Effect of recreational marijuana sales on police-reported crashes in Colorado, Oregon, and Washington

October 2018

Samuel S. Monfort
Insurance Institute for Highway Safety

1005 N. Glebe Road, Suite 800
Arlington, VA 22201
+1 703 247 1500

iihs.org

ABSTRACT

In January 2014, Colorado became the first U.S. state to allow retail sales of recreational marijuana, with Washington (July 2014) and Oregon (October 2015) following shortly afterward. With more states weighing legalization, it is important to understand the degree to which recreational marijuana legalization has affected traffic safety outcomes. The current study was based on the 2018 Highway Loss Data Institute research on the subject, which estimated that the legalization of retail sales was associated with a 6.0% increase in insurance collision claims compared with control states. The current study investigated police-reported crashes rather than insurance claims. Crash rates were computed for each month between January 2012 and December 2016 for the three study states as well as their neighboring states, which served as controls. Controlling for several demographic factors, the change in crash rate that occurred after recreational marijuana was legalized was compared with the change in crash rate in the control states over the same time frame. The legalization of retail sales in Colorado, Washington, and Oregon was associated with a 5.2% higher rate of police-reported crashes compared with neighboring states that did not legalize retail sales. These results contribute to the growing body of research on the impact of recreational marijuana legalization.

Keywords: recreational marijuana; traffic safety; crash risk; legalization; cannabis; THC

1. Introduction

Marijuana dulls the perceptual and cognitive abilities required for safely operating a motor vehicle (Bosker et al., 2012), and the legalization of recreational sales in several western states has drawn the attention of researchers and policymakers who seek to understand its effects on traffic safety. Results from simulator studies suggest that consuming marijuana increases lane weaving behavior and interferes with drivers' ability to maintain a constant headway (Bondallaz et al., 2017; Bosker et al., 2012). Despite the number of laboratory studies that have demonstrated a link between the use of marijuana and poor driving, the net effect that marijuana legalization has on real-world traffic safety outcomes is less clear. Meta-analyses of epidemiological research have found that drivers who use marijuana are slightly more likely to be involved in crashes than drivers who do not (Asbridge, Hayden, & Cartwright, 2012; Li et al., 2012; Rogeberg & Elvik, 2016), but some of the studies included did not carefully match control drivers to crash-involved drivers or failed to control for concurrent alcohol use. The best controlled study to date on the subject, conducted by the National Highway Traffic Safety Administration, found that drivers involved in crashes were not more likely to test positive for marijuana compared with drivers not involved in crashes after controlling for gender, age, race, and alcohol consumption (Lacey et al., 2016). Similarly, a recent study of recreational marijuana legalization in Colorado and Washington did not find a statistically significant increase in crash rates compared with control states (Aydelotte et al., 2017). Although some studies have found that liberalizing marijuana laws increases the proportion of drivers in fatal crashes that test positive for marijuana (Pollini, Romano, Johnson, & Lacey, 2015; Salomonsen-Sautel, Min, Sakai, Thurstone, & Hopfer, 2014), legalization seems to increase the number of users overall; an increase in marijuana-positive drivers alone does not necessarily imply impairment (Pacula,

Powell, Heaton, & Sevigny, 2015). Further, the presence of marijuana metabolites in the blood does not strongly predict impairment. Unlike alcohol, marijuana metabolites can remain in the bloodstream for days after the drug's effects wear off (Compton, 2017; Ramaekers et al., 2006).

1.1 Medical versus recreational marijuana

The effect that marijuana laws have on traffic safety may be related to whether the law governs medical or recreational use. Advocates of medical marijuana argue that the drug is a safe and efficacious treatment for several conditions and can serve as a substitute for other substances that are popularly used to manage those conditions (e.g., Lucas, 2012). Consistent with this conceptualization, research has found that legal medical marijuana is associated with lower rates of opioid and alcohol positivity among fatally injured drivers (Anderson, Hansen, & Rees, 2013; Kim et al., 2016). The reduction in opioid and alcohol abuse may offset (partially or entirely) the effects of more prevalent marijuana consumption (Anderson et al., 2013; Santaella-Tenorio et al., 2017). Thus, while medical marijuana legalization may increase the proportion of fatalities that involve marijuana (e.g., Pollini et al,. 2015), some research suggests that it may nonetheless reduce the overall number of fatalities (Hansen, Miller, & Weber, 2018; Santaella-Tenorio et al., 2017; Vogler, 2017). Efforts to understand the potential effects of legalizing marijuana should consider total crash numbers in addition to the proportion of fatal crashes involving marijuana.

Although research suggests that access to medical marijuana may reduce the prevalence of alcohol- and opioid-related crashes, these benefits may not extend to legalizing its recreational use. The size of the effect varies by study and state, but legalizing recreational marijuana seems to be associated with slightly increased fatality rates (Vogler, 2017). A study conducted by the Highway Loss Data Institute (HLDI) found that legal recreational marijuana sales in Colorado, Washington, and Oregon were associated with a 6.0% increase in collision claims compared with

neighboring states that did not legalize (HLDI, 2018). Except for HLDI (2018), most research evaluated the effect of marijuana legalization by analyzing fatal crashes. The current study was conducted to examine police-reported crashes of all severities in Colorado, Washington, Oregon, and several comparable western states that did not legalize recreational marijuana. Where possible, the methods, including covariates, from the 2018 HLDI study were used on the police-reported crash data. Given that the current study was designed to replicate and expand on this HLDI (2018) study, we hypothesized that the onset of recreational marijuana sales would be associated with a small increase in crash rates.

2. Method

2.1 Data

Monthly counts of police-reported crashes that occurred in the states of Colorado, Idaho, Nebraska, Oregon, Utah, Washington, and Wyoming were collected from annual published summaries. Data were available for years 2012–2016. Estimated counts of passenger vehicle registrations by state and year (IIHS analysis of data obtained from IHS Markit) were used as an exposure measure, and the outcome variable—crashes per million registrations—was computed to standardize crash data across states with varying vehicle population sizes.

