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Does Recreational Marijuana Dispensing Induce Substitution for Alcohol?

Aubrey E. Mange
Portland State University, Aubreymange@hotmail.com

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Evidence from Alcohol Mortality Data

1. Abstract

I exploit geographic and temporal variation in recreational marijuana dispensing to estimate its effect on alcohol related prices and mortalities. I interpret the finding of a casual reduction in alcoholic poisonings as evidence for a substitutive relationship, contributing to a growing marijuana policy literature and the divided economic literature exploring substitution between the two goods.

Aubrey Mange

2. Introduction

To date, 29 states including the District of Columbia have adopted some form of marijuana legislation. Popularized by its medicinal uses, medical marijuana laws are the most common (Bridgeman & Abazia, 2017). Nine states have elected to regulate the sale of marijuana for recreational purposes in addition to medical, sparking a highly divided nation-wide conversation about the public health effects of accessible recreational marijuana (Center for Disease Control, 2018). Because marijuana use increases after legalization it is natural to assume that any adverse outcomes of marijuana use are exacerbated by legal recreational marijuana dispensing (Anderson, Hansen, Rees, & Sabia, 2019). It is thus important to understand the effects recreational marijuana has had on legal states to inform the conversation around legalization more thoroughly. Several economists have studied marijuana legalization in the context of other illicit substances, asking, do people substitute marijuana for or with other drugs, and how do these dynamics relate to public health? Although we have seen substantial reductions in opioid prescriptions, use, and mortalities result from marijuana dispensing, its relationship with alcohol use and mortalities is not well understood (Chan, Burkhardt, & Flyr, 2020). In this study I evaluate alcohol mortality and price data to estimate how recreational marijuana dispensing has impacted alcohol use and ask, does recreational marijuana dispensing cause people to offset alcohol use with marijuana? Are the goods substitutes, and through that, how can dispensing affect public health outcomes?

The effect of marijuana dispensing on other forms of mortality has been repeatedly examined. Economists have shown that medical marijuana laws are associated with a reduction in rates of violent crime including homicide, especially in southern border states (Gavrilova, 2017 & Morris, TenEyck, Barnes, & Kovandzic, 2014). A study using data from the Behavioral Risk Factor Surveillance System found a link between medical marijuana and a decline in alcohol-related traffic fatalities (Anderson, Hansen, & Rees 2013). Although, this result was not replicated when a similar study utilizing synthetic controls and data from the Fatality Analysis Reporting System found no link between legalization and the incidence of alcohol related traffic fatalities in Washington and Colorado (Hansen, Miller, & Weber, 2018). Another study indicates that dispensing reduces opioid mortality rates by as high as 30% (Chan, Burkhardt, & Flyr, 2020). Although cannabis use can treat alcohol-related illnesses, dependence, and seeking-behavior, I am unaware of a study outside the pharmacology literature that assesses the relationship between marijuana and mortalities from alcohol-related diseases (Colombo, Serra, Vacca, Carai, & Gessa, 2005).

To do so, I exploit spatial and temporal variation in recreational marijuana dispensing to estimate its effect on four outcomes using a differences-in-differences approach: total deaths from alcohol-related diseases, deaths from accidental alcoholic poisonings, deaths from cirrhosis, and the consumer price index of alcohol. I posit that if marijuana is a perfect substitute for alcohol, then we should see significant mortality and price reductions in post-dispensing years. Due to its chronic nature cirrhosis deaths may be slow to respond to marijuana access. I still chose to examine cirrhosis data following findings that marijuana use is associated with delayed progression of alcoholic liver disease in chronic users (Adejumo, et al., 2018). I find recreational marijuana dispensing causes significant and highly robust reductions in poisoning mortality rate, no change in cirrhosis mortality rates or the price of alcohol, and inconclusive effects on total mortality rates. This result indicates that marijuana is heterogeneously substituted for alcohol, but that the goods are not economic substitutes in aggregate.

The paper opens with a background section dedicated to summarizing the economic and pharmacological work related to this project. It proceeds into section 4 with data sources and summaries and an account of my econometric approach. Next, section 5 presents the results and explains interpretation of the coefficients. Section 6 evaluates the robustness of my estimates to data suppression, sample selection, and model selection. Finally, section 7 summarizes the implications of my findings and poses questions for further research.

3. Background and Literature Review

3.1 Biological Motivation

Cannabis naturally produces a range of compounds which, when ingested orally or through inhalation, interact with a network of neurotransmitters known as the endocannabinoid system. This system contributes to numerous vital bodily processes and through it the ingestion of cannabis produces a psychological and physiological response (Atakan, 2012). Marijuana's stimulation of the endocannabinoid system may be useful in the treatment of illnesses related to endocannabinoid processes (Bridgeman & Abazia, 2017). Its ability to treat chronic pain through endocannabinoid stimulation has aroused interest in the relationship between cannabis access and the use and provision of opioids. One study indicates that access to recreational marijuana induces substitution among opioid addicts resulting in mortality reductions as substantial as 30%

(Chan, Burkhardt, & Flyr, 2020).. A Colorado case study found that legalization reduced opioid deaths by a little under 1 death per month (Livingston, Barnett, Delcher, & Wagenaar, 2017). The availability of *medical* marijuana likewise induces substitution among medical opioid users, causing an estimated reduction in opioid prescriptions, in terms of morphine milligram equivalents, of approximately 4% (McMichael, Horn, & Viscusi, 2020). Another study found that opioid usage declined 64% after access to medical marijuana was legalized which resulted in improved quality of life for sufferers of chronic pain (Boehnke, Litinas, & Clauw, 2016).

