Changes in Traffic Crash Rates After Legalization of Marijuana: Results by Crash Severity

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ABSTRACT. Objective: The objective of this study was to estimate the effects of marijuana legalization and the subsequent onset of retail sales on injury and fatal traffic crash rates in the United States during the period 2009–2019. **Method:** State-by-state quarterly crash rates per mile of travel were modeled as a function of time, unemployment rate, maximum posted speed limit, seat belt use rate, alcohol use rate, percent of miles driven on rural roads, and indicators of legalized recreational marijuana use and sales. **Results:** Legalization of the recreational use of marijuana was associated with a 6.5% increase in injury crash rates and a 2.3% increase in fatal crash rates, but the subsequent onset of retail marijuana sales did not elicit additional substantial changes. Thus, the combined effect of legalization and retail sales was a 5.8% increase in injury crash rates and a 4.1% increase in fatal crash rates. Across states, the effects on injury crash rates ranged from a 7% decrease to an 18% increase. The effects on fatal crash rates ranged from a 10% decrease to a 4% increase. **Conclusions:** The estimated increases in injury and fatal crash rates after recreational marijuana legalization are consistent with earlier studies, but the effects varied across states. Because this is an early look at the time trends, researchers and policymakers need to continue monitoring the data. (*J. Stud. Alcohol Drugs, 83,* 494–501, 2022)

SAFE OPERATION OF AN AUTOMOBILE requires a degree of perception, judgment, coordination, and alertness. Impairment of any of these faculties can lead drivers to collide with other vehicles or with people and objects along the road. Even small amounts of alcohol can affect driving skills. As the amount of alcohol in a driver's blood increases, the likelihood of a collision increases steadily (Compton & Berning, 2015; Peck et al., 2008). Drivers with a blood alcohol level of .08% are 4 times as likely to be involved in any crash and 6 to 10 times as likely to be involved in a fatal crash compared with drivers with no blood alcohol (Lacey et al., 2016; Voas et al., 2012). It is estimated that worldwide more than a quarter million people die each year in motor vehicle crashes involving alcohol (International Transport Forum, 2017).

Although alcohol has long been the most common impairing substance found among crash-involved drivers, marijuana impairment is becoming more common, especially in places where restrictions against marijuana use have been relaxed (Tefft & Arnold, 2020). But questions remain as to how marijuana use before driving affects crash risk. And, how does increased public access to marijuana affect the number of traffic crashes?

Driving simulator studies have demonstrated that marijuana use slows reaction time, hampers road tracking and lane keeping, and impairs one's ability to maintain attention, but some drivers under the influence of marijuana compensate by slowing down or increasing their following distances (Brooks-Russell et al., 2019; Hartman et al., 2016). It remains unclear whether this compensation by drivers aware of their impairment entirely makes up for that impairment. Indeed, research regarding the net effects of marijuana use on driver crash risk has been inconclusive. Some studies have reported a higher crash risk for drivers testing positive for marijuana (Li et al., 2013). Other studies have reported no difference in crash risk, especially after accounting for other factors (e.g., driver age, sex) that are known to affect crash risk (Compton, 2017). A meta-analysis of 26 published studies concluded that marijuana use increases the odds of driver crash involvement by 32% (Rogeberg et al., 2018). However, the odds ratios for the 26 studies varied widely, and the 95% confidence interval for the pooled odds ratio stretched from 1.09 to 1.59.

As with the research on marijuana use and crash risk, research relating marijuana decriminalization and legalization to crash rates has reached various conclusions. Decriminalization, defined as significantly reducing the penalties for marijuana possession, can be thought of as a middle ground between prohibition and legalization. Cook et al. (2020) tracked the rate of fatal crashes in 24 U.S. cities that decriminalized marijuana possession. They found that decriminalization was not associated with a change in overall fatal crash rates (incident rate ratio = 1.02), but that there was a 13% increase in fatal crashes involving 15- to 24-year-old male drivers. On the other hand, laws allowing the distribution of marijuana for medical purposes have been associated with an 8% to 11% reduction in traffic fatality rates—possibly because drivers are substituting marijuana for other more impairing substances (Anderson et al., 2013; Cook et al., 2020; Santaella-Tenorio et al., 2017).