States that legalized recreational marijuana sales were compared with neighboring states without such laws. Control states were chosen to match those used by HLDI (2018), which selected them according to their proximity to the study states and because of the strong correlation between the crash rates of these states and the study states in the years prior to legalization. This pattern was observed in the current study as well; Figure A1 in Appendix A shows the correlations and the changing crash rates over time per million registrations for Colorado, Washington, and Oregon, as well as their surrounding control states.

2.2 Legislation status

Each state in the sample that legalized recreational marijuana sales did so at a different time. For each study state and its matching controls, the months prior to legalization were coded as *pre-retail sales* and the months following legalization were coded as *post-retail sales*. States that legalized recreational sales were labeled *study states* and states that did not legalize recreational sales were labeled *control states*. Colorado (January 2014) was matched with Nebraska, Wyoming, and Utah; Washington (July 2014) and Oregon (October 2015) were matched with Idaho and Montana.

2.3 State characteristics

Monthly average temperature and precipitation data were obtained from the National Oceanic and Atmospheric Administration (NOAA, 2018) to control for the seasonal variation of crash rates. Data on unemployment were obtained from the Bureau of Labor Statistics (BLS, 2018) to account for differential economic conditions across states and time, which has been shown to be related to vehicle fatalities (Farmer, 2017; He, 2016).

2.4 Demographics

The population proportion of young drivers (20–24) and male drivers by state and year were included in the regression models to account for variation in state demographics (U.S. Census Bureau, 2016).

2.5 Model specification

States that legalized recreational marijuana sales were compared with neighboring states without such laws in a series of linear regression models. For all models, the crash rate outcome was log transformed to produce more interpretable estimates.

Two linear regression models were conducted for each study state. In the first model, a categorical state variable was used to make individual state comparisons. By setting the study state as the reference group, the differential effect of legalization on the study state compared with each of its controls was estimated through interactions between legislation status and the contrast terms for the control states. In the second regression model, a binary categorical variable was used that combined each control state into a single estimate (i.e., *study state* vs. *control states*). In this way, the study state was compared with the average of its control states, and the differential effect that legalization had on the study state compared with the aggregate of its controls was estimated through the interaction between legislation status and the contrast term for the control states.

Lastly, a single combined analysis was conducted to combine all study states and all control states. This regression produced an estimate for the overall effect of legal recreational sales on crash rates. All regression models described in this report were weighted by the number of crashes reported each month (i.e., sampling weights). Weighting improves the accuracy of parameter estimates by granting greater influence to months with more observations (i.e., crashes).

3. Results

3.1 Overall analysis

The combined analysis of all study states compared with all control states estimated the overall effect of legalizing recreational marijuana on traffic crashes at a relative increase of 5.2% (B=.0507, SE=.0213, t=2.38, p=.018) (Table 1). Although not always statistically significant, the estimated effects of the covariates tended to be in the hypothesized direction (Table B1 in Appendix B). For example, the parameter estimates for the proportion of young people and the

proportion of males were positive, while the parameter estimates for the unemployment rate were negative. It is estimated that if none of the covariates had changed over time, the three states in our sample that legalized recreational marijuana would have experienced a 4.1% increase in traffic crashes (Figure 1). In contrast, the control states would have experienced a 1.0% decrease in traffic crashes over the same period.

Table 1. Summary results of regression analyses comparing crash rates between study and control states before and after legalization of retail marijuana sales.

Study State(s)	Control State(s)	Effect	*B*	*SE*	*t*	*p*	
Colorado	Nebraska	+5.7%	.0551	.0457	1.21	.229	
	Utah	+8.5%	.0812	.0375	2.16	.032	*
	Wyoming	+7.4%	.0717	.0647	1.11	.269	
	Nebraska, Utah, Wyoming	+7.4%	.0718	.0307	2.34	.020	*
Washington	Idaho	+3.9%	.0387	.0563	.687	.493	
	Montana	+3.3%	.0321	.0573	.561	.576	
	Idaho and Montana	+3.6%	.0355	.0433	.819	.414	
Oregon	Idaho	+1.5%	.0148	.0494	.299	.765	
	Montana	+8.4%	.0807	.0565	1.43	.155	
	Idaho and Montana	+4.3%	.0417	.0420	.991	.323	
Colorado, Washington, Oregon	Idaho, Montana, Nebraska, Utah, Wyoming	+5.2%	.0507	.0213	2.38	.018	*

Note. This table contains summary results from seven different regression models. * = p<.05.

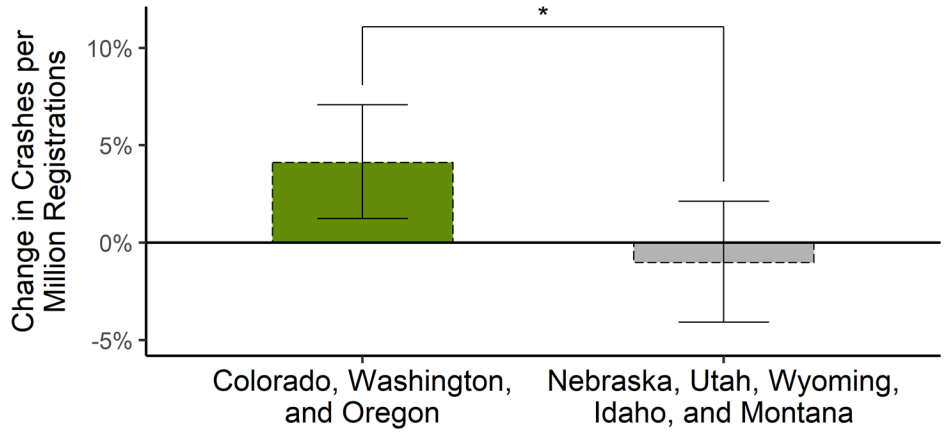

Figure 1. Estimated percent change in crash rates from pre- to post-legalization with covariates held constant. Error bars represent 95% confidence intervals.* = p<.05.