Despite the endocannabinoid similarities between opioid and alcohol dependence, marijuana use has been studied very sparsely in the context of alcoholism and related fatalities. Pharmacological studies suggest that much like opioid use and withdrawal, alcohol use and withdrawal are tied to the endocannabinoid system: when alcohol-dependent mice were modified for deletion of the endocannabinoid receptors relevant to alcoholism, alcohol-seeking behavior and the physiological symptoms of withdrawal significantly diminished (Racz, et al., 2003). Since compounds in marijuana antagonize, or block, those same endocannabinoid receptors, this result suggests that the availability of c cannabis alleviate the social cost of alcohol consumption through induced substitution and mortality reduction, as it has for opioids (Colombo, Serra, Vacca, Carai, & Gessa, 2005). Of course, alcohol use need be substantially substituted with marijuana for this effect to be realized.

3.2 Economic Substitution

Investigation into the substitutability of marijuana and alcohol has been hindered by the legal status of cannabis, which, until recently, has been under severe federal restriction (Kronaizl, 2020). In the absence of an observable marijuana market, earlier studies relied on indirect methods to estimate the prevalence of marijuana use and its relationship with alcohol consumption. Its role as an alcohol substitute was first observed in a positive relationship between marijuana prices and drinking frequency among young adults (Chaloupka & Laixuthai, 1997). Later, it was noted that higher minimum drinking ages were associated with greater incidence of marijuana use, confirming the earlier finding of substitution (DiNardo & Lemieux, 2001). However, several studies from the same era of prohibition produced the conflicting result that marijuana use declined among consumers subjected to increasing prices of alcohol (Farrelly, Bray, Zarkin, Wendling, & Pacula, 1999) (Williams, Pacula, Chaloupka, & Wechsler, 2004). These opposing findings may be the result of heterogenous preferences for illicit substances or indicate that substitution is group-specific; such confounding factors are more easily controlled by the construction of natural experiments.

Several natural experiments examining substitution were conducted during the early stages of legalization, and their results were somewhat more consistent. A regression discontinuity design which examined changes in marijuana consumption around the minimum legal drinking age indicated that marijuana use declined at age 21 among the National Survey of Drug Use and Health 2007 cohort, particularly among women (Crost and Guerrero, 2012). However, this result was not replicated when the same design was applied to the National Longitudinal Survey of Youth 1997 cohort (Crost and Rees, 2012). Despite their inconsistent results, these survey studies and regression discontinuity designs are more compelling than the indirect methods of earlier work, and generally support the substitution hypothesis. However, many are still hindered by the legal status of marijuana in the survey years; marijuana use, frequency, and dependence increase after legalization, meaning any findings of a substitution effect among these cohorts may be understated (Anderson, Hansen, Rees, & Sabia, 2019). The most recent natural experiment to study this effect contained over a billion internet searches and found that interest in alcohol declined 10% in areas with legal cannabis (Wang, Xiong, & Yang, 2019). Clearly, there is less evidence than before for complementarity, but still insufficient evidence to determine substitution. A goal of my price and mortality analysis is to further inform the inconsistent findings of the substitution literature.

4. Data and Methods

4.1 Data

To examine alcohol mortality, I utilize the CDC's Multiple Cause of Death data from the years 1999 to 2019 in all 51 states including the district of Columbia. This results in 1071 state-year observations. I designate state-years as "dispensing" or "non-dispensing" by cross-referencing the data with information available on the PotGuide website regarding legalization and dispensing dates. The dates of legalization and dispensing are detailed in Table 1. For the consumer price of alcohol section of my analysis, I obtain regional alcohol CPI data from the FRED. This necessitates the assumption that aggregation of CPI to the regional level does not bias the result. For demographic controls, I also obtain median income data by state from the FRED. Additionally, using the 2000 and 2010 US Demographic Censuses I compute estimates of median age and the percentage of state populations that are male, white, Hispanic, and Native American, in every year. Finally, I obtain beer and wine taxes in dollars/lb. from the Tax Foundation, motivated by prior findings that alcohol taxes affect the demand for marijuana (Pacula, 1998).

4.2 Summary Statistics

In Figure 1 I show time series of the three alcohol related mortality categories where it is apparent that total mortalities have doubled in the time horizon, a growth rate that far exceeds the population growth rate of 17.5% in that same period. In the years 2007-2008 the count of poisonings tripled, presumably in response to the financial crisis. Figure 2 is included to illustrate this change. In Table 2 I display the annual means of death rates by mortality category and by legalization status; if a state has legal recreational marijuana, it is post-legalization mean is calculated using only the post-legalization years. For non-legalizers, the "post-legalization" era is defined as the *recent* era, or the latter half of the total legalization era, which began in 2012. I use these post-legalization era means of death rates in nonlegal states in section 5 to interpret the approximate change in death counts that results from recreational marijuana dispensing. In all states, the post-legalization means of death rates are higher; in all mortality types, the legalizer's means of death rates are higher.

