recreational cannabis. When considering the potential implications of these findings, it is important to interpret these result combined with the following recent studies.

Firstly, a paper by Hain et al. (2020) concluded that increased cannabis availability is likely to help mitigate the impact of the opioid crisis. However, the study also emphasizes the need to consider the effects of this new availability on at-risk groups—individuals who may be more prone to misuse cannabis.

Secondly, a recent analysis of media coverage regarding cannabis, conducted by Abraham and his team, found that the majority of reports tend to highlight the positive aspects of cannabis, while fewer address the health consequences of cannabis consumption. This highlights the need for more balanced media coverage of cannabis-related issues.

Thirdly, a paper by Lucas (2012) suggests that cannabis is a superior alternative to opioids as an analgesic, given its fewer side effects, lower risk of dependence, and lack of potential for fatal overdose.

The findings of this paper, coupled with the existing literature, have significant policy implications. The substitution of cannabis for opioids may encourage more states to endorse the legalization of recreational cannabis, as it may be viewed as the less harmful option. The combined results of these papers supports the push for a policy to adopt recreational cannabis legalization as a less harmful alternative to deal with the opioid crisis.

Furthermore, the legalization of recreational cannabis could incentivize efforts to control crimes related to illegal cannabis. A behavioral study conducted by Amlung & MacKillop (2018) found that following the legalization of recreational cannabis in Canada, the availability of legal cannabis reduced the demand for illegal cannabis.

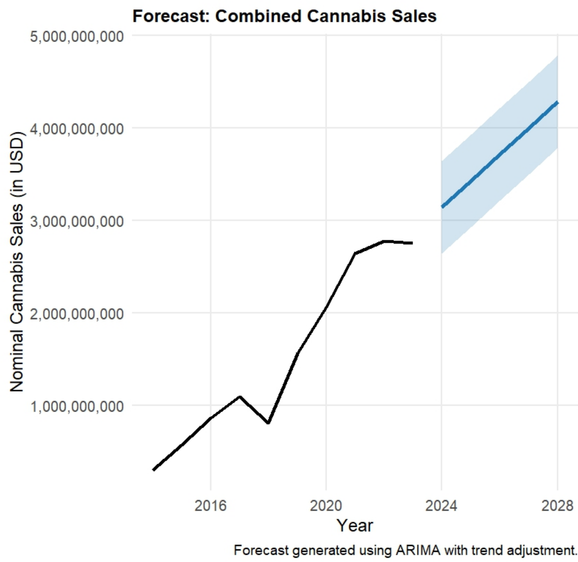

Figure 2: Combined Forecast of Recreational Cannabis Sales

5.2 Time Series Forecast of Cannabis Market

A time series forecast of the combined and individual cannabis markets (Alaska, Arizona, Colorado, and Maine - individual forecase in Appendix; Figure 3 - 6) was conducted using historical sales data from each state, with a particular focus on projecting future trends in sales growth. The model utilized the ARIMA (AutoRegressive Integrated Moving Average) approach, which is well-suited for time series forecasting, as it accounts for the inherent patterns in data, such as trends and seasonality, while also factoring in external influences. For this analysis, a trend component was included to reflect the potential long-term growth of the cannabis market as it matures in these states.

The data used in the model covers several years of cannabis sales figures, with a frequency of annual data. The ARIMA model was applied separately to the sales data of each state—Alaska, Arizona, Colorado, and Maine—while also generating a combined forecast by summing the sales of these four states. This approach allowed us to identify both individual state dynamics and overall market trends. The results indicated an overall upward trajectory in cannabis sales in the near future for each state, suggesting that the market is continuing to expand.

The forecasts for all four states show a consistent growth pattern, with sales in Alaska, Arizona, Colorado, and Maine expected to rise over the next few years. This upward trend is consistent with the broader national picture of expanding cannabis legalization and increasing consumer demand, which is being driven by changes in laws, growing public acceptance, and expanding retail infrastructure.