3.2 Individual state analyses

We also compared the study states individually with each of their control states, expecting the results to be consistent with the aggregate analysis.

3.2.1 Colorado

Consistent with the overall effect described previously, recreational marijuana legalization increased the police-reported crash rate in Colorado by 7.4% (*B*=.0718, *SE*=.0307, *t*=2.34, *p*=.020) (Table B2 in Appendix B). The regression model suggests that, if none of the covariates had changed, crash rates in the control states would have decreased by an average of 8.7% from pre- to post-legalization, compared with a decrease of 1.9% in Colorado (Figure 2). The individual comparisons between Colorado and its control states were not all statistically significant but were in the predicted direction (Table 1).

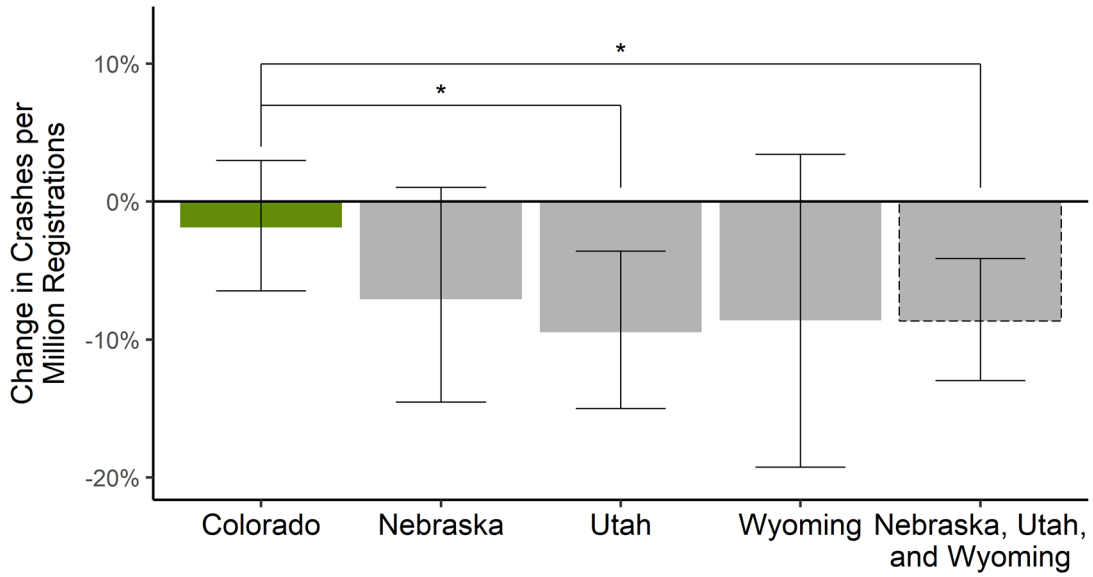

Figure 2. Estimated percent change in crash rates from pre- to post-legalization in Colorado and its controls with covariates held constant. Error bars represent 95% confidence intervals.
* = p<.05.

3.2.2 Washington

The effect of recreational marijuana legalization on crash rates in Washington was smaller than the effect for Colorado, a relative increase of 3.6% (Figure 3 and Table B3 in Appendix B). Although this effect was in the predicted direction, it was not statistically significant (p=.414). Individual comparisons between Washington and each control state resulted in similarly nonsignificant estimates (Table 1).

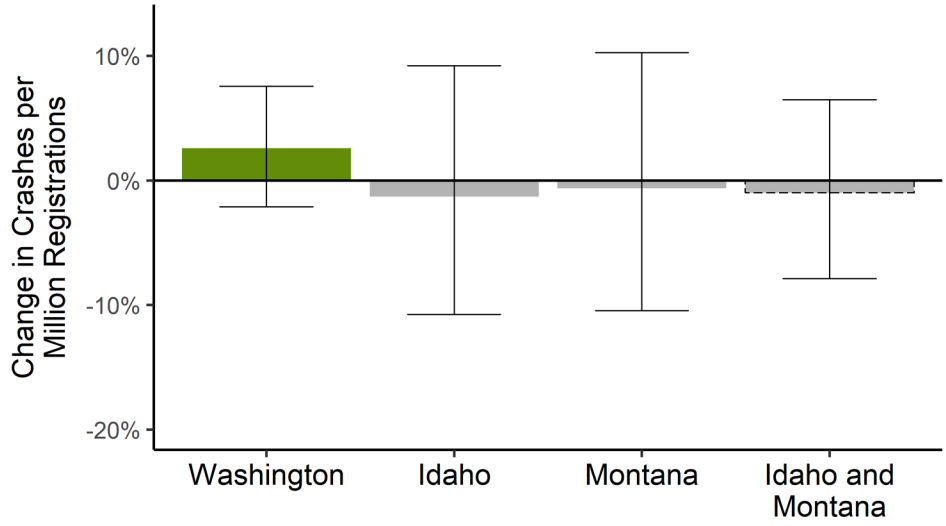

Figure 3. Estimated percent change in crash rates from pre- to post-legalization in Washington and its controls with covariates held constant. Error bars represent 95% confidence intervals.

3.2.3 Oregon

The effect of recreational marijuana legalization on crash rates in Oregon was also smaller than the effect for Colorado, a relative increase of 4.3% (Figure 4 and Table B4 in Appendix B). Although this effect also was in the predicted direction, it again was not statistically significant (p=.323). Individual comparisons between Oregon and each control state resulted in similarly nonsignificant estimates (Table 1).