Figure 1: Mortalities Over Time

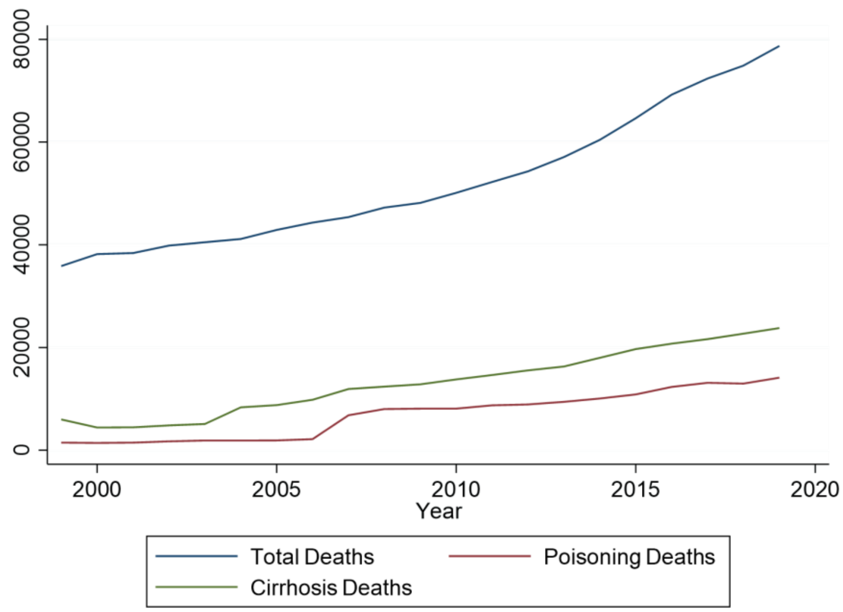


Figure 2: Poisonings Over Time

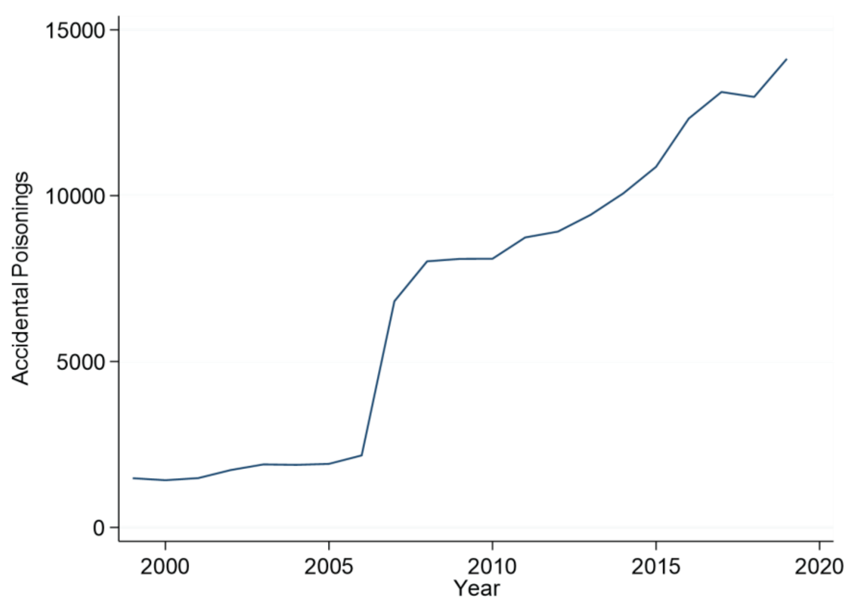


Table 1: Dates of Legalization and Dispensing

State	Date of Medical Legalization	Date of Medical Dispensing	Date of Recreational Legalization	Date of Recreational Dispensing
Alaska	March 1999	October 2016	February 2015	October 2016
Arizona	November 2010	December 2012		
Arkansas	May 2017			
California	November 1996	December 1996	November 2016	January 2018
Colorado	December 2000	January 2005	December 2012	November 2014
Connecticut	October 2012	October 2014		
Delaware	May 2011	August 2014		
DC	July 2010	July 2013	February 2015	
Florida	January 2017	July 2016		
Hawaii	June 2000	May 2016		
Illinois	January 2014	November 2015		
Louisiana	May 2016			
Maine	December 1999	March 2011	January 2016	
Massachusetts	January 2013	June 2015	December 2016	November 2018
Michigan	December 2008	May 2009	November 2018	December 2019
Minnesota	May 2014	July 2015		
Montana	November 2004	January 2009		
Nevada	October 2001	January 2009	January 2016	July 2017
New Hampshire	July 2013	April 2016		
New Jersey	June 2010	December 2012		
New Mexico	July 2007	March 2009		
New York	July 2014	January 2016		
North Dakota	December 2016			
Ohio	September 2016			
Oregon	December 1998	January 2009	July 2015	October 2015
Pennsylvania	May 2016			
Rhode Island	January 2006	April 2013		
Vermont	July 2004	June 2013	July 2018	
Washington	December 1998	January 2009	November 2012	July 2014

Using information from PotGuide.com this table is adapted from Chan, N. W., Burkhardt, J., & Flyr, M. (2020). The Effects of Recreational Marijuana Legalization and Dispensing on Opioid Mortality. Economic Inquiry.

Table 2: Annual Means of Deaths per 100k by Legalization Status

	Era	Non-Legalizers	Legalizers	Difference
Poisonings	Pre Legalization	2.34	2.85	0.51***
	Post Legalization	4.52	5.83	1.31***
Cirrhosis	Pre Legalization	3.34	4.60	1.26***
	Post Legalization	6.68	8.53	1.85***
All	Pre Legalization	16.58	22.21	5.64***
	Post Legalization	25.20	31.83	6.63***