As of July 2021, the recreational use of marijuana was legal in 18 U.S. states and the District of Columbia, and nationwide in Canada and Uruguay. Some recent studies

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have examined the effects on crash risk of laws legalizing recreational use and sales of marijuana. Vogler (2017) estimated an 8% increase in quarterly fatalities per capita in Colorado, Washington, Oregon, and Alaska after recreational marijuana use was legalized. Delling et al. (2019) reported a 9% increase in motor vehicle crash–related hospitalizations in Colorado after marijuana legalization. Aydelotte et al. (2019) concluded that fatal crash rates in Colorado and Washington increased by approximately 1.8 fatal crashes per billion vehicle miles of travel (VMT) after retail marijuana sales began. Hansen et al. (2020) concluded that deaths per billion VMT in Colorado and Washington increased slightly after retail sales began. Santaella-Tenorio et al. (2020) concluded that deaths per billion VMT increased in Colorado after retail sales began, but there was no change in Washington. Lane and Hall (2019) concluded that death rates in Colorado, Washington, and Oregon increased by approximately 0.90 deaths per million population in the month after retail sales began, but then declined slightly in subsequent months. Windle et al. (2021) estimated a 15% increase in fatal crashes per capita after recreational marijuana was legalized in 10 states and the District of Columbia. Finally, laws legalizing retail sales of recreational marijuana in Colorado, Washington, and Oregon have been associated with 4% to 6% increases in crashes of all severities (Highway Loss Data Institute, 2018, 2020; Monfort, 2018).

In sum, the research to date has reported increases in crashes after the legalization of recreational marijuana, but the estimated effects vary depending on the states and years examined and the methodology used. One reason for the varying effects could be the relative paucity of data for the periods after marijuana legalization. Including additional years of data as well as additional states should provide a better picture of the trends in crash rates.

The objective of the current study was to see how the legalization of recreational marijuana use has affected highway safety, both in the three states that have been the focus of earlier studies and in the states that legalized marijuana several years later. Specifically, the objective was to determine the effects of the state-by-state changes in marijuana laws on trends in their traffic crashes during the years 2009 through 2019 for Colorado, Washington, Oregon, California, and Nevada.

Method

Data on quarterly traffic crashes in 11 U.S. states during 2009–2019 were extracted from the databases maintained by each state (either directly or by special request). Data on quarterly VMT by state and roadway type were obtained from the Traffic Volume Trends series of the Federal Highway Administration (2020). Quarterly estimates of the civilian population employed and unemployed for each state were obtained from the U.S. Bureau of Labor Statistics (2020). Annual estimates of each state population by age were obtained from the U.S. Bureau of the Census (2020). The estimated annual percentages of front-seat vehicle occupants using seat belts in each state were obtained from the National Center for Statistics and Analysis (2020). Estimates of annual per capita alcohol consumption by state were obtained from the National Institute on Alcohol Abuse and Alcoholism (Slater & Alpert, 2021).

Table 1. Effective dates of laws regarding recreational marijuana, Western U.S. states, 2009–2019

State	Recreational use	Retail sales
Colorado	December 10, 2012	January 1, 2014
Washington	December 6, 2012	July 8, 2014
Oregon	July 1, 2015	October 1, 2015
California	November 9, 2016	January 1, 2018
Nevada	January 1, 2017	July 1, 2017

Note: Recreational use was not legalized in the remaining Western states: Arizona, Idaho, Montana, New Mexico, Utah, and Wyoming.

Colorado and Washington both legalized recreational use of marijuana among adults ages 21 and older in December 2012. However, retail sales of marijuana were not permitted until 2014. Three additional western states—Oregon, California, and Nevada—followed suit during the years 2015–2018 (Table 1). These five states comprised the five study groups. The comparison group comprised the six remaining western states (as defined by the U.S. Census Bureau): Arizona, Idaho, Montana, New Mexico, Utah, and Wyoming. The Census Bureau also classifies Alaska and Hawaii in the western region, and Alaska legalized recreational use of marijuana in 2015. However, the limited roadway networks of Alaska and Hawaii, as well as their separation from the other states, may lead to different patterns in their crash rates. To avoid the effects of such differences, analyses were conducted with Alaska and Hawaii excluded.