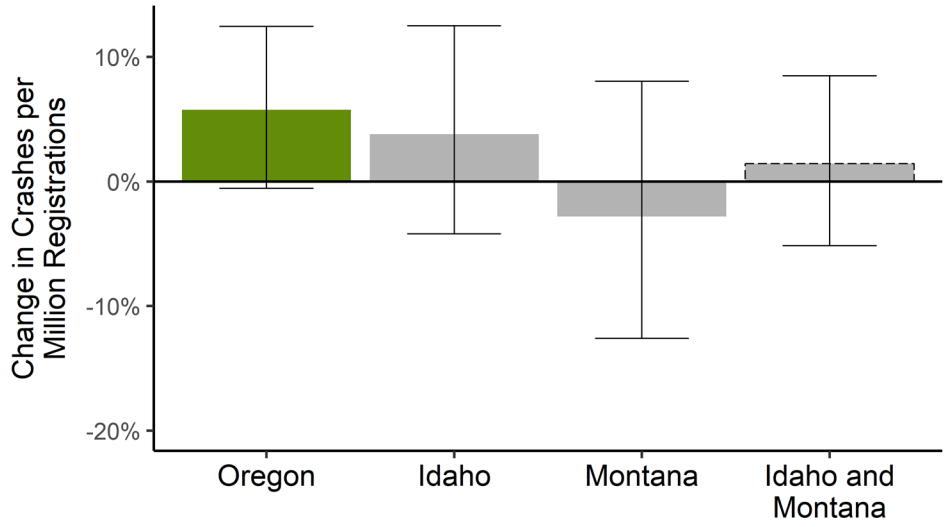

Figure 4. Estimated percent change in crash rates from pre- to post-legalization in Oregon and its controls with covariates held constant. Error bars represent 95% confidence intervals.

4. Discussion

Legalized recreational marijuana was hypothesized to be associated with increased police-reported crash rates in the affected states. Consistent with this hypothesis, crash rates in Colorado, Washington, and Oregon increased by an average of 5.2% from pre- to post-legalization relative to comparison states. Both the direction and size of this effect are consistent with past research by HLDI (2018), which found a 6.0% increase in collision claim rates over the same period.

4.1 State differences

The degree to which recreational marijuana legalization affected crash rates differed in the three study states, both in the size of the effects and in their statistical significance. Although the regression models included several variables intended to control for state differences, the three study states (and their controls) differ in ways that are difficult to quantify. For example, the details of the legislation in the three 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.

4.2 Enforcement options

Part of the reason that recreational marijuana legalization increases crash rates might be related to the lack of practical enforcement options. No test currently exists for law enforcement to measure marijuana impairment. Field sobriety tests have been adapted from their use in detecting alcohol-impaired drivers, but states vary widely in terms of their regulations governing tests for drivers (Romano, Torres-Saavedra, Voas, & Lacey, 2017). Research also suggests that field sobriety tests designed to assess alcohol-impaired drivers are only moderately successful at detecting impairment from marijuana (Papafotiou, Carter, & Stough, 2005). Ineffective enforcement may encourage drivers to engage in this risky behavior. Indeed, community intervention research suggests that the key mechanism in legislation's ability to deter impaired drivers lies in a greater perception of the risk of being arrested (Voas, Holder, & Gruenewald, 1997). It is likely that the development of portable technology capable of measuring driver THC levels will reduce marijuana-involved crashes in any state where it is legalized. Indeed, the development of portable blood-alcohol breathalyzer tests coupled with laws governing the legal limit of alcohol sharply reduced crash rates (Asbridge, Mann, Flam-Zalcman, & Stoduto, 2004). Nonetheless, potential complications remain if states adopt different legal limits for THC concentration, particularly because there is no convincing evidence to date to support what an appropriate per se limit would be. Legislation that considers legalizing recreational marijuana should consider available enforcement options when calculating potential societal costs.

4.3 Education options

Intervention-based education programs have been designed to change a variety of risky driving behaviors, from texting and driving (Unni, Morrow, Shultz, & Tian, 2013), to drowsy driving (James & Lauer, 1998), to driving while impaired by drugs or alcohol (Holder et al., 2000). However, these programs tend to have a limited effect on real-world driving behaviors and crash outcomes, particularly in the long-term (Vernick et al., 1999; Mayhew & Simpson, 2002). Some research on risk perceptions, for example, found that the risk that a driver perceives in performing a driving behavior is only weakly associated with performing that behavior (R^2=.044; Rhodes & Pivik, 2011). Increasing driver knowledge of risky behaviors can even make those behaviors more likely by engendering overconfidence (Mayhew & Simpson, 2002). Campaigns that seek to reduce marijuana-impaired driving by raising awareness of legal consequences may be similarly ineffective. A study of Colorado drivers after the state launched its "Drive High, Get a DUI" campaign found that knowledge of DUI laws alone is a weak predictor of DUI behavior (Davis et al., 2016). Programs aimed at reducing marijuana-impaired drivers may therefore have more success by focusing their efforts on targets ancillary to the drivers themselves. For example, Denver voters approved a social consumption law in 2016 that would allow certain establishments to serve marijuana. Education programs may be particularly important if legalization leads to marijuana "bars" where patrons arrive and depart by car. Training bartenders and servers to intervene when they observe rapid drinking (Russ & Geller, 1987) and to discourage patrons from leaving the premises with BACs above 0.08 g/dL (Lang, Stockwell, Rydon, & Beel, 1998) has been shown to have a substantial effect on alcohol-involved crashes.

Educational programs may also reduce harm from impaired driving by convincing the public to accept a greater legislative focus on regulating sales and advertising for the substance (Anderson, Chisholm, & Fuhr, 2009; Elder et al., 2004). Laws that limit the volume of alcohol advertising, for example, have been successful at reducing abuse, particularly in the case of indirect advertising (e.g., sponsorships, product placement; Anderson, de Bruijn, Angus, Gordon, & Hastings, 2009; Engels, Hermans, van Baaren, Hollenstein, & Bot, 2009). As recreational marijuana becomes more commonplace, it will be important to leverage legislation that has been effective at protecting the public from alcohol abuse to reduce the negative side effects of legal marijuana.