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

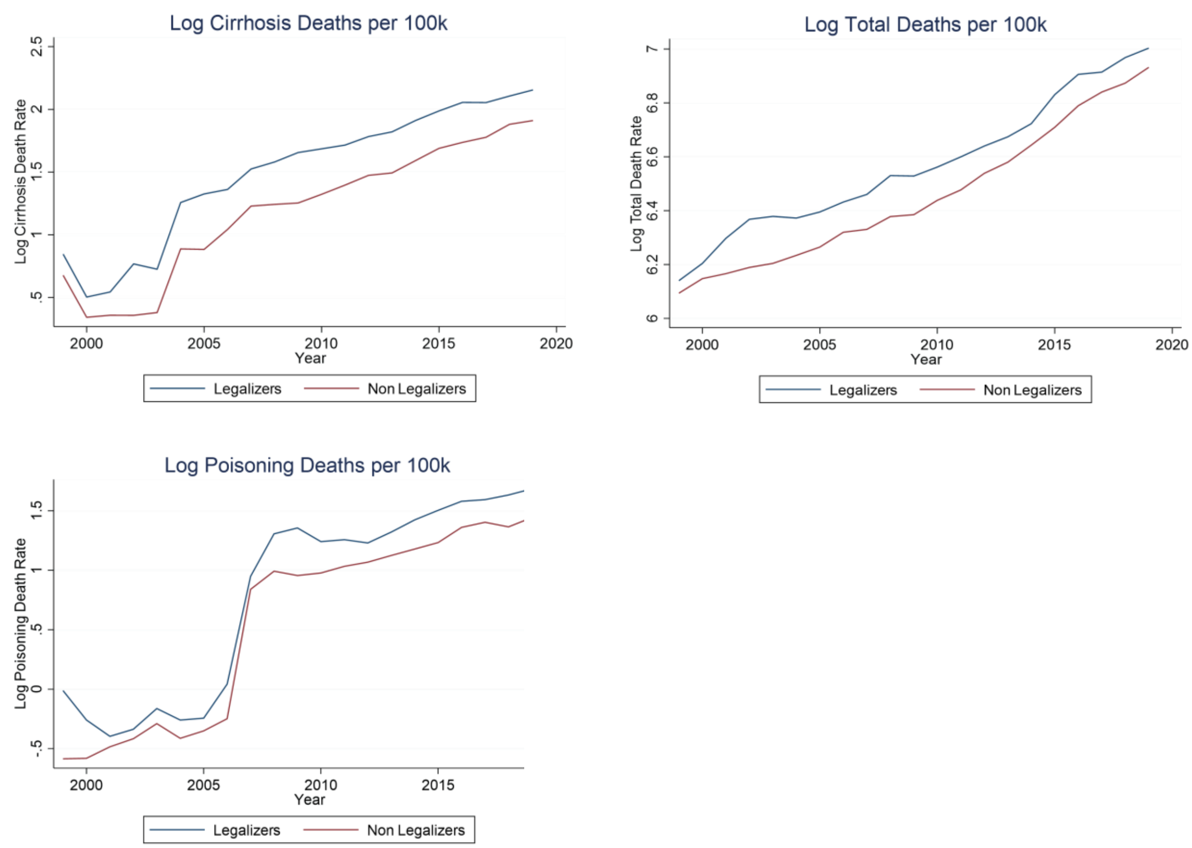
4.3 Estimation Strategy

My empirical approach is difference-in-differences analysis, a statistical technique that under a certain set of assumptions can identify the effect of a treatment (or in my case, a policy) using only observational data. This approach requires outcomes in treated (legal) and untreated (nonlegal) states to behave similarly prior to treatment, else the effect cannot be casually attributed to the treatment intervention. I econometrically explore the validity of this assumption in the results section, but below in Figure 3 we can conclude upon inspection that mortality trends in nonlegal states closely follow trends in legal states, evidence that the critical assumption of the estimation method is satisfied. Figure 3 includes the logarithm of mortality rates on the vertical axis because that is outcome variable of my equation. This estimation method was used by several other papers in the literature that assess the effects of marijuana policy on deaths (Anderson, Hansen, & Rees, 2013 & Chan, Burkhardt, & Flyr, 2020 & Morris, TenEyck, Barnes, & Kovandzic, 2014). The equation is reported below:

$$\log(y_{it}) = \beta_0 + \beta_1 RMD_{it} + \beta_2 MMD_{it} + X\delta_1 + T\delta_2 + \alpha_i + \gamma_t + \epsilon_{it}$$

Where subscript i denotes the state and t indicates the year of observation. Parameters α_i capture state-variant effects and γ_t capture time-variant effects. The matrix X contains the census and FRED data, while matrix T contains the beer and wine tax data outlined in section 3. RMD_{it} and MMD_{it} are dummies equal to one in all years where recreational and medical marijuana, respectively, are legally dispensed. I control for MMD to avoid attributing an effect of access to medical marijuana to access to recreational marijuana. The dependent variable y_{it} is varied to equal the annual rates of total alcohol related deaths, death rates from poisonings and cirrhosis, and the consumer price index of alcohol. In the mortality specifications the value $(e^{\beta_1} - 1)$ is equal to the percent change in mortality rates attributed to recreational marijuana dispensing (Halvorsen & Palmquist, 1980). If marijuana dispensing reduces a form of death, then β_1 will be significant and negative. In the CPI specification $(e^{\beta_1} - 1)$ is the percentage change in CPI as the result of marijuana dispensing. If recreational marijuana and alcohol are economic substitutes, we would expect to see a significant and negative estimate for β_1 indicating that recreational marijuana dispensing lowered the real price of alcohol.