Given the suggestion that recreational cannabis may be used as a tool to combat the opioid crisis, it is critical to further investigate the potential long-term implications of increased accessibility to cannabis. As the market matures, it is important to understand not only the direct economic effects of cannabis legalization (such as the revenue generated from sales and taxes) but also the broader societal impacts, particularly in relation to public health and the opioid epidemic. Recent studies have suggested that cannabis legalization could serve as a substitute for opioids, reducing their use in certain segments of the population. This potential for substitution makes it essential to closely monitor the relationship between cannabis access and opioid use, as well as the broader implications for public health outcomes.

However, it is also essential to note that the cannabis market in these states is still relatively young, with the first legalization occurring in 2014. Although early trends are promising, the long-term effects of cannabis legalization remain uncertain and unpredictable. The market is still evolving, and factors such as changing regulations, shifts in consumer preferences, and emerging research on cannabis and public health could significantly alter the trajectory of the industry in the coming years. Given these uncertainties, future research will be crucial to refining our understanding of how cannabis legalization affects not only the economy but also public health, particularly in the context of combating the opioid crisis.

In conclusion, while the forecast suggests continued growth in cannabis sales across the four states, it is imperative to conduct further research that incorporates a range of factors—including demographic, social, and economic variables—to fully assess the long-term impact of cannabis legalization. This ongoing research will provide valuable insights into how cannabis consumption interacts with broader social issues, such as the opioid crisis, and will inform policymakers on the potential benefits and challenges of expanding cannabis access in the future.

5.3 Possible Negative Effects of Legalizing Recreational Cannabis

The introduction of a new more captivating form of consumption of cannabis introduces new concerns for cannabis-related negative effects. With the introduction of new vape devices, a study conducted by Walley, Wilson, Wiknickoff, and Groner (2019) found that these devices increase the likelihood of smoking both cannabis and nicotine, and are associated with a lower success rate in quitting. This emerging form of cannabis consumption requires further investigation, especially considering its popularity among youth, which may contribute to an early onset of addiction.

Besides, possible new interactions, earlier studies found contradictory conclusions that recreational cannabis may reduce opioid consumption. An earlier study by Hall and Lynskey (2005) found evidence supporting the theory that cannabis acts as a gateway drug to illicit substances. It was suggested that early initiation of cannabis use, even with limited exposure, is associated with a higher risk of subsequent illicit drug use. An alarming 69% of the sample in a study by Fergusson and Horwood (2000) reported using cannabis by the age of 21, followed by the use of illicit drugs. These findings were further supported by Moral's (2002) simulation studies and a behavioral study by Lynskey, Agrawal, and Heath (2011), which controlled for genetic effects. An animal study conducted by Nahas in his book Keep Off the Grass suggests that both illicit drugs and cannabis affect similar regions of the brain responsible for reward and pleasure. These substances act on the dopamine system, which is the brain's reward center. Additionally, Nahas cited Gardner's study, which showed that the interaction between cannabis and opioids produces euphoric effects. These studies suggest causality, highlighting the potential counterproductive effect of legalizing recreational cannabis as a strategy to control the opioid crisis, possibly leading to an increase in opioid and illicit drug abuse. Furthermore, the interaction between cannabis and opioids warrants further investigation.

In addition to its potential interaction with opioids, a study by Larmarque, Taghzouti, and Simon (2001) found evidence suggesting that cannabis use enhances the brain's locomotor responses to heroin and amphetamines. This raises serious concerns about the suitability of cannabis as a tool to reduce opioid abuse.

5.4 Increased Exposure to Cannabis

According to Han and Shi (2023), the establishment of recreational cannabis dispensaries has been associated with increased visibility, awareness, and social acceptance of cannabis use. Furthermore, with the privatization of the cannabis market, cannabis commercialization has been linked to an increase in cannabis use disorder among adults (Shi & Liang, 2020).

It can be observed that the legalization of recreational cannabis, in all aspects, is met with inconclusive results. This topic requires more in-depth research to draw more definitive conclusions.

6 Limitations

6.1 Challenges in Data Acquisition

Due to the sensitive nature of the topic, the data required were particularly challenging to obtain. This posed significant difficulties in acquiring reliable and comprehensive datasets, potentially affecting the robustness of the findings.