5. Conclusion

Colorado, Washington, and Oregon experienced a 5.2% higher police-reported crash rate overall than would have been expected had they not legalized recreational marijuana. These findings are consistent with past research that found a similarly sized effect on insurance collision claims (HLDI, 2018). Although the causal link between marijuana use and crash risk remains unproven, the consistent pattern of findings in the current study and in the 2018 HLDI study suggest with reasonable certainty that crash rates in Colorado, Washington, and Oregon did indeed increase after recreational marijuana was legalized there. The extent to which these findings will generalize to other states remains to be seen. States considering recreational marijuana legalization should weigh the impact of a higher crash rate and consider how enforcement and education can be developed to counteract a rise in impaired driving.

ACKNOWLEDGEMENTS

This work was supported by the Insurance Institute for Highway Safety.

REFERENCES

Anderson, P., Chisholm, D., & Fuhr, D.C. (2009). Effectiveness and cost-effectiveness of policies and programmes to reduce the harm caused by alcohol. *Lancet*, *373*, 2234–2246.

Anderson, P., de Bruijn, A., Angus, K., Gordon, R., & Hastings, G. (2009). Impact of alcohol advertising and media exposure on adolescent alcohol use: A systematic review of longitudinal studies. *Alcohol and Alcoholism*, *44*, 229–243.

Anderson, D.M., Hansen, B., & Rees, D.I. (2013). Medical marijuana laws, traffic fatalities, and alcohol consumption. *The Journal of Law and Economics*, *56*(2), 333–369.

Asbridge, M., Hayden, J.A., & Cartwright, J.L. (2012). Acute cannabis consumption and motor vehicle collision risk: Systematic review of observational studies and meta-analysis. *The BMJ*, *344*, 14.

Asbridge, M., Mann, R.E., Flam-Zalcman, R., & Stoduto, G. (2004). The criminalization of impaired driving in Canada: Assessing the deterrent impact of Canada's first per se law. *Journal of Applied Studies on Alcohol*, *65*(4), 450–459.

Aydelotte, J.D., Brown, L.H., Luftman, K.M., Mardock, A.L., Teixeira, P.G.R., Coopwood, B., Brown, C.V.R. (2017). Crash fatality rates after recreational marijuana legalization in Washington and Colorado. *American Journal of Public Health*, *107*(8), 1329–1331.

Bondallaz, P., Chtioui, H., Favrat, B., Fornari, E., Giroud, C., & Maeder, P. (2017). Assessment of cannabis acute effects on driving skills: Laboratory, simulator, and on-road studies. *Handbook of Cannabis and Related Pathologies*, 379–390.

Bosker, W.M., Kuypers, K.P., Theunissen, E.L., Surinx, A., Blankespoor, R.J., Skopp, G., Jeffery, W.K., Wals, H.C., van Leeuwen, C.J., & Ramaekers, J.G. (2012). Medicinal Delta(9)-tetrahydrocannabinol (dronabinol) impairs on-the-road driving performance of

occasional and heavy cannabis users but is not detected in standard field sobriety tests. *Addiction*, 107, 1837–1844.

Bureau of Labor Statistics. (2018, May 9) *Local area unemployment statistics* [Unemployment Rates]. Retrieved from http://www.bls.gov/lau

Compton, R. (2017). *Marijuana-impaired driving: A report to Congress* (DOT HS 812 440). Washington, DC: National Highway Traffic Safety Administration. Retrieved from https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/812440-marijuana-impaired-driving-report-to-congress.pdf

Davis, K.S., Allen, J., Duke, J., Nonnemaker, J., Bradfield, B., Farrelly, M.C., Shafer, P., & Novak, S. (2016). Correlates of marijuana drugged driving and openness to driving while high: Evidence from Colorado and Washington, *PLoS One*, *11*(1).

Elder, R.W., Shults, R.A., Sleet, D.A., Nichols, J.L., Thompson, R.S., Rajab, W. (2004). Effectiveness of mass media campaigns for reducing drinking and driving and alcohol-involved crashes. *American Journal of Preventive Medicine*, *27*(1), 57–65.

Engels, R.C.M.E., Hermans, R., van Baaren R.B., Hollenstein, T., & Bot, S.M. (2009). Alcohol portrayal on television affects actual drinking behavior. *Alcohol and Alcoholism*, *44*, 244–249.

Farmer, C. (2017). *A projection of United States traffic fatality counts in 2024*. Arlington, VA: Insurance Institute for Highway Safety.

Hansen, B., Miller, K.S., & Weber, C. (2018). *Early evidence on recreational marijuana legalization and traffic fatalities* (NBER Working Paper No. 24417). Cambridge, MA: National Bureau of Economic Research.

He, M.M. (2016). Driving through the Great Recession: Why does motor vehicle fatality decrease when the economy slows down? *Social Science & Medicine*, *155*, 1–11.

Highway Loss Data Institute. (2018). Recreational marijuana and collision claim frequencies. *HLDI Bulletin*, *35*(8), 1–14.

Holder, H.D., Gruenewald, P.J., Ponicki, W.R., Treno, A.J., Grube, J.W., Saltz, R.F., Voas, R.B., Reynolds, R., Davis, J., Sanchez, L., Gaumont, G., & Roeper, P. (2000). Effect of community-based interventions on high-risk drinking and alcohol-related injuries. *Journal of the American Medical Association*, *284*(18), 2341–2347.

James, S.L. & Lauer, H.E. (1998). Community-based education of youth and the dangers of driving drowsy. *Sleep*, *21*(3), A383.