Figure 3: Time Series of Deaths by Legalization Status



5. Results

5.1 Mortalities

The results from my morality specification are presented in Table 3. The coefficients on RMD indicate significant reductions in total and poisoning deaths resulting from access to recreational marijuana, but no effect on deaths from cirrhosis. The coefficient on poisonings is substantial at approximately -0.41, which translates to an effect size of $(e^{-0.41} - 1) = -33.65\%$. As outlined in Table 3, the 2016-2019 annual poisoning death rate in nonlegal states is roughly 4.52 deaths per 100,000. For a nonlegal state of population 5 million, that indicates a predicted decline in total annual poisonings by roughly 76 deaths as the result of recreational marijuana dispensing. The same calculation for total deaths reveals a predicted 103 deaths from alcohol related diseases averted. Together these results imply that legal recreational marijuana dispensing reduces total alcohol related deaths by 8.3%, over four-fifths of which are averted poisonings.

Next, I evaluate the validity of my model assumptions using a parallel trends analysis in Table 4. By estimating the differences-in-differences in the pre and post-treatment years, I can simultaneously test for similarity in pre-treatment trends and persistence of the post-treatment effects. The year prior to recreational dispensing is omitted so that estimates may be interpreted in relation to that year. Non-significance of the pre-treatment years is consistent with satisfaction of the critical model assumption in all three mortality types. The only significant post-treatment effects are seen in poisonings and occur in the second year of marijuana dispensing. These effects persist into the third year, remaining highly significant and close to the initial estimates. I cannot evaluate for persistence of the effects beyond three years, however, because the sample of states with four years of post-dispensing becomes prohibitively small (there are only two).

Table 3: Mortality Results

VARIABLES	(1) Log Death Rate	(2) Log Poisoning Rate	(3) Log Cirrhosis Rate
RMD	-0.0861**	-0.410***	0.0485
	(0.0351)	(0.0990)	(0.0535)
MMD	0.0285*	-0.00564	0.0192
	(0.0163)	(0.0473)	(0.0249)
Unemployment	-0.0126**	0.0163	-0.0165**
	(0.00495)	(0.0151)	(0.00758)
Beer Tax	0.0199	-0.156	0.0118
	(0.0451)	(0.129)	(0.0710)
Wine Tax	-0.00104	0.0156***	-0.00293
	(0.00135)	(0.00401)	(0.00210)
Median Age	0.0131	0.0285	-0.0674***
	(0.0121)	(0.0439)	(0.0189)
Income per Capita	-1.79e-06	-1.20e-05*	-1.75e-05***
	(2.12e-06)	(6.97e-06)	(3.27e-06)
Population	-2.43e-08***	-6.52e-08**	-2.24e-08*
	(8.83e-09)	(2.66e-08)	(1.35e-08)
Male (% pop)	0.206***	0.202	0.00981
	(0.0469)	(0.158)	(0.0735)
White (% pop)	-0.0166***	-0.0155	-0.0118
	(0.00470)	(0.0164)	(0.00743)
Native (% pop)	0.0544	0.346*	-0.0888
	(0.0495)	(0.181)	(0.0777)
Hispanic (% pop)	0.00127	-0.0170	0.0135
	(0.00690)	(0.0221)	(0.0106)
Constant	-6.976***	-11.21	3.834
	(2.382)	(7.764)	(3.707)
Untreated Mean	25.2	4.52	6.68
Observations	1,020	877	1,011
R-squared	0.924	0.891	0.933

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Parallel Trends Results

VARIABLES	(1) Total Death Rate	(2) Poisoning Death Rate	(3) Cirrhosis Death Rate
5 year lead, RMD	0.0131	0.119	-0.107
	(0.0466)	(0.131)	(0.0707)
4 year lead, RMD	0.0195	-0.0214	-0.0638
	(0.0610)	(0.170)	(0.0925)
3 year lead, RMD	-0.00222	0.0344	-0.0963
	(0.0608)	(0.170)	(0.0921)
2 year lead, RMD	0.0111	0.0882	-0.0266
	(0.0606)	(0.169)	(0.0918)
RMD, t	0.0140	-0.0335	0.0140
	(0.0607)	(0.169)	(0.0920)
1 year lag, RMD	-0.0697	-0.240	-0.0250
	(0.0668)	(0.186)	(0.101)
2 year lag, RMD	-0.0910	-0.400**	-0.0527
	(0.0718)	(0.200)	(0.109)
3 year lag, RMD	-0.0662	-0.396**	0.0200
	(0.0686)	(0.192)	(0.104)
Constant	-8.272***	-13.14*	0.774
	(2.403)	(7.775)	(3.712)
Observations	1,020	877	1,011
R-squared	0.924	0.891	0.933

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5.2 Consumer Price Index

The results from the consumer price analysis are straightforward. I detect no effect of recreational marijuana dispensing on the consumer price of alcohol, indication that the goods are not substitutes in aggregate. Although, medical marijuana may have reduced the consumer price of alcohol by about 0.4%.

Table 5: CPI Results

VARIABLES	(1) cpi
RMD	-0.000649
	(0.00292)
MMD	-0.00466***
	(0.00132)
Constant	81.77***
	(26.25)
Observations	1,020
R-squared	0.993

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6. Robustness Checks

6.1 Data Suppression

The Multiple Cause of Death Data contain numerous missing observations as the result of the CDC's data suppression practices. Intended to promote privacy, suppression of observed state-years with less than ten mortalities poses a substantial barrier to estimation. 143 of the 1071 poisoning observations and 9 of the 1071 cirrhosis observations are missing. To evaluate the implications of suppression on my estimate I construct three scenarios for the means of missing observations. In the "best case" scenario there is a small average of deaths of 2.5 per missing state-year. In the "mid case" this rate is increased to 5, and in the "worst case" it is assumed to be 7.5. The results are presented in Table 6. Because there were no missing observations for total deaths it is omitted from this robustness check. The estimates for total death rates are largely unchanged and remain insignificant, but for poisonings, the estimates increase in magnitude and range, in the worst to best cases, from -33% to -44%. Only the "best case" estimate of 0.582 (the coefficient associated with the estimated effect of -44%) is more than one standard deviation away from the initial estimate. In any case, my estimates appear robust to data suppression and indicate that most alcohol related deaths averted by the dispensing of recreational marijuana are poisoning deaths. I omit the estimates for the demographic controls from the tables for brevity, but they are largely unchanged across scenarios.