The choice of comparison states is one of the features differentiating earlier studies of marijuana legalization. Some researchers have chosen to include only states geographically adjacent to the study states, whereas others have included all U.S. states that did not change marijuana policies. Others have defined the comparison states to be those that exhibited crash trends consistent with the study states during the period before legalization. All these approaches have merit, but none are perfect. The four regions defined by the U.S. Census Bureau are based on state-by-state similarities including "historical development, population characteristics, [and] economy" (U.S. Department of Commerce, 1994). So, the states in the western region share many characteristics that likely affect highway travel patterns. In addition, the western region, except for Alaska and Hawaii, comprises states that each border at least one study state. Finally, all these states are contained within the Mountain and Pacific Time Zones.

Although the six comparison states have many similarities, they differ in their population sizes and demographics. Population estimates for 2019 ranged from 580,000 in Wyoming to 7.3 million in Arizona. And, except for Arizona, none of these states had more than 100 fatal crashes during any of the quarters from 2009 to 2019. Such small numbers lead to a great deal of variability in fatal crash rates over time, so the comparison states were pooled together into one group. The pooled population was approximately 16 million in 2019, and quarterly fatal crashes ranged from 325 to 572.

The covariates considered in the statistical model were time (i.e., quarters since the 2009 starting point), unemployment rate, percentage of driving-age population younger than age 25, percentage of VMT on rural roads, maximum posted speed limit, seat belt use rate, and per capita alcohol consumption. U.S. traffic injury and fatality rates have been shown to be negatively correlated with the unemployment rate and seat belt use rate (Longthorne et al., 2010) and positively correlated with the percentage of young drivers, the percentage of rural VMT, maximum speed limits, and alcohol consumption (Patterson et al., 2002; Voas & Lacey, 2011).

Most covariates differed across the states. For example, VMT on rural roads in California ranged from 16% to 18% of total VMT, whereas rural VMT in the comparison group of states ranged from 40% to 44%. Differential changes in these covariates over time (e.g., the increase in alcohol consumption in California from 8.6 liters per person in 2015 to 9.7 liters in 2019) could mask the true effects of the law changes. Logarithms of quarterly crash rates per VMT in each state were modeled as a function of the six state groups (five study states and one comparison group) and the covariates.

Separate analyses were conducted for fatal crashes and other injury crashes. Further breakdowns by level of injury (e.g., serious/minor) were not possible with the available data. Crashes not involving injury were excluded because, although all states report crashes involving injury, they differ in their requirements for reporting property-damage-only crashes. Also, the reporting requirements for a state may change over time. For example, Oregon reported all crashes involving property damage of at least $1,500 from 2009 through 2017, but the cutoff increased to $2,500 in 2018.

The statistical models also included two indicator variables related to marijuana legalization. One indicator variable was equal to zero for all quarters before legalization of recreational marijuana use and equal to one for all quarters thereafter. This allowed for the possibility of a step change in the crash rate when recreational use was legalized. The second indicator variable was defined to be zero for all quarters before legalization of retail marijuana sales and equal to one for all quarters thereafter (i.e., a step change when retail sales were allowed).

Estimation of model parameters and standard errors was accomplished using the time series cross section regression (TSCSREG) and PANEL procedures in SAS 9.4 (SAS Institute Inc., Cary, NC). These procedures allowed for comparisons both across cross sections (i.e., states) and across time, while accounting for the within-state correlations across time (Chen et al., 2010; Crane et al., 1991). The statistical modeling of the time series involved 44 time points for each of the six cross sections.

Quarterly crash rates tend to follow a seasonal pattern (e.g., fatal crash rates are lower in winter, higher in summer and fall), so the X11 procedure of SAS was used to adjust for the seasonal trend. The indicator variables in the model represent the difference in the logarithms of the (seasonally adjusted) crash rates before and after legalization. Thus, the percent change in crash rates after legalization was estimated as $100\ (e^{A} - 1)$, where A was the parameter estimate for the indicator variable.

Statistical models were constructed using all potential covariates as well as various subsets. The best-fitting and most parsimonious models were chosen based on evaluation of squared multiple correlation coefficients (R^2), Mallow's C_p, and Akaike's Information Criterion (Shumway & Stoffer, 2006). Covariates retained for the model predicting injury crash rates were unemployment, maximum posted speed limit, seat belt use rate, and per capita alcohol consumption. Covariates retained for the model predicting fatal crash rates were unemployment, maximum posted speed limit, seat belt use rate, per capita alcohol consumption, and the percentage of rural VMT.