Kim, J., Santaella-Tenorio, J., Mauro, C., Wrobel, J., Cerdá, M., Keyes, K.M., Hasin, D., Martins, S.S., & Li, G. (2016). State medical marijuana laws and the prevalence of opioids detected among fatally injured drivers. *American Journal of Public Health*, *106*(11), 2032–2037.

Lacey, J.H., Kelley-Baker, T., Berning, A., Romano, E., Ramirez, A., Yao, J., … & Compton, R. (2016, December). *Drug and alcohol crash risk: A case-control study* (Report No. DOT HS 812 355). Washington, DC: National Highway Traffic Safety Administration.

Lang, E., Stockwell, T., Rydon, P., & Beel, A. (1998). Can training bar staff in responsible serving practices reduce alcohol-related harm? *Drug and Alcohol Review*, *17*, 39–50.

Lucas, P. (2012). Cannabis as an adjunct to or substitute for opiates in the treatment of chronic pain. *Journal of Psychoactive Drugs*, *44*(2), 125–133.

Li, M., Brady, J.E., DiMaggio, C.J., Lusardi, A.R., Yzong, K.Y., & Li, G. (2012). Marijuana use and motor vehicle crashes. *Epidemiologic Reviews*, *34*(1), 62–72.

Mayhew, D.R. & Simpson, H.M. (2002). The safety value of driver education and training. *Injury Prevention*, *8*, 3–8.

National Oceanic and Atmospheric Administration. (2018, May 9) *Climate data online*: *Dataset discovery* [Dataset]. Retrieved from https://www.ncdc.noaa.gov/cdo-web/datasets

Pacula, R.L., Powell, D., Heaton, P., & Sevigny, E.L. (2015). Assessing the effects of medical marijuana laws on marijuana use: The devil is in the details. *Journal of Policy Analysis and Management*, *34*(1), 7–31.

Papafotiou, K., Carter, J.D., & Stough, C. (2005). The relationship between performance on the standardised field sobriety tests, driving performance and the level of Δ9-tetrahydrocannabinol (THC) in blood. *Forensic Science International*, *155*, 172–178.

Pollini, R.A., Romano, E., Johnson, M.B., & Lacey, J.H. (2015). The impact of marijuana decriminalization on California drivers. *Drug and Alcohol Dependence*, *150*, 135–140.

Ramaekers, J.G., Moeller, M.R., van Ruitenbeek, P., Theunissen, E.L., Schneider, E., & Kauert, G. (2006). Cognition and motor control as a function of Δ^9-THC concentration in serum and oral fluids: Limits of impairment. *Drug and Alcohol Dependence*, *85*, 114–122.

Rhodes N., & Pivik K. (2011). Age and gender differences in risky driving: The roles of positive affect and risk perception. *Accident Analysis & Prevention*, *43*(3), 923–31.

Rogeberg, O. & Elvik, R. (2016). The effects of cannabis intoxication on motor vehicle collision revisited and revised. *Addiction*, *111*(8), 1348–1359.

Romano, E., Torres-Saavedra, P., Voas, R.B., & Lacey, J.H. (2017). Marijuana and the risk of fatal car crashes: What can we learn from FARS and NRS data? *The Journal of Primary Prevention*, 38, 315–328.

Russ, N.W. & Geller, E.S. (1987). Training bar personnel to prevent drunken driving: A field evaluation. *American Journal of Public Health*, *77*, 952–954.

Salomonsen-Sautel, S., Min, S., Sakai, J.T., Thurstone, C., & Hopfer, C. (2014). Trends in fatal motor vehicle crashes before and after marijuana commercialization in Colorado. *Drug and Alcohol Dependence*, *140*, 137–144.

Santaella-Tenorio, J., Mauro, C.M., Wall, M.M., Kim, J.H., Cerdá, M., Keyes, K.M., Hasin, D.S., Galea, S., & Martins, S.S. (2017). US traffic fatalities, 1985-2014, and their relationship to medical marijuana laws. *American Journal of Public Health*, *107*(2), 336–342.

Unni, P., Morrow, S.E., Shultz, B.L., & Tian, T.T. (2013). A pilot hospital-school educational program to address teen motor vehicle safety. *Journal of Trauma and Acute Care Surgery*, *75*(4), S285–S289.

U.S. Census Bureau. (2018). *Data on young drivers by state and year* [Population data]. Retrieved from https://www.census.gov/data.html

Vernick, J.S., Li, G., Ogaitis, S., MacKenzie, E.J., Baker, S.P., & Gielen, A.C. (1999). Effects of high school driver education on motor vehicle crashes, violations, and licensure. *American Journal of Preventive Medicine*, *16*(1), 40–46.

Voas, R.B., Holder, H.D., & Gruenewald, P.J. (1997). The effect of drinking and driving interventions on alcohol-involved traffic crashes within a comprehensive community trial. *Addiction*, *92*(2), S221–S236.

Vogler, J. (2017). State marijuana policies and vehicle fatalities. *SSRN Working Paper*, 1–63.