Table 6: Suppressed Data

	VARIABLES	"Worst Case" death rate	"Mid Case" death rate	"Best Case" death rate
Panel (A)				
	RMD	-0.430***	-0.486***	-0.582***
Poisoning Deaths		(0.112)	(0.123)	(0.155)
	MMD	-0.0608	-0.0756	-0.101
		(0.0519)	(0.0570)	(0.0717)
	Constant	-8.190	-9.972	-13.02
		(6.596)	(7.241)	(9.110)
	Observations	1,020	1,020	1,020
	R-squared	0.883	0.877	0.851
Panel (B)				
	RMD	0.0452	0.0470	0.0501
Cirrhosis Deaths		(0.0562)	(0.0605)	(0.0713)
	MMD	0.0238	0.0230	0.0218
		(0.0260)	(0.0279)	(0.0329)
	Constant	6.000*	5.858*	5.616
		(3.297)	(3.549)	(4.184)
	Observations	1,020	1,020	1,020
	R-squared	0.927	0.917	0.891

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6.2 Sample Selection

I also evaluate robustness of my estimates to sample selection by varying the sample in two ways. When it comes to marijuana legalization, Washington and Colorado stand out as exceptionally early adopters, and of the 21 post-dispensing state-years, ten are observed in Washington and Colorado. It is natural to wonder if preferences for marijuana behave differently in these states and drive the primary results, and as such, a complete analysis would evaluate robustness of my estimates to the omission of these states. The results of estimation without these states in the sample are presented in Table 7, Panel A. Next, I eliminate states from the Southeast and Midwest Census regions from the sample, once again because of evidence that preferences for marijuana behave differently in these states. These regions are overwhelmingly non-legalizers, and their omission leaves a sample of states that are economically and geographically linked, that share similarities in marijuana preferences, and are a mix of recreational and medical legal and nonlegal states. The results from this analysis are presented in Panel B. All together, these results indicate that my estimates are highly robust to sample selection.

Table 7: Sample Selection

	VARIABLES	(1) total death rate	(2) poisoning death rate	(3) cirrhosis death rate
Panel (A)				
Late Adopters	RMD	-0.0709	-0.362**	0.0898
		(0.0515)	(0.143)	(0.0783)
	MMD	0.0290*	0.0529	0.0118
		(0.0176)	(0.0505)	(0.0268)
	Constant	-6.795***	-9.027	5.114
		(2.150)	(7.245)	(3.345)
	Observations	980	837	971
	R-squared	0.921	0.893	0.931
Panel (B)				
Census Regions with Dense Marijuana Legislation	RMD	-0.103***	-0.383***	0.0344
		(0.0352)	(0.0976)	(0.0564)
	MMD	-0.00128	0.114*	0.0242
		(0.0203)	(0.0600)	(0.0328)
	Constant	1.441	17.51	30.86***
		(4.111)	(13.69)	(6.744)
	Observations	440	373	433
	R-squared	0.948	0.885	0.944

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6.3 Model Selection

Finally, I evaluate robustness to model selection by running a Poisson regression on the raw death counts. Although my methodology of a semi-logarithmic ordinary least squares regression on mortality rates is prominent in the literature, deaths are left-skewed count data and approximately Poisson distributed, motivating a secondary empirical strategy. I reconduct the entire mortality analysis using Poisson regression in the appendix. The results indicate a highly significant reduction in total deaths and poisoning deaths by 64 and 63, respectively – a very much similar result to my initial interpretation of 74 poisoning deaths averted by recreational marijuana dispensing in a state of population 5 million. Together, these results indicate the estimates are highly robust to data suppression, sample selection, *and* model selection.

7. Conclusion

The findings of my study indicate recreational marijuana dispensing causally reduces the annual rate of alcohol poisoning deaths in a previously non-dispensing state by about 33% and that this effect is sustained over time. Although there is evidence that total alcohol related mortality also decreases by around 10%, this estimate is less robust to sample selection. It can be inferred that access to recreational cannabis at least induces substitution among those prone to alcoholic poisoning, which primarily afflicts non-Hispanic white men between the ages of 35 and 64 (Center for Disease Control, 2015). This substitution is not substantial enough to affect the price of alcohol or for marijuana to be considered an economic substitute for alcohol. It is unclear how much of the reduction in total deaths is due to averted poisonings alone, but the results indicate that likely most avoided total deaths are averted poisonings. Future investigation is needed into the effect of marijuana dispensing on chronic diseases, which may be much slower than poisonings to respond to cannabis dispensing. Substitution of marijuana for alcohol has been shown to be heterogenous across gender and race (Crost & Guerrero, 2012). More investigation is needed into the demographically heterogenous effects of marijuana dispensing on alcohol related mortalities, although analysis data suppression renders analysis of demographic heterogeneity entirely impossible using the Multiple Cause of Death data alone. Further, the demographic data used in this analysis would benefit from future updates upon release of the 2020 demographic census, and the use of a different alcohol mortality data source that does not utilize data suppression. Lastly, because marijuana use increases over time following legalization, this analysis should be extended several years to evaluate persistence of the effect on poisonings or any delayed effect of dispensing on the price of alcohol (Anderson, Hansen, Rees, & Sabia, 2019).