Results

Seasonally adjusted, quarterly traffic crash rates for the group of six comparison states (Arizona, Idaho, Montana, New Mexico, Utah, and Wyoming) are plotted in Figure 1. There was no obvious trend over the 11 years, with fatal crash rates ranging from 10.6 to 13.1 per billion VMT and injury crash rates ranging from 488 to 544 per billion VMT.

For ease of presentation, quarterly crash rates for each of the five study states were divided by the corresponding rates from the comparison group of states. These relative crash rates are plotted in Figure 2. Fatal crash rates in the study states tended to be lower than those in the comparison group, but injury crash rates tended to be higher.

Legalization of recreational marijuana use was associated with increased injury crash rates (+6.5%), whereas the subsequent legalization of retail sales was associated with a slight decrease (−0.7%, Table 2). Thus, the combined effect of legalizing use and sales was a 5.8% increase in injury crash rates (i.e., $100\ (e^{0.0631 - 0.0066} - 1)$).

Legalization of recreational marijuana use was associated with a slight increase in fatal crash rates (+2.3%), whereas the subsequent legalization of retail sales was associated with another slight increase (+1.8%). The combined effect

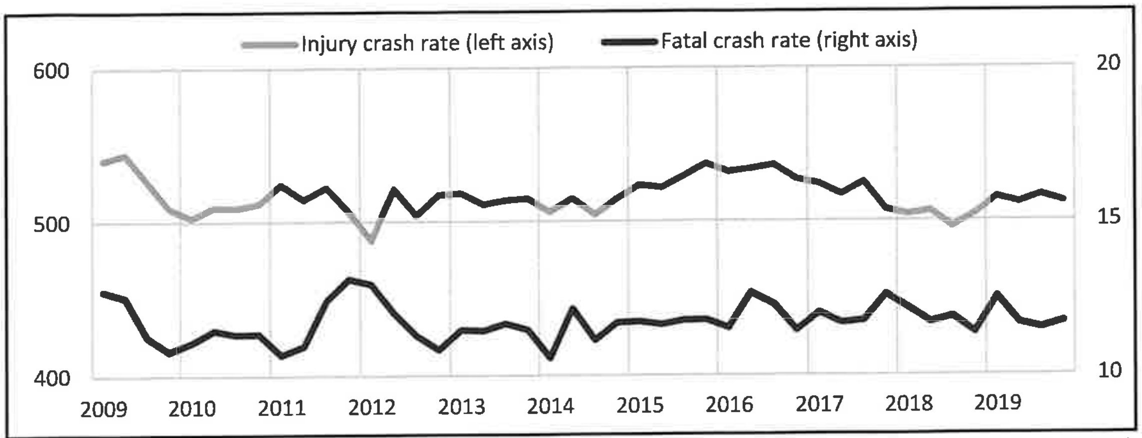

FIGURE 1. Quarterly traffic crashes per billion vehicle miles traveled, 2009–2019 (seasonally adjusted): Western U.S. states not legalizing marijuana (Arizona, Idaho, Montana, New Mexico, Utah, Wyoming)

