HLDI
Highway Loss Data Institute

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Recreational marijuana and collision claim frequencies

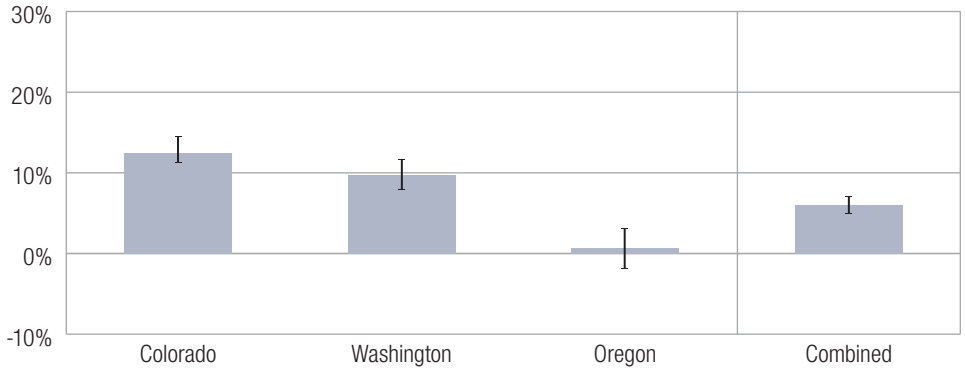
Summary

Colorado was the first state to legalize recreational marijuana for adults 21 and older in the United States. Voters approved the measure in November 2012 and sales began in January 2014. Washington voters also approved recreational marijuana in November 2012 and sales began in July 2014. Oregon followed suit two years later, legalizing marijuana in November 2014, with sales starting in October 2015. In April 2017, the Highway Loss Data Institute (HLDI) published the first study analyzing changes in collision claim frequencies in each of these states, relative to nearby states, following the inception of legal recreational use. The analyses controlled for differences in the rated driver populations, the insured vehicle fleet, the mix of urban versus rural exposure, unemployment, weather, and seasonality. The results indicated that for all three states, the legalization of retail marijuana sales was correlated with increases in collision claim frequency. This study expands on the prior study by including an additional year of collision loss data and methodology changes. It also accounts for the recent legalization of retail marijuana sales in Nevada.

As shown in the following figure, the legalization of retail sales is associated with increases in collision claim frequencies. Collision claim frequencies in Colorado were 12.5 percent higher than in Nebraska, Utah, and Wyoming after legalization. Similarly, claim frequencies in Washington state increased by 9.7 percent compared with Idaho and Montana. Both results were statistically significant. In Oregon, the increase in collision claim frequency was not significant and less than 1 percent higher than in Idaho and Montana.

Note that Nevada was removed as a control state from the Oregon analysis, since Nevada voters approved recreational marijuana in November 2016. Retail sales in Nevada began in July 2017. HLDI is currently monitoring collision claim frequencies in Nevada and will update results after enough time has passed since legalization to provide meaningful results.

Estimated effect of marijuana sales on collision claim frequencies



A single analysis that combined each of the states with legal recreational use was also conducted. In this analysis, the study states were compared with other western states whose monthly collision claim frequencies before legalization were highly correlated with the frequencies for each of the study states. Using this approach, the legalization of retail sales was associated with a 6.0 percent increase in collision claim frequency.

Introduction

Colorado was the first state to legalize recreational marijuana for adults 21 and older in the United States. Voters approved the measure in November 2012 and sales began in January 2014. Washington voters also approved recreational marijuana in November 2012 and sales began in July 2014. Alaska, Oregon, and Washington D.C. followed suit two years later, legalizing marijuana in November 2014, with sales starting in October 2015 for Oregon and October 2016 for Alaska. Retail sales were not allowed in Washington D.C. The trend in marijuana legalization continued with voters in California, Maine, Massachusetts, and Nevada approving recreational marijuana use in November 2016. Although sales have not yet begun in Maine and Massachusetts, retail sales began in Nevada in July 2017 and in California in January 2018. Most recently, Vermont became the first state to legalize marijuana use through the state legislature, although sales there are not yet authorized.