APPENDIX A: FIGURES

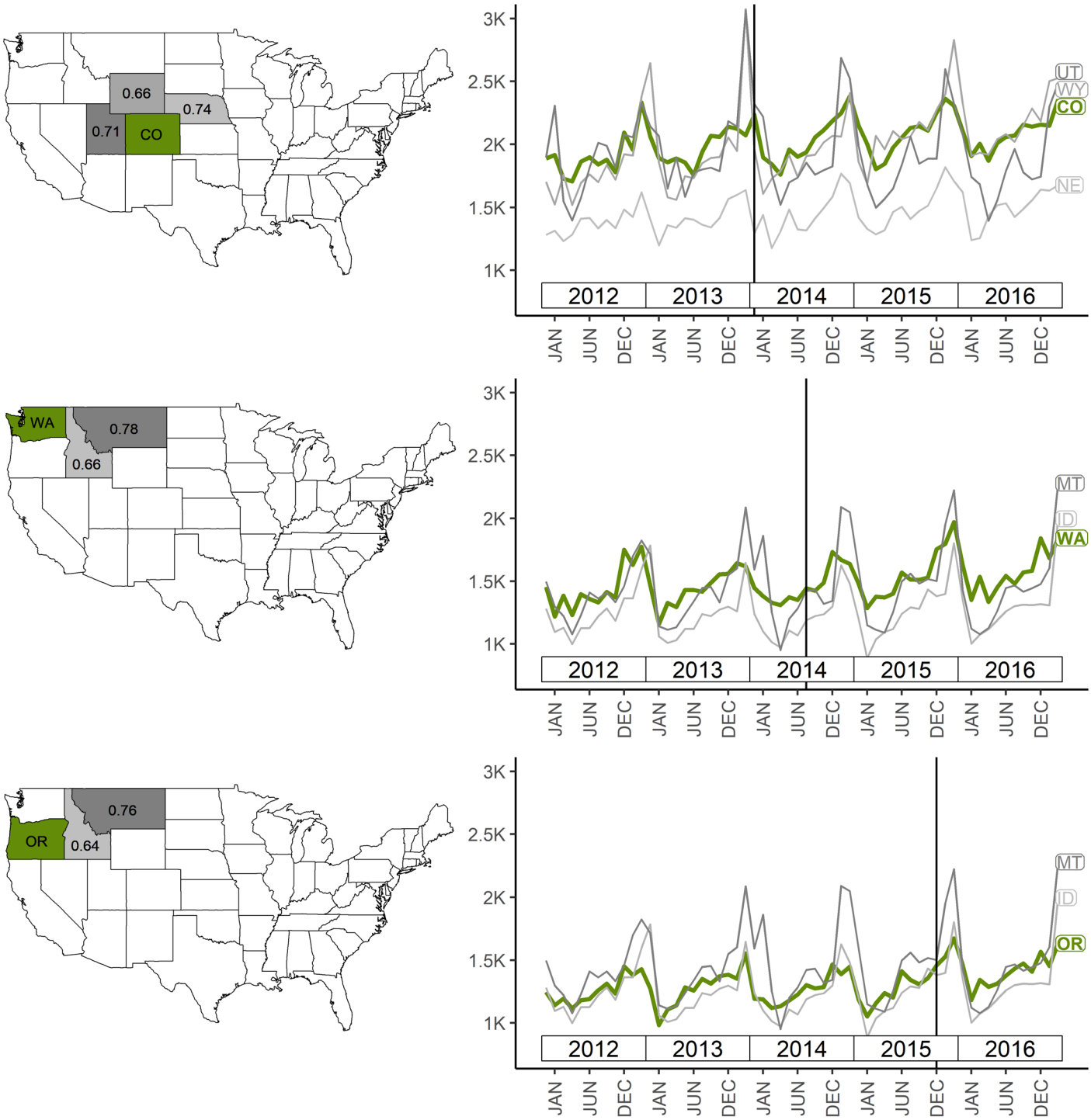

Figure A1. Correlations in police-reported crash rates pre-legalization between study states and neighboring control states (L) and crash rates per registered vehicle over time (R).

APPENDIX B: TABLES

Table B1. Output from regression analysis comparing crash rates between study states and control states before and after legalization of retail marijuana sales.

Parameter		*B*	*SE*	*t*	*p*	
(Intercept)		−1.04	10.5	−.10	.921	
Proportion age 20–24		.0635	.0650	.98	.329	
Proportion male		.167	.211	.79	.428	
Unemployment rate		−.000120	.00587	−.020	.984	
Temperature range (˚F)	32+	−.125	.0166	−7.52	<.001	***
	<32	—	—	—	—	
Precipitation (inches/month)		.00160	.00459	.35	.727	
Temperature × Precipitation	32+	.00934	.00472	1.98	.049	*
	<32	—	—	—	—	
State	Idaho	−.473	.0242	−19.5	<.001	***
	Montana	−.367	.0346	−10.6	<.001	***
	Nebraska	−.285	.0917	−3.11	.002	**
	Utah	−.195	.0935	−2.09	.037	*
	Wyoming	−.170	.195	−.87	.382	
	Oregon	−.322	.131	−2.47	.014	*
	Washington	−.273	.0620	−4.40	<.001	***
	Colorado	—	—	—	—	
Legislation status	Post-retail sales	−.0103	.0160	−.65	.517	
	Pre-retail sales	—	—	—	—	
Month index		.000262	.00100	.26	.794	
Month index × State	Idaho	.00158	.000970	1.62	.105	
	Montana	.00111	.000850	1.31	.192	
	Nebraska	.00104	.00104	1.00	.316	
	Utah	.00381	.000889	4.29	<.001	***
	Wyoming	−.000250	.00134	−.18	.854	
	Oregon	.00150	.000846	1.77	.078	†
	Washington	.000821	.000690	1.19	.235	
	Colorado	—	—	—	—	
Month	January	−.150	.0157	−9.50	<.001	***
	February	−.266	.0167	−15.9	<.001	***
	March	−.223	.0196	−11.4	<.001	***
	April	−.240	.0202	−11.9	<.001	***
	May	−.170	.0192	−8.85	<.001	***
	June	−.137	.0195	−7.00	<.001	***
	July	−.119	.0196	−6.06	<.001	***
	August	−.0972	.0192	−5.06	<.001	***
	September	−.101	.0187	−5.41	<.001	***
	October	−.0338	.0178	−1.89	.059	†
	November	−.0214	.0168	−1.28	.202	
	December	—	—	—	—	
State type × Legislation status		.0507	.0213	2.38	.018	*

* = p<.05. ** = p<.01. ***= p<.001. † = p<.10.

Table B2. Output from regression analysis comparing crash rates between Colorado and control states before and after legalization of retail marijuana sales.