6.1.1 Data Availability and Quality

Historical price data for oxycodone and cannabis were not readily accessible, as both substances are controlled within the United States. As a result, data had to be sourced from alternative channels that may lack reliability.

In addition, certain cannabis sales data were restricted, allowing access exclusively to American citizens. This limitation led the paper to rely on non-government sources, such as Statista, to obtain cannabis sales data. Consequently, the reliability and quality of the data from Statista are lower compared to official government sources.

Furthermore, age-related, gender-specific, and geographic-specific data were unavailable. Such data typically require surveys conducted within the country, which proved difficult to obtain since this paper was written in Singapore. As a result, the paper lacks control over age, gender, and geography, all of which are well-documented factors influencing cannabis and oxycodone consumption.

Existing literature suggests that these factors play a significant role in the patterns of cannabis consumption. According to the Canadian Government (2019), younger adults and males are more likely to demonstrate higher rates of cannabis consumption and its related consequences. Additionally, significant interactions between age and cannabis consumption were observed by Imtiaz et al. (2023). This further emphasizes the limitations introduced by the absence of these controls.

The reduced reliability of the data introduces potential bias and imperfections into the Difference-in-Differences (DiD) model, resulting in less definitive conclusions. The model imperfections includes:

- Model Bias
  - The model excludes key demographic factors such as age, gender and geography, potentially distorting the results. The estimated relationship may by misrepresented.
- Limited Generalizability
  - The results reflect only trends within a specific subset of the population. While the findings may be less generalizable, it is sufficient as a proxy study for implications of the legalization of recreational cannabis on opioids demand.
- Missed Interactions
  - Important interactions between age, gender, and geography are potentially overlooked. By not including these variables, the model fails to account and differentiate for these interactions.

Nevertheless, despite these limitations, the model remains a valuable proxy for examining the relationship between the legalization of recreational cannabis and the demand for oxycodone prescriptions. While the absence of age, gender, and geographic controls introduces some degree of bias, the model still captures broader trends and provides meaningful insights into how cannabis legalization influences opioid prescription patterns. By leveraging available data and employing a Difference-in-Differences (DiD) approach, the analysis offers a structured framework to assess potential substitution effects between cannabis and opioids. Future research incorporating more granular demographic and regional data would enhance the robustness of these findings, enabling a more precise evaluation of the impact of cannabis legalization on opioid use across various population groups.

6.1.2 Opportunities for Improvement

The limitations in data acquisition highlight opportunities for improvement in future research. Specifically, the relationship between the legalization of recreational cannabis and prescription demand should be further explored with models that control for key demographic and geographic factors. These key factors should also be studied in greater depth to extend the scope of this research and produce more conclusive results.

Future models could incorporate a cross-sectional survey conducted in the eight states analyzed to account for these demographic and geographic influences.

6.2 Time Frame Limitations

It should be noted that the first legalization occurred in 2014, which provides a relatively short observational period to study the full impact of legalization. To obtain more conclusive results, continuous updates to the model are necessary. Additionally, the lack of quarterly cannabis sales data in Colorado resulted in a smaller sample size, which constrained the model's ability to detect trends and reduced the overall model fit.

In the near future, incorporating monthly or quarterly data could enhance the model's precision and improve the reliability of its findings.

A longitudinal study spanning a longer time frame could provide deeper insights into long-term trends. This would strengthen causal inferences regarding the relationship between cannabis legalization and opioid prescriptions.

6.3 Iteractions with drug overdose

The model utilizes opioid prescription data, which includes patients who are not misusing oxycodone and are instead using it for legitimate medical purposes. As a result, the analysis may not fully capture the relationship between cannabis legalization and opioid misuse.

A potential extension of this study would involve directly regressing on the number of oxycodone overdose cases, as this would provide a more precise measure of opioid misuse. However, due to data limitations, only overall drug overdose data is available, rather than specific data for oxycodone or other opioids. This means that we are unable to isolate the effects of cannabis legalization on opioid misuse specifically.

As a result, we can only consider the broader impact of cannabis legalization on overall drug overdose deaths. This limitation restricts the ability to analyze the direct relationship between cannabis legalization and opioid misuse, but still provides valuable insight into how the broader category of drug overdose deaths has been influenced by the policy change.