As more states consider legalizing recreational marijuana use, understanding the effect that marijuana has on driving and vehicle crashes is of growing importance. Although there have been numerous studies thus far, the results have been somewhat conflicting, with some studies showing impairment or culpability and others not (Sewell et. al. 2009). For example, a study by the National Highway Traffic Safety Administration (Lacey et. al., 2016) found no significant increase in crash risk after controlling for drivers' age, gender, race, and the presence of alcohol. Other studies, however, have found that crash risk increases significantly after marijuana use (Elvik, 2013). Driving and simulator studies have found that marijuana use by drivers is likely to result in decreased speed, fewer attempts to overtake, and increased following distance. However, marijuana use was also associated with increases to reaction times and incorrect responses to emergency situations (Smiley, 1986).

In April 2017, HLDI released the first study estimating the effect of legalization of retail marijuana sales on collision claim frequencies. That study found that legalization was associated with statistically significant increases to collision claim frequencies in Colorado, Washington, and Oregon. A single analysis that combined these three states found a statistically significant increase of 2.7 percent. A similar study by Aydelotte et. al (2017) looked at the effect of legalization on fatal crash rates in Washington and Colorado. Although their study found no statistically significant difference in fatal crash rates as a result of legalization, they did note that their findings "would equate to approximately 77 excess crash fatalities (of 2,890 total)" (p. 1,330), which is equivalent to a 2.7 percent increase and consistent with HLDI's findings.

Method

Vehicles

The vehicles in this study were 1981–2018 models. The 33 most recent model years available for each calendar year were used (e.g., data from calendar year 2014 included 1985–2015 models). Loss data were included from January 2012 through October 2017. **Table 1** summarizes the exposure and claims for the study, and the control states used in both the single state and combined analyses.

Table 1: Summary of exposure and claims

Single state analysis	Exposure	Claims
Colorado	27,177,296	1,408,125
Oregon	16,503,915	759,099
Washington	24,681,640	1,221,521
Combined analysis	64,321,136	3,272,545

Insurance data

Automobile insurance covers damages to vehicles and property in crashes plus injuries to people involved in crashes. Different insurance coverages pay for vehicle damage versus injuries, and different coverages may apply depending on who is at fault.

This study is based on collision coverage data. This coverage insures against physical damage to a driver's vehicle sustained in a crash with an object or other vehicle, generally when the driver is at fault. Because such claims are the most frequent for insurers, they provide the greatest power in looking at changes in crash frequency. In addition, because they represent the crashes of culpable drivers, they should be sensitive to changes in driving ability; although, they do not necessarily account for all crashes that might be attributable to marijuana use. For example, a driver under the influence of marijuana might crash into another vehicle that violates their right of way; the other person is at fault, but absent marijuana influence, the crash might not have occurred.

Rated drivers

HLDI collects a limited number of factors about rated drivers including age, gender, marital status, and garaging location. The rated driver is the one considered to represent the greatest loss potential for an insured vehicle. In a household with multiple vehicles and/or drivers, the assignment of drivers to vehicles can vary from insurance company to company and from state to state, but typically it reflects the driver most likely to operate the vehicle. Information on the actual driver at the time of a loss is not available in the HLDI database. In the current study, the data were stratified by rated driver age group (<25, 25–65, or 66+), gender (male, female, or unknown), marital status (married, single, or unknown), and registered vehicle density of garaging location (<50, 50–99, 100–249, 250–499, 500– 99, ≥1,000 registered vehicles per square mile).

External data

Unemployment: State monthly unemployment data were obtained from the Bureau of Labor Statistics. Unadjusted unemployment percentages were used.

Monthly mean temperature: State monthly mean temperatures, measured in degrees Fahrenheit, were obtained from the National Oceanic and Atmospheric Administration (NOAA) for January 2012 through October 2017 and were linked to HLDI loss data. Daily mean temperatures for states were unknown. Mean monthly temperatures were divided into two ranges: below freezing (<32 °F), and above freezing (32+ °F).

NOAA state monthly precipitation, measured in inches for January 2012 through October 2017, were also linked to HLDI loss data. The type of precipitation and number of days in a given month with measurable precipitation were not available. Temperature and precipitation were further used to create a proxy for the amount of snowfall—the amount of precipitation during months with average temperatures below freezing.

Tax data: State monthly tax revenues for marijuana retail sales were obtained from each respective state's department of tax revenue.

Study states

The three studied states with legal recreational marijuana sales are Colorado, Washington, and Oregon. Relevant law dates are summarized in **Table 2**.