Parameter		***B***	***SE***	***t***	***p***	
(Intercept)		−14.1	19.0	−.74	.461	
Proportion age 20–24		.267	.110	2.43	.016	*
Proportion male		.400	.377	1.06	.289	
Unemployment rate		−.0267	.00984	−2.71	.007	**
Temperature range (°F)	32+	−.0363	.0378	−.960	.339	
	<32	—	—	—	—	
Precipitation (inches/month)		.0653	.0260	2.52	.013	*
Temperature × Precipitation	32+	−.0541	.0271	−2.00	.047	**
	<32	—	—	—	—	
State	Nebraska	−.313	.159	−1.97	.050	†
	Utah	−.618	.178	−3.47	.001	**
	Wyoming	−.579	.362	−1.60	.111	*
	Colorado	—	—	—	—	
Legislation status	Post-retail sales	−.0906	.0246	−3.68	<.001	***
	Pre-retail sales	—	—	—	—	
Month index		−.00168	.00158	−1.06	.288	
Month index × State	Nebraska	.00291	.00135	2.15	.033	*
	Utah	.00716	.00131	5.46	<.001	***
	Wyoming	.00539	.00194	2.79	.006	**
	Colorado	—	—	—	—	
Month	January	−.0992	.0257	−3.86	<.001	***
	February	−.192	.0254	−7.54	<.001	***
	March	−.176	.0338	−5.20	<.001	***
	April	−.206	.0347	−5.94	<.001	***
	May	−.138	.0345	−3.99	<.001	***
	June	−.133	.0334	−3.98	<.001	***
	July	−.129	.0340	−3.78	<.001	***
	August	−.0942	.0334	−2.82	.005	**
	September	−.0953	.0331	−2.88	.004	**
	October	−.0325	.0324	−1.00	.317	
	November	−.00747	.0314	−.240	.812.	
	December	—	—	—	—	
State type × Legislation status		.0718	.0307	2.34	.020	*

* = p <.05. ** = p<.01. *** = p<.001. † = p<.10.

Table B3. Output from regression analysis comparing crash rates between Washington and control states before and after legalization of retail marijuana sales.

Parameter		***B***	***SE***	***t***	***p***	
(Intercept)		−13.8	18.8	−.732	.464	
Proportion age 20–24		−.212	.128	−1.66	.099	†
Proportion male		.460	.387	1.19	.236	
Unemployment rate		−.00334	.0107	−.311	.756	
Temperature range (°F)	32+	−.214	.0351	−6.10	<.001	***
	<32	—	—	—	—	
Precipitation (inches/month)		−.0152	.00763	−1.99	.049	*
Temperature × Precipitation	32+	.0293	.00790	3.71	<.001	***
	<32	—	—	—	—	
State	Idaho	−.317	.115	−2.77	.006	**
	Montana	−.228	.157	−1.45	.149	
	Washington	—	—	—	—	
Legislation status	Post-retail sales	−.00972	.0367	−.265	.791	
	Pre-retail sales	—	—	—	—	
Month index		−.00191	.00213	−.896	.372	
Month index × State	Idaho	.00121	.00154	.787	.432	
	Montana	.00195	.00168	1.17	.246	
	Washington	—	—	—	—	
Month	January	−.189	.0309	−6.11	<.001	***
	February	−.338	.0333	−10.2	<.001	***
	March	−.277	.0365	−7.61	<.001	***
	April	−.288	.0381	−7.57	<.001	***
	May	−.197	.0370	−5.33	<.001	***
	June	−.150	.0361	−4.15	<.001	***
	July	−.129	.0370	−3.48	<.001	***
	August	−.108	.0360	−2.99	.003	**
	September	−.110	.0336	−3.27	.001	**
	October	−.0354	.0286	−1.24	.217	
	November	−.0445	.0263	−1.69	.093	†
	December	—	—	—	—	
State type × Legislation status		.0355	.0433	.819	.414	

* = p <.05. ** = p<.01. *** = p<.001. † = p<.10.

Table B4. Output from regression analysis comparing crash rates between Oregon and control states before and after legalization of retail marijuana sales.

Parameter		***B***	***SE***	***t***	***p***	
(Intercept)		−4.48	17.6	−.251	.800	
Proportion age 20–24		−.135	.166	−.814	.417	
Proportion male		.261	.363	.720	.473	
Unemployment rate		−.000440	.0106	−.0420	.967	
Temperature range (°F)	32+	−.231	.0368	−6.29	<.001	***
	<32	—	—	—	—	
Precipitation (inches/month)		−.0287	.00990	−2.90	.004	**
Temperature × Precipitation	32+	.0369	.0102	3.61	<.001	***
	<32	—	—	—	—	
State	Idaho	−.196	.211	−.930	.355	
	Montana	−.0935	.256	−.370	.715	
	Oregon	—	—	—	—	
Legislation status	Post-retail sales	.0144	.0340	.424	.672	
	Pre-retail sales	—	—	—	—	
Month index		−.000113	.00152	−.0746	.941	
Month index × State	Idaho	−.000179	.00117	−.153	.879	
	Montana	.000358	.00167	.215	.830	
	Oregon	—	—	—	—	
Month	January	−.214	.0342	−6.25	<.001	***
	February	−.365	.0368	−9.90	<.001	***
	March	−.314	.0396	−7.93	<.001	***
	April	−.303	.0435	−6.96	<.001	***
	May	−.237	.0408	−5.81	<.001	***
	June	−.171	.0411	−4.15	<.001	***
	July	−.124	.0427	−2.89	.004	**
	August	−.122	.0423	−2.90	.004	**
	September	−.132	.0399	−3.31	.001	**
	October	−.0800	.0369	−2.17	.032	*
	November	−.0775	.0337	−2.30	.023	*
	December	—	—	—	—	
State type × Legislation status		.0417	.0420	.991	.323	

* = p <.05. ** = p<.01. *** = p<.001.