7 Expansion & Improvement of studies: Legalization of Recreational Cannabis and the rate of drug overdose

While expanding the scope to include data on multiple opioids would certainly enhance the explanatory power of the model, the current dataset confines our analysis to the more general category of drug overdoses. Despite this, the findings still contribute to understanding the overall effect of cannabis legalization on public health, especially in relation to overdose deaths.

The rate of annual drug overdose adjusted for per 100,000 was obtained from CDC Wonder[10].

The model utilized is an enhanced DiD Model accounting for fixed year, state and income effect. The DiD interaction term captures the effect of cannabis legalization on the rate of drug overdose.

The table below summarize the obtained result.

Variable	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
`did`	8.097234	2.527350	3.20384	0.010765 *
`state_income`	0.000235	0.000209	1.12333	0.290367
Model Statistics:				
RMSE		2.89088		
Adjusted R-squared		0.897734		
Within R-squared		0.340837		
*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*				

Table 6: Regression Results for the Effect of Cannabis Legalization on Drug Overdose Deaths

The regression results suggest a significant relationship between the legalization of cannabis and drug overdose rates across various states. States that legalized recreational cannabis, indicated by the treated variable, show an average increase of 8.097 drug overdose incidents compared to non-treated states, with a highly significant p-value (0.010765). Additionally, the pre-treatment effect shows that, before legalization, treated states experienced an average of 8.28 fewer drug overdose incidents compared to their control states, with statistical significance (p = 0.001121). The year variable reveals a steady increase in drug overdoses over time, with an average annual increase of 1.48 units, further highlighting the temporal trend in the data.

The model fits the data well, as indicated by a high R-squared value of 0.8977, meaning that about 89.77% of the variation in drug overdoses is explained by the model. These findings suggest that cannabis legalization is associated with an increase in drug overdoses, with varying effects across different states, and that the data is consistent with the hypothesized trends over time.

These findings contribute to the ongoing debate in the literature regarding cannabis as a gateway drug, suggesting that while cannabis may reduce reliance on prescription opioids, it may also be associated with an increase in other drug overdoses, warranting a deeper investigation into the potential unintended consequences of cannabis legalization.

[10] `https://wonder.cdc.gov/controller/datarequest/D76;jsessionid=9AD8B431A48F3C47B8257C6B3084?stage=results&action=toggle&p=O_show_totals&v=false`

8 Conclusion

This study provides empirical evidence that the legalization of recreational cannabis is correlated with a reduction in opioid prescriptions. This finding contribute to broader literature on the the harm reduction strategies during the opioid crisis. The expansion study shown that while opioid prescription has fallen, there is an increase in overall drug over-doze rate post legalization. This introduces a critical paradox, warranting further investigation. on the unintended consequences of increase cannabis availability. The overall results, suggests a potential policy benefit of cannabis legalization to mitigate the current opioid dependency, the "gateway hypothesis" to other drugs suggest otherwise. These study consists of several limitations in data availability and methodological cosntraints, suggesting that furture research could improve on these areas. Future research should incorporate more granular demographic data, extended time frames, and direct measures of opioid misuse to refine the understanding of this complex relationship. Policymakers must balance the potential benefits of cannabis legalization with the risks it may pose, ensuring that harm reduction strategies are evidence-based and targeted toward addressing both opioid misuse and broader substance abuse trends.