Table 2: Key effective marijuana law dates

	Colorado	Washington	Oregon
Vote	November 2012	November 2012	November 2014
Retail sales	January 2014	July 2014	October 2015

Analysis method

Regression analysis was used to quantify the effect of changes in the legal status of marijuana on collision claim frequency while controlling for other factors that also varied with time. Collision claim frequency was defined as the number of collision claims divided by the number of insured vehicle years and was modeled using Poisson regression with a logarithmic link function.

Separate analyses were conducted for the states of Colorado, Washington, and Oregon. Each of these study states was compared with control states with no change in the legal status of marijuana. Control states were selected based on proximity to the study state as well as on the similarity of seasonal crash patterns prior to 2014. This similarity was based on the correlations between the monthly frequencies in the study state and each potential control state during the 24 months of 2012–13. The Pearson correlation coefficient for Colorado and Nebraska was 0.85; for Wyoming, 0.79; and for Utah, 0.60. For Washington, the states of Montana (0.67) and Idaho (0.63) were selected as controls. For Oregon, the states of Idaho (0.67) and Montana (0.83) were used. Nevada, which was used in the prior study, began retail marijuana sales in July 2017 and was therefore excluded as a control state for Oregon from this analysis.

The insurance data were stratified by vehicle age and vehicle type, rated driver age group, gender, marital status, garaging state, vehicle density, and calendar year and month. For example, a unit of observation was May 2012 collision exposure and claim count for 2007 model luxury SUVs, with young married males as rated drivers and vehicles garaged in an area of Idaho with a vehicle density of 50–99 vehicles per square mile. The characteristics of each stratum were treated as independent variables in the model to control for the effects on claim frequency of fluctuations in the demographic composition over time. The categorical month variable (i.e. January, February, etc.) controlled for seasonality. Monthly unemployment rate was also included to control for economic conditions. State average temperature and precipitation were used to control for weather differences independent of season. Finally, a categorical variable—legislation status—was used to track the change in marijuana's legal status, and the passing of time was represented by a monthly sequential variable.

The estimate for the month index variable represents the claim frequency trend for the study state. The estimates for the interactions between month index and state represent the differences between trends for the study state and each of the controls.

The effect of the law change in each study state (Colorado, Washington, Oregon) was compared with each of its controls individually and as a group. In the model comparing each study state with its controls individually, the interaction between garaging state and legislation status represents the change in collision claim frequency that occurred after marijuana retail sales began relative to the comparison state. This provides separate estimates for the study state compared with each of its control states. The model comparing each study state with its grouped controls included an additional variable called state type, which identified the data as being from either the study state or one of its controls. The interaction between legislation status and state type was used instead of its interaction with garaging state to estimate the effect on claim frequency of legalizing marijuana. Using state type instead of garaging state provides a single estimate for the study state compared with all its control states combined. The interaction estimates with p-values less than 0.05 indicate that the legalization of retail sales had a statistically meaningful effect on collision claim frequency in the study state. For space reasons, illustrative full regression results on Colorado collision claim frequency are shown in **Appendix A**.

This represents a slight change from the models used in the prior study. **Appendix B** discusses the modeling changes in further detail.

Combined analysis

In addition to the six models described previously, an analysis that combined Colorado, Washington, Oregon, and Nevada in a single dataset was also conducted. Idaho, Montana, Utah, and Wyoming served as controls. The four control states had statistically significant correlations of monthly claim frequencies with each of the four study states. This model was essentially the same as those described above except that a single variable was used to estimate the main effect instead of the interaction between state (or state type) and legislation status. This variable was based on both the month and the state, and equaled 1 only in the study states after the legislation took effect in that state.

Results

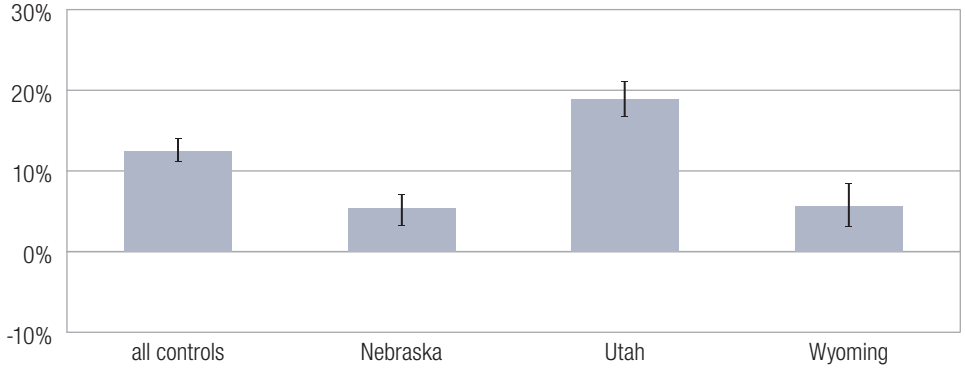
Single state analysis

The following figures (1–3) illustrate the estimated changes in collision claim frequency that are estimated to be associated with legalized recreational marijuana sales. A summary table (**Table 3**) at the end of the Results section contains the model estimates and regression details. **Figure 4** compares the current results with those of the prior analysis.