Given that marijuana has been linked to declines in deaths from opioids, violent crime, traffic accidents, and alcohol poisonings, I find compelling evidence that legalization and dispensing have net positive effects on public welfare. Additionally, marijuana regulation allows surpluses from transactions involving cannabis to be captured by the state. In the 2019 Colorado's public schools received roughly $136 million in funding generated from the taxation of recreational marijuana (Colorado Department of Education, 2020). Since marijuana can be safely and beneficially dispensed, I would urge policy makers in nonlegal states to reconsider their approach to marijuana legislation.

Another interesting consideration regarding marijuana's causal reduction in poisoning deaths is the potential for marijuana dispensing to reduce or diminish the apparently procyclical nature of poisonings. Referring to Figure 2, the proportion of alcohol related deaths from poisonings nearly tripled between 2006 and 2009 following the 2007-2008 financial crisis, despite an increase in total alcohol related deaths of only 8.6%. The results of this study pose the question that if people had access to recreational cannabis during the crisis, could induced substitution have allowed us to avoid that substantial change in poisoning mortality trends? And if so, what does this imply for states with recreational marijuana dispensing during the financial crisis that followed the global corona virus pandemic?

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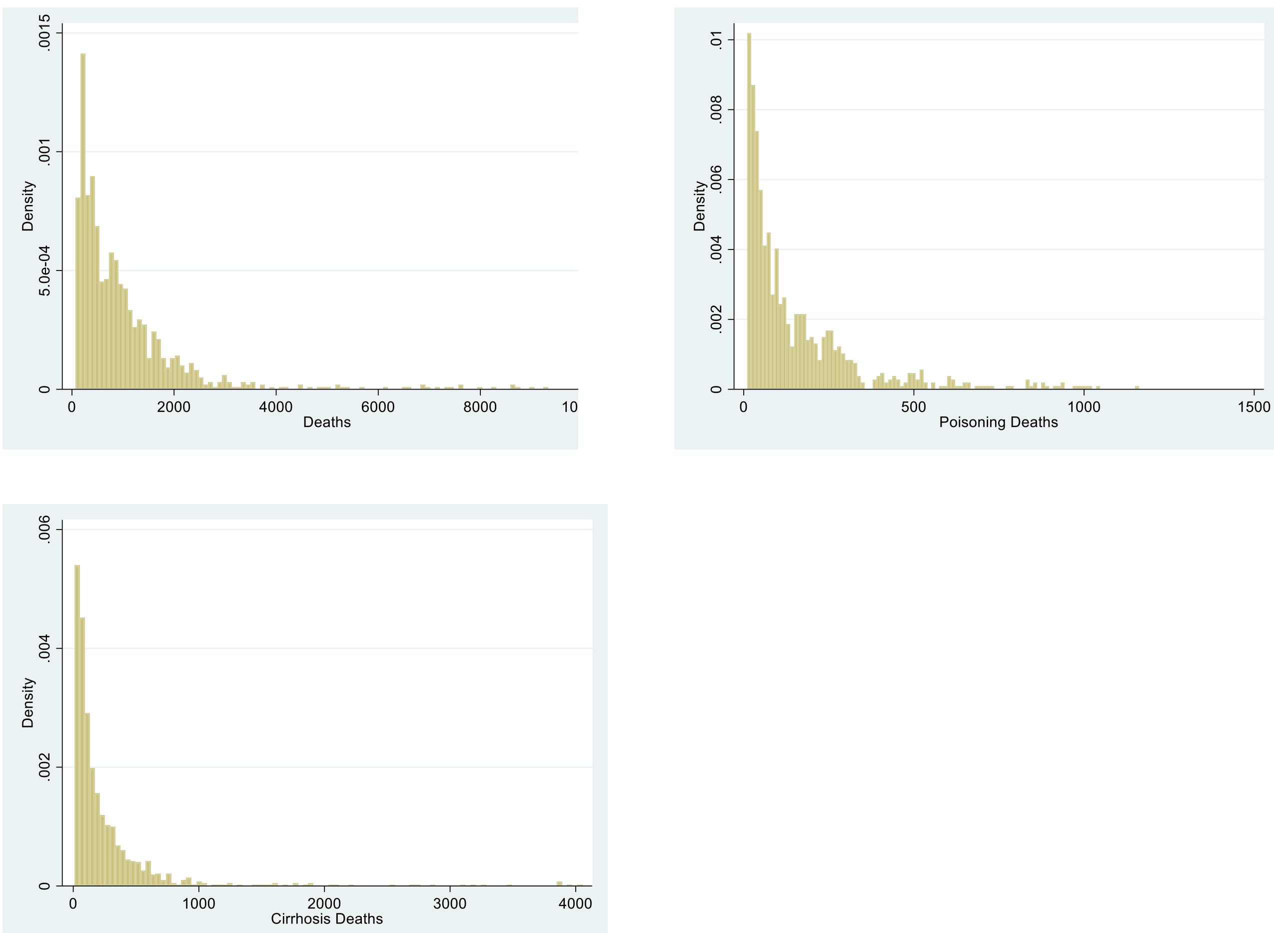
Appendix: Poisson Regression Model

1. Motivation

While a difference-in-differences using OLS regression on the log of alcohol related death rates is commonly used in the literature[1], actual deaths are positive integers, or counts, motivating the use of a count model such as Poisson. In this appendix I explore alternative estimates for the effect of recreational marijuana dispensing on alcohol related deaths using Poisson regression. As shown in Figure 2, the death count data display concentration around lower counts which is consistent with Poisson distribution. [2]

Figure 1A: Histograms of Alcohol Related Death Counts



[1] (Chan, Burkhardt, & Flyr, 2020; Anderson, Hansen, & Rees, 2013; Morris, TenEyck, Barnes, & Kovandzic, 2014).
[2] The log of death rates utilized in the primary paper are approximately normally distributed.