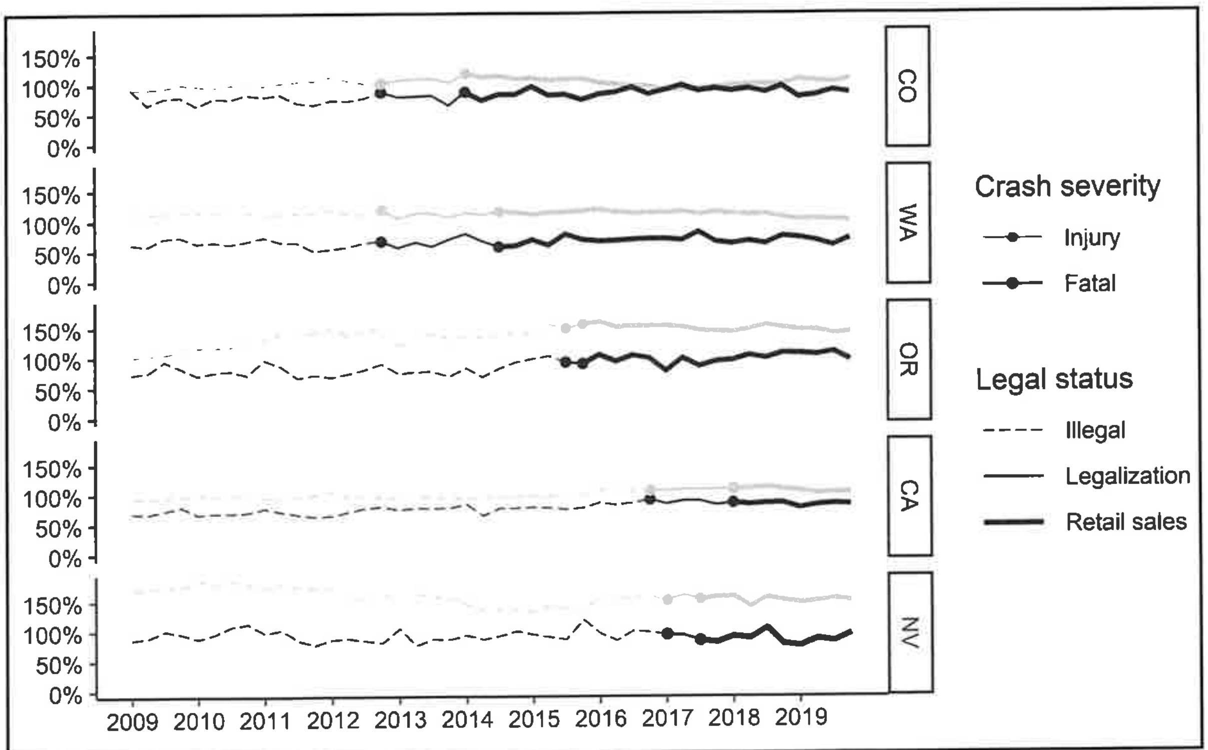

FIGURE 2. Quarterly crash rates relative to comparison states, 2009–2019: Western U.S. states legalizing marijuana. CO = Colorado, WA = Washington, OR = Oregon, CA= California, NV = Nevada.

of legalizing use and sales was a 4.1% increase in fatal crash rates (Table 3).

State-by-state differences

The analyses were performed separately for each study state to get a sense of the variability of results. For the sake of parsimony, we highlight the combined effects of legalization and retail sales by study state here, but the individual effects are decomposed in Table 4. Of the five study states, four experienced a net increase in injury crash rates following legalization and retail sales: Colorado (+17.8%), Washington (+8.4%), Oregon (+9.2%), and California (+5.7%). Only Nevada reported a decrease in injury crash rates (−6.7%). The pattern for fatal crash rates was less clear, however, with two states reporting an increase—Colorado (+1.4%) and Oregon (+3.8%)—and three reporting a decrease: Washington (−1.9%), California (−7.6%), and Nevada (−9.8%).

TABLE 2. Time-series cross section regression of state-by-state injury crash rates, 2009–2019

Parameter	Estimate	Effect (%)	[CI]	p
Unemployment rate (%)	0.0060	0.6	[0.0, 1.2]	.0339
Maximum speed limit (miles per hour)	-0.0016	-0.2	[-0.9, 0.6]	.6733
Percent seat belt use	0.0008	0.1	[-0.5, 0.7]	.7918
Per capita alcohol use (liters)	0.0454	4.6	[0.5, 9.0]	.0285
Indicator of recreational use (step)	0.0631	6.5	[2.6, 10.6]	.0012
Indicator of retail sales (step)	-0.0066	-0.7	[-4.5, 3.3]	.7417
Combined effect of legalization	0.0565	5.8	[0.2, 11.7]	.0431

Notes: CI = 95% confidence interval; R^2 = .8716.

TABLE 3. Time-series cross section regression of state-by-state fatal crash rates, 2009–2019

Parameter	Estimate	Effect (%)	[CI]	p
Unemployment rate (%)	-0.0061	-0.6	[-1.4, 0.2]	.1534
Maximum speed limit (miles per hour)	0.0018	0.2	[-0.8, 1.2]	.7282
Percent seat belt use	-0.0030	-0.3	[-1.1, 0.5]	.4363
Per capita alcohol use (liters)	0.0539	5.5	[0.1, 11.3]	.0465
Percent rural VMT	-0.0107	-1.1	[-2.1, -0.1]	.0370
Indicator of recreational use (step)	0.0223	2.3	[-2.7, 7.4]	.3748
Indicator of retail sales (step)	0.0175	1.8	[-3.3, 7.1]	.5052
Combined effect of legalization	0.0398	4.1	[-3.1, 11.7]	.2736

Notes: CI = 95% confidence interval; R^2 = .7191; VMT = vehicle miles of travel.