Colorado

Figure 1 shows the estimated effect of marijuana sales in Colorado, which began in January 2014. A significant 12.5 percent increase in collision claim frequency was estimated in Colorado compared with the three control states combined. Results vary when each individual control state is examined independently, with effects ranging from a 5.3 percent increase in Colorado compared with Nebraska to an 18.9 percent increase when compared with Utah. All the claim frequency increases were significant.

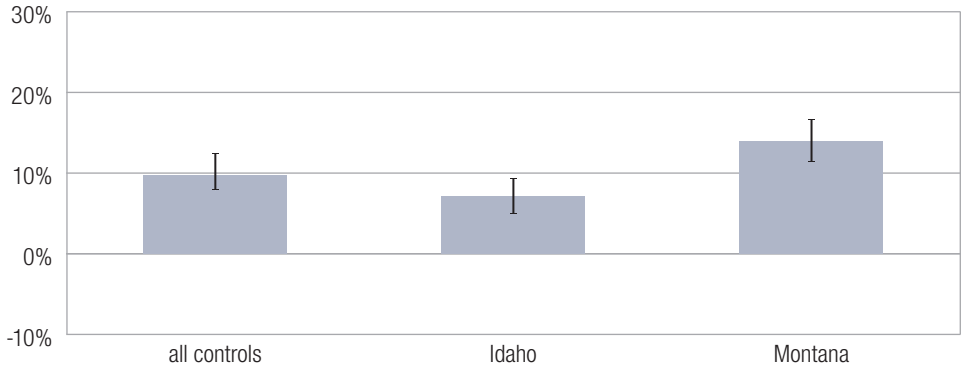
Figure 1: Estimated effect of marijuana sales on collision claim frequencies in Colorado



Washington

Figure 2 shows the estimated effect of marijuana sales in Washington, which began 6 months after Colorado. A significant 9.7 percent increase in collision claim frequency was estimated in Washington after retail sales began in July 2014 compared with the control states combined. When compared with Idaho and Montana individually, claim frequencies were also up by 7.1 and 14.0 percent, respectively. These increases were also statistically significant.

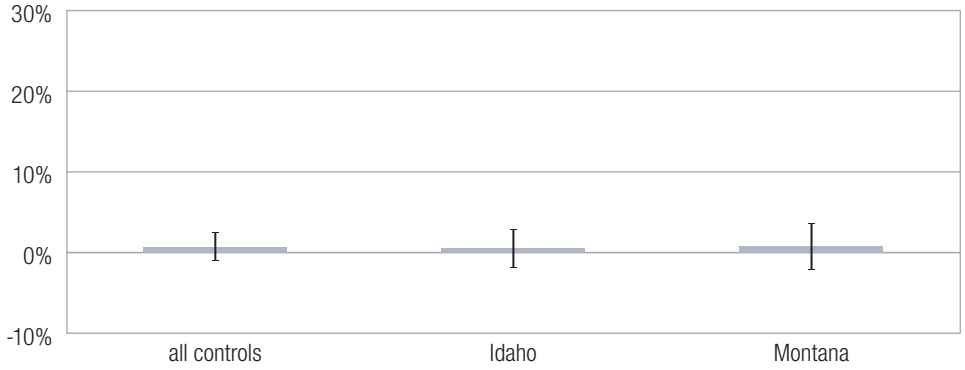
Figure 2: Estimated effect of marijuana sales on collision claim frequencies in Washington



Oregon

Oregon began retail sales of marijuana to the public in October 2015. **Figure 3** shows the estimated effect of legalizing marijuana sales in the state compared with two control states. Unlike Colorado and Washington, collision claim frequencies for Oregon show no statistically significant differences. Collision claim frequencies are less than 1 percent higher when compared with the control states combined. Effects are similar compared with each control state individually and range from a 0.5 percent increase compared with Idaho to a 0.9 percent increase compared with Montana. None of the results were statistically significant.