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10 Appendix

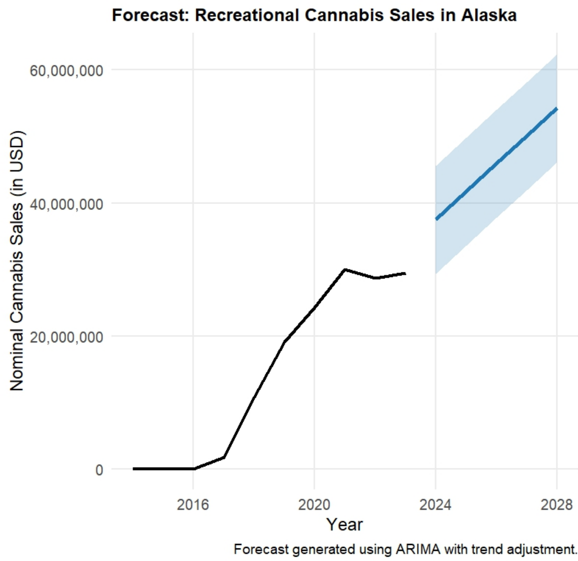

Figure 3: Forecast of Alaska's Nominal Cannabis Sales

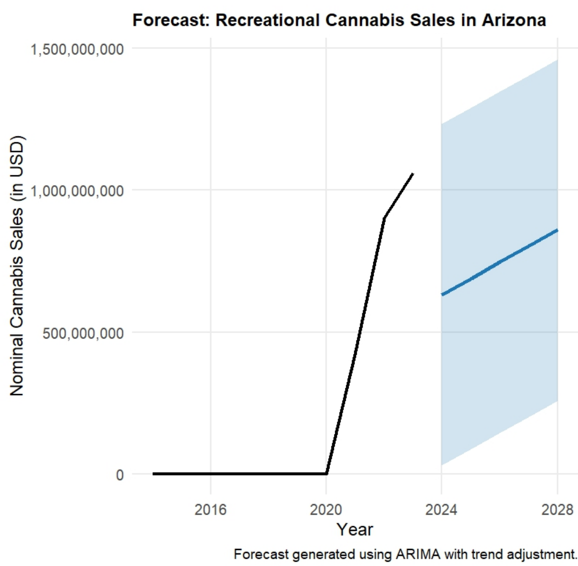

Figure 4: Forecast of Arizona's Nominal Cannabis Sales

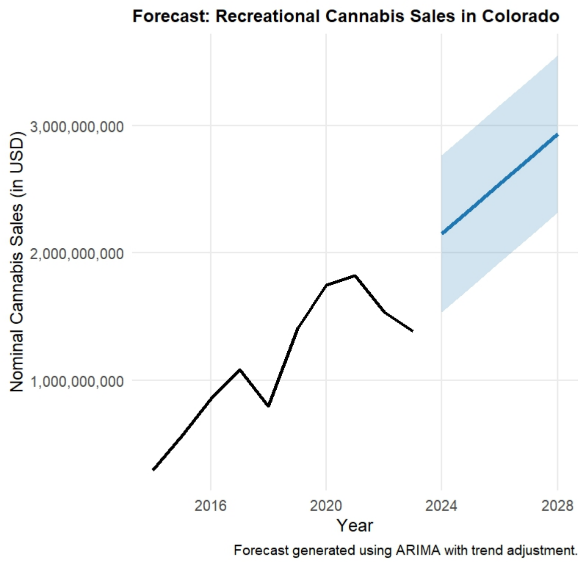

Figure 5: Forecast of Colorado's Nominal Cannabis Sales

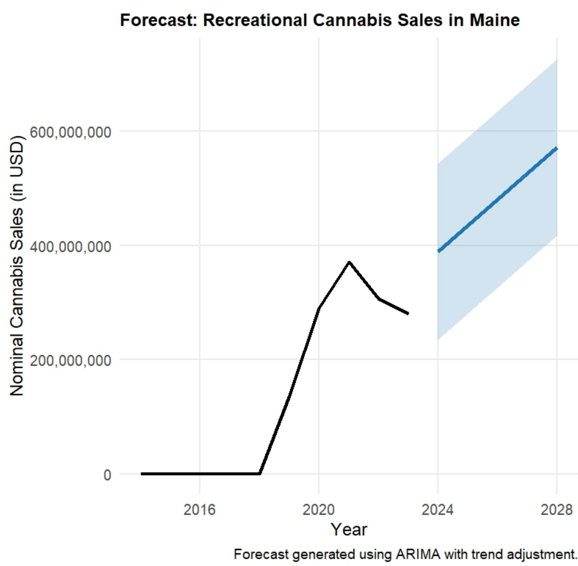

Figure 6: Forecast of Maine's Nominal Cannabis Sales