Discussion

Legalization of the recreational use of marijuana and the subsequent onset of retail sales in five U.S. states was on average associated with a 5.8% increase in injury crash rates and a 4.1% increase in fatal crash rates. The effect that marijuana legalization and the onset of retail sales had on crash injuries and fatalities varied somewhat by state. For injury crash rates, the data suggest the first three states to legalize experienced a greater injury rate increase compared with the two later states. In Colorado, Washington, and Oregon, injury crash rates increased after marijuana use was legalized, then increased again after retail sales began; overall increases ranged from 8% to 18%.

In contrast, California—which legalized recreational marijuana a few years later—saw just a 5% increase in injury crash rates following legalization and a 1% increase after retail sales began. Nevada began the legalization process around the same time as California and saw decreases in injury crash rates both after marijuana use was legalized and again after retail sales began. The effect of marijuana legalization on fatal crash rates was similarly less severe for California and Nevada.

The differing crash effects in California and Nevada could be attributable to lessons learned from the earlier states. Reports have catalogued lessons learned regarding enhanced enforcement against marijuana-impaired driving and preventing marijuana access to minors (National Highway Traffic Safety Administration, 2020; Smart Approaches to Marijuana, 2019). There also has been work developing more effective public service announcements about responsible use of marijuana (Davis et al., 2016; Governors Highway Safety Association, 2018).

On the other hand, the differing effects in California and Nevada could be because of cultural, environmental, and economic differences that may have affected public reaction to the liberalization of marijuana laws. And the timing of the law changes is notable. Colorado, Oregon, and Washington changed their marijuana laws during the years 2012–2015, when recovery from the 2007–2009 U.S. recession was still incomplete (Shambaugh & Strain, 2021).

Drivers impaired by marijuana have been observed to compensate for their impairment by slowing down and increasing following distance (Brooks-Russell et al., 2019; Hartman et al., 2016). It is reasonable to expect that such behaviors will reduce the severity of crashes that result. In that sense, past research suggests that fatal crash rates may be less affected by marijuana legalization than less severe crash rates. That is, the compensation exhibited by marijuana-impaired drivers, especially lower speeds, may not be sufficient to avoid a crash, but it may be enough to reduce the severity of that crash. Consistent with this conceptualization, the current study found that the increase in injury crash rates following legalization and retail sales was larger and more consistent across the states than the increase in fatal crash rates. Similarly, Monfort (2018) reported a 5.2% increase in police-reported crashes of all severities in Colorado, Washington, and Oregon, whereas the Highway Loss Data Institute (2018) reported a 6% increase in collision insurance claims (the latter typically being less severe than the former).

Alcohol use has a much greater effect than marijuana use on individual crash risk (Lacey et al., 2016; Rogeberg et al., 2018). However, compared with laws increasing the availability of alcohol, the estimated effect of marijuana legalization on crash rates is only slightly lower than the estimated effects of lowering the legal drinking age in the United States from 21 to 18. Williams et al. (1975) concluded that the temporary lowering of the drinking age in the 1970s increased fatal crash involvements of drivers under age 21 by about 5%. Carpenter and Dobkin (2011) estimated that returning to an 18-year-old drinking age would lead to a 9% increase in deaths to young drivers.