Figure 3: Estimated effect of marijuana sales on collision claim frequencies in Oregon



Combined analysis

A final analysis was completed that combined the loss results for Colorado, Washington, Oregon, and Nevada and four highly correlated control states in the west that included Idaho, Utah, Montana, and Wyoming. This analysis yielded a significant 6.0 percent increase in collision claim frequency for states that are currently legally selling recreational marijuana.

Table 3 summarizes the results across the different analyses.

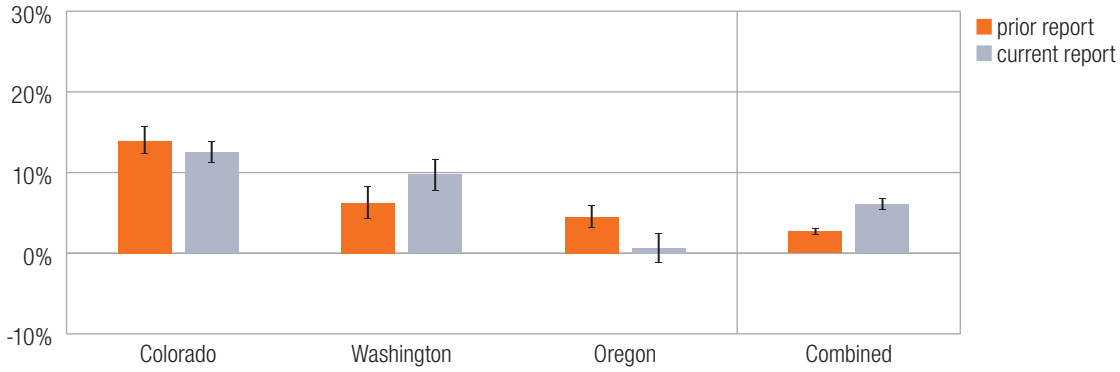
Table 3: Detailed results of regression analysis on collision claim frequencies

Study	Control	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	P-value
Colorado	Nebraska	0.0521	5.3%	0.0093	0.034	0.070	31.34	<0.0001
	Utah	0.1732	18.9%	0.0079	0.158	0.189	477.21	<0.0001
	Wyoming	0.0551	5.7%	0.0147	0.026	0.084	14.04	0.0002
	Nebraska, Utah, Wyoming	0.1178	12.5%	0.0066	0.105	0.131	323.06	<0.0001
Washington	Idaho	0.0684	7.1%	0.0108	0.047	0.090	40.16	<0.0001
	Montana	0.1311	14.0%	0.0131	0.106	0.157	100.84	<0.0001
	Idaho and Montana	0.0930	9.7%	0.0089	0.076	0.110	110.45	<0.0001
Oregon	Idaho	0.0053	0.5%	0.0111	-0.016	0.027	0.23	0.6295
	Montana	0.0086	0.9%	0.0131	-0.017	0.034	0.43	0.5125
	Idaho and Montana	0.0066	0.7%	0.0094	-0.012	0.025	0.49	0.4832
Colorado, Washington, Oregon, Nevada	Idaho, Montana, Utah, Wyoming	0.0581	6.0%	0.0024	0.053	0.063	569.97	<0.0001

Comparison with prior results

Figure 4 compares the current results with the results of the prior study. It should be noted that these results are not directly comparable, as some changes were made to the model used in the prior study. A more in-depth discussion of these changes and their impact on the results is contained in Appendix B. Additionally, the legal status of marijuana sales for Nevada changed in July 2017, which affects both the Oregon analysis and the combined analysis. Given these caveats, compared with prior results, the estimated effect of marijuana sales increased in Washington state, from 6.2 percent to 9.7 percent. However, the effect declined in both Colorado and Oregon compared with last year's results. The effect in Colorado declined from 13.9 percent to 12.5 percent and from 4.5 percent to 0.7 percent in Oregon.

Figure 4: Estimated effect of marijuana sales on collision claim frequencies



One key difference in the Oregon analysis was that Nevada was included as a control state in the prior analysis. However, Nevada began marijuana retail sales in July 2017 and consequently, is excluded as a control state from the current analysis. Figure 5 compares results for Oregon with and without Nevada as a control state, using loss data up until the month before Nevada retail sales began (i.e. June 2017). This shows that including or excluding Nevada as a control state had minimal impact on the overall results (4.6 percent versus 4.3 percent).