2. Results

a. Primary Specification

Table 1A: Mortalities

VARIABLES	(1) total deaths	(2) poisoning deaths	(3) cirrhosis deaths
Unemployment	-1.160	2.925	-0.022
	(1.522)	(0.646)***	(0.088)
Beer tax	53.195	8.568	-0.001
	(11.950)***	(4.847)*	(0.723)
Wine tax	-2.224	2.120	-0.013
	(0.419)***	(0.175)***	(0.026)
Median age	-33.354	29.770	-0.034
	(5.250)***	(3.171)***	(0.254)
Income per capita	-0.006	0.001	-0.000
	(0.001)***	(0.000)***	(0.000)*
Population	-0.000	-0.000	-0.000
	(0.000)***	(0.000)***	(0.000)
Male (% pop)	271.431	-4.767	0.926
	(15.268)***	(8.242)	(1.032)
White (% pop)	-9.979	4.421	-0.065
	(1.807)***	(1.030)***	(0.099)
Native (% pop)	-138.305	59.097	-0.599
	(20.732)***	(11.662)***	(1.055)
Hispanic (% pop)	4.568	-4.039	0.109
	(2.412)*	(1.178)***	(0.142)
RMD	-63.857	-64.119	0.006
	(8.410)***	(3.682)***	(0.457)
MMD	56.959	3.832	-0.001
	(4.430)***	(1.738)**	(0.266)
Observations	1,020	877	1,011

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The Poisson results from the primary specification on mortalities indicates that recreational marijuana dispensing reduces the count of total mortalities and poisonings by 64 deaths. This result is congruent with my conclusion from the preceding analysis that it is likely that all alcohol related mortalities averted by marijuana dispensing are poisonings, although it is possible that changes in other alcohol related mortalities from marijuana dispensing offset each other and obscure their effect.

b. Parallel Trends

Table 2A: Parallel Trends

VARIABLES	(1) Total deaths	(2) Poisoning deaths	(3) Cirrhosis deaths
5 year lead, RMD	91.181	34.155	1.138
	(9.493)***	(3.872)***	(4.322)
4 year lead, RMD	56.866	19.887	-6.782
	(12.151)***	(4.892)***	(5.287)
3 year lead, RMD	41.171	15.752	0.172
	(11.952)***	(4.758)***	(5.124)
2 year lead, RMD	18.580	8.824	0.002
	(11.713)	(4.637)*	(4.999)
RMD t	10.092	-0.741	-2.266
	(11.509)	(4.604)	(4.905)
1 year lag, RMD	1.303	-19.452	0.768
	(15.460)	(6.440)***	(7.040)
2 year lag, RMD	-38.628	-49.289	-10.969
	(16.039)**	(6.978)***	(7.358)
3 year lag, RMD	5.252	-49.766	18.826
	(13.471)	(5.849)***	(6.036)***
Constant	91.181	34.155	1.138
	(9.493)***	(3.872)***	(4.322)
Observations	1,020	877	1,011

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results from the Poisson parallel trends analysis certainly pull parallel trends into question. The significance of the treatment leads indicate that we may not have a suitable control group formed by non-dispensing states. Although, the sign on the poisoning estimate for RMD does flip to negative in post-dispensing years indicating that same persistent decline identified in the preceding analysis.

3. Robustness Checks

a. Suppressed Data

Table 3A: Suppressed Data

	VARIABLES	"Worst Case" death rate	"Mid Case" death rate	"Best Case" death rate
Panel (A)				
Poisoning Deaths	RMD	-56.961	-57.821	-58.724
		(3.184)***	(3.178)***	(3.171)***
	MMD	1.961	1.883	1.813
		(1.500)	(1.498)	(1.496)
	Observations	1,020	1,020	1,020
Panel (B)				
Cirrhosis Deaths	RMD	0.006	0.006	0.004
		(0.457)	(0.457)	(0.453)
	MMD	-0.001	-0.001	-0.004
		(0.266)	(0.266)	0.004
	Observations	1,020	1,020	1,020

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The Poisson estimates appear highly robust to data suppression and indicate a reduction in the count of alcohol related mortalities by between 56 and 59 deaths as the result of recreational marijuana dispensing,

b. Heterogenous effects

Table 4A: Sample Selection

		(1)	(2)	(3)
	VARIABLES	total deaths	poisoning deaths	cirrhosis deaths
Panel (A)				
Late Adopters	RMD	-63.857	-63.588	15.113
		(8.410)***	(6.901)***	(6.550)**
	MMD	56.959	11.801	9.329
		(4.430)***	(1.837)***	(2.374)***
	Observations	980	837	971
Panel (B)				
Regional Clusters with Existing Marijuana Legislation	RMD	-72.816	-61.366	10.743
		(9.705)***	(4.208)***	(5.090)**
	MMD	34.598	14.606	11.347
		(7.129)***	(2.770)***	(3.978)***
	Observations	440	373	433

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The Poisson estimates appear highly robust to spatial variation and indicate a reduction in the count of total mortality by between 63 and 72 deaths and a reduction in poisoning mortalities by between 61 and 63 deaths as the result of recreational marijuana dispensing,