Legalization of the recreational use and retail sale of marijuana at the state level does not necessarily increase

TABLE 4. Time-series cross section regression of state-by-state crash rates, 2009–2019

State	Parameter	Injury crashes			Fatal crashes		
		Effect (%)	[CI]	*p*	Effect (%)	[CI]	*p*
CO	Indicator of recreational use (step)	14.2	[9.1, 19.6]	<.0001	-5.5	[-13.0, 2.6]	.1823
	Indicator of retail sales (step)	3.2	[-1.3, 7.9]	.1744	7.4	[-1.0, 16.5]	.0912
	Combined effect of legalization	17.8	[10.5, 25.7]	<.0001	1.4	[-9.7, 13.9]	.8100
WA	Indicator of recreational use (step)	5.3	[0.9, 9.9]	.0201	5.3	[-3.4, 14.8]	.2418
	Indicator of retail sales (step)	3.0	[-1.2, 7.4]	.1661	-6.9	[-14.3, 1.2]	.0974
	Combined effect of legalization	8.4	[2.2, 15.1]	.0080	-1.9	[-13.0, 10.6]	.7545
OR	Indicator of recreational use (step)	3.9	[-7.3, 16.5]	.5141	7.9	[-8.0, 26.6]	.3539
	Indicator of retail sales (step)	5.1	[-9.4, 22.0]	.5113	-3.8	[-21.9, 18.4]	.7155
	Combined effect of legalization	9.2	[-9.4, 31.8]	.3571	3.8	[-20.1, 34.9]	.7804
CA	Indicator of recreational use (step)	4.8	[1.4, 8.4]	.0075	6.5	[0.7, 12.6]	.0300
	Indicator of retail sales (step)	0.9	[-3.9, 5.9]	.7311	-13.3	[-19.8, -6.1]	.0007
	Combined effect of legalization	5.7	[-0.3, 12.2]	.0652	-7.6	[-16.1, 1.7]	.1086
NV	Indicator of recreational use (step)	-2.0	[-13.3, 10.9]	.7541	-1.4	[-18.4, 19.2]	.8863
	Indicator of retail sales (step)	-4.8	[-12.0, 3.0]	.2233	-8.6	[-19.0, 3.3]	.1530
	Combined effect of legalization	-6.7	[-19.4, 8.0]	.3557	-9.8	[-28.0, 13.0]	.3690

Note: CI = 95% confidence interval.

the legal availability of marijuana within all areas of a state. Counties within each of the study states have the option of restricting and prohibiting marijuana processing and retail centers. For example, as of April 2019, 23% of the counties in Washington and 48% of the counties in Colorado prohibited recreational marijuana facilities (Payan et al., 2021). It is possible that the effects of marijuana legalization have been lower in these counties. Future analyses should attempt to separate counties that have opted out.

Increased legal availability of marijuana does not necessarily imply increased use of marijuana before driving. However, research suggests that there is a significant correlation between U.S. trends in marijuana laws and policies and trends in self-reported use of the drug (Yu et al., 2020). Similarly, several studies have reported a higher incidence of drivers testing positive for marijuana after the liberalization of state marijuana policies (Eichelberger, 2019; Ramirez et al., 2016; Tefft & Arnold, 2020). Thus, the evidence suggests that the legality and availability of marijuana are related to the frequency of its use before driving.

Even if legalization leads to a higher prevalence of driving after marijuana use, the increased crash rates may be attributable to other unobserved factors. Marijuana users may be riskier drivers even when not impaired, and the legalization of marijuana may encourage more travel by these risky drivers. For example, marijuana users in counties that do not allow retail sales may drive to counties where such sales are permitted. Some states have used the legalization of marijuana as part of their tourism promotions, bringing in more potentially risky drivers (Kang et al., 2016). Thus, the results of this study do not necessarily imply that marijuana use before driving increases the risk of a crash.

The current study has several limitations. Although all the states in this study are in the western region of the United States, their crash rates during the years 2009–2019 may have been affected by unique factors not addressed here. These factors could affect the suitability of the states selected as a comparison group to the states legalizing marijuana. The details of the legislation in the various states differ slightly in terms of daily purchase limits, sales taxes involved, and available options for home growing. These differences, as well as other factors, might affect the ways consumers typically behave; how often they buy marijuana, where they buy it, and where they consume it. Finally, data were only available through 2019, which may not be sufficient to detect changes in trends. The data for California cover only 2 years after retail marijuana sales began.

In conclusion, the estimated increase in traffic crash rates after marijuana legalization is consistent with earlier studies: a 5.8% increase in injury crash rates and a 4.1% increase in fatal crash rates. Overall, we also found legalization of recreational use to have a more substantial effect on crash rates than the subsequent onset of retail sales. Our data suggest a large amount of variance in these effects by state, however, and these estimates represent an early look at the time trends.

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