Figure 5: Estimated effect of marijuana sales on collision claim frequencies in Oregon through June 2017

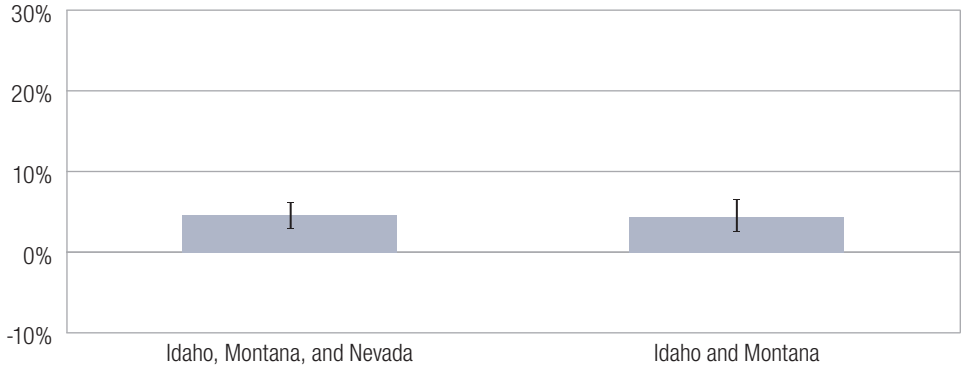
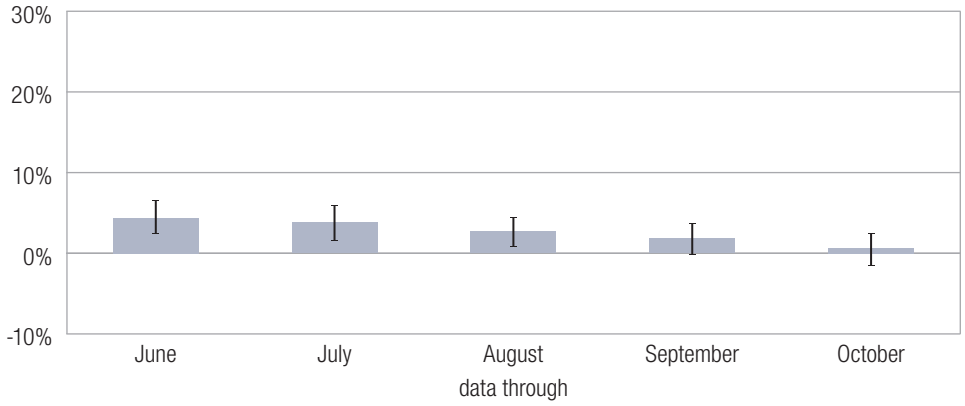


Figure 6 shows results over time for Oregon compared with Idaho and Montana. Using loss data through June 2017, the estimated effect of marijuana retail sales was 4.3 percent. However, this effect gradually diminishes with the inclusion of each additional month of data. By August 2017, the estimated effect had declined to 2.7 percent and by October 2017, the estimated effect had further declined to 0.7 percent.

Figure 6: Estimated effect of marijuana sales on collision claim frequencies in Oregon through listed month in 2017



Discussion

In January 2014, Colorado became the first state in the U.S. to legalize retail sales of marijuana for recreational purposes. Since then, voters in numerous states have moved to legalize recreational marijuana use. Currently nine states and the District of Columbia have legalized recreational marijuana use. Eight of those states either currently allow or plan to allow legal marijuana sales. As more states move toward legalizing recreational marijuana use, it is imperative to better understand how this may affect crash risk.

HLDI has been monitoring changes in collision claim frequency in states that legalized recreational sales since Colorado first began sales in 2014. Current results still indicate that the legalization of marijuana is associated with increases in collision claim frequencies. Results for both Colorado and Washington were statistically significant and consistent with prior results. Collision claim frequencies for Oregon, however, showed only a slight increase associated with the legalization of retail sales, and the result was not statistically significant. Results from the prior study showed a statistically significant increase in Oregon of 4.5 percent, but **Figure 6** shows that the effect in Oregon has been decreasing gradually with each month since June 2017.

Tax revenue data for marijuana sales in the three study states may provide one explanation for the diminished effect in Oregon. **Figures 7–9** show recent monthly marijuana tax revenue for Colorado, Washington, and Oregon. Oregon had the highest state marijuana tax rate at 17 percent compared with 15 percent in Colorado and only 6.5 percent in neighboring Washington. The pattern of tax revenue was also different for Oregon. Both Colorado and Washington exhibited a trend of increasing monthly tax revenues over time. Marijuana tax revenues in Oregon showed a similar pattern until October 2016, but since then revenues have fluctuated. The tax revenue data imply increasing marijuana sales in both Colorado and Washington, but the same does not appear to be true for Oregon.

Figure 7: Colorado marijuana retail tax revenue, February 2014–January 2018

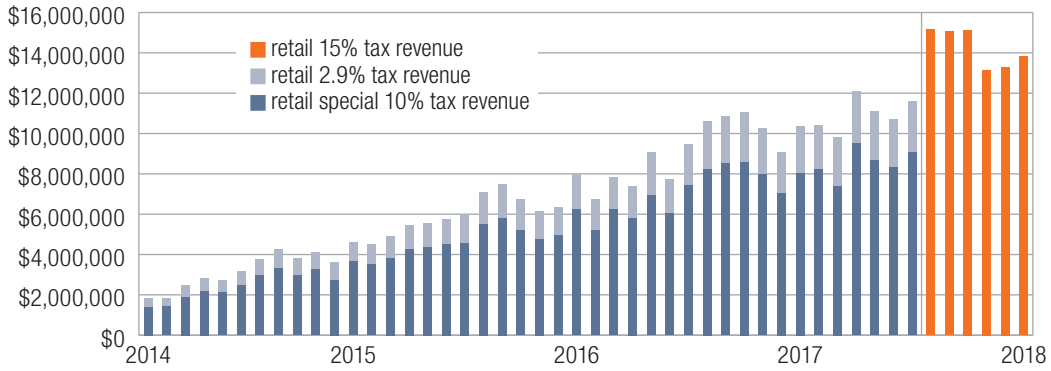


Figure 8: Washington marijuana retail tax revenue, July 2014–October 2017

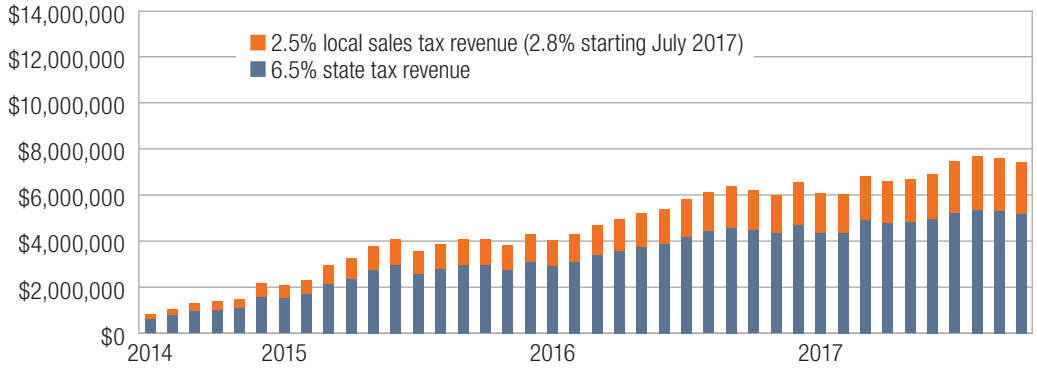
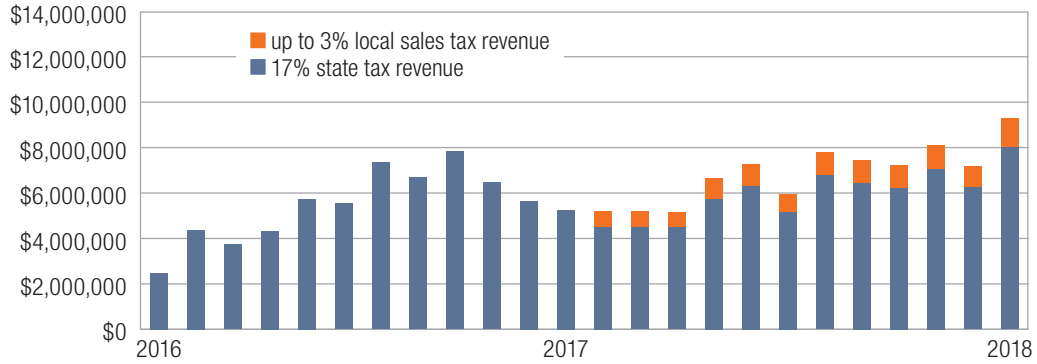


Figure 9: Oregon marijuana retail tax revenue, February 2016–January 2018



Although the current results for Oregon no longer exhibit a statistically significant difference, a single analysis that looked at Colorado, Washington, Oregon, and Nevada together still found a significant increase of 6 percent to collision claim frequencies associated with the legalization of recreational marijuana sales.

References

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Appendices

Appendix A: Illustrative regression results — collision frequency									
Parameter		Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	P-value
Intercept		1	-8.2915		0.0203	-8.3312	-8.2518	167643	<0.0001
Vehicle age	-1	1	-0.1243	-11.7%	0.0151	-0.1539	-0.0948	67.94	<0.0001
	0	1	0.0156	1.6%	0.0048	0.0062	0.0249	10.68	0.0011
	2	1	-0.0379	-3.7%	0.0041	-0.046	-0.0297	83.77	<0.0001
	3	1	-0.0731	-7.0%	0.0042	-0.0814	-0.0648	298.42	<0.0001
	4	1	-0.1072	-10.2%	0.0043	-0.1155	-0.0988	634.98	<0.0001
	5	1	-0.1399	-13.1%	0.0043	-0.1483	-0.1315	1063.29	<0.0001
	6	1	-0.1639	-15.1%	0.0043	-0.1723	-0.1555	1459.82	<0.0001
	7	1	-0.2032	-18.4%	0.0043	-0.2116	-0.1948	2245.74	<0.0001
	8	1	-0.2374	-21.1%	0.0043	-0.2458	-0.2290	3066.65	<0.0001
	9	1	-0.2914	-25.3%	0.0044	-0.3000	-0.2828	4455.42	<0.0001
	10	1	-0.3385	-28.7%	0.0045	-0.3473	-0.3297	5644.70	<0.0001
	11	1	-0.4007	-33.0%	0.0047	-0.4099	-0.3914	7158.19	<0.0001
	12	1	-0.4498	-36.2%	0.0050	-0.4597	-0.4399	7979.78	<0.0001
	13	1	-0.5001	-39.4%	0.0055	-0.5117	-0.4903	8423.85	<0.0001
	14	1	-0.5556	-42.6%	0.0061	-0.5675	-0.5437	8404.14	<0.0001
	15	1	-0.5970	-45.0%	0.0068	-0.6103	-0.5837	7716.43	<0.0001
	16	1	-0.6507	-47.8%	0.0079	-0.6662	-0.6352	6789.57	<0.0001
	17	1	-0.6805	-49.4%	0.0092	-0.6986	-0.6624	5426.49	<0.0001
	18	1	-0.7285	-51.7%	0.0110	-0.7500	-0.7070	4408.56	<0.0001
	19	1	-0.7840	-54.3%	0.0132	-0.8098	-0.7582	3537.91	<0.0001
	20	1	-0.8523	-57.4%	0.0159	-0.8833	-0.8212	2889.65	<0.0001
	21	1	-0.9209	-60.2%	0.0192	-0.9585	-0.8833	2303.23	<0.0001
	22	1	-0.9568	-61.6%	0.0224	-1.0008	-0.9128	1817.04	<0.0001
	23	1	-1.0357	-64.5%	0.0271	-1.0888	-0.9826	1461.92	<0.0001
	24	1	-1.0798	-66.0%	0.0318	-1.1422	-1.0174	1150.88	<0.0001
	25	1	-1.2307	-70.8%	0.0388	-1.3066	-1.1547	1008.66	<0.0001
	26	1	-1.2708	-71.9%	0.044	-1.3569	-1.1846	835.80	<0.0001
	27	1	-1.4088	-75.6%	0.0524	-1.5114	-1.3062	724.02	<0.0001
	28	1	-1.4374	-76.2%	0.0586	-1.5522	-1.3225	601.71	<0.0001
	29	1	-1.4857	-77.4%	0.067	-1.6171	-1.3543	491.28	<0.0001
	30	1	-1.5165	-78.1%	0.075	-1.6635	-1.3695	408.75	<0.0001
	31	1	-1.735	-82.4%	0.0921	-1.9155	-1.5545	355.01	<0.0001
	1	0	0	0	0	0	0		
Rated driver age group	<25	1	0.2939	34.2%	0.003	0.2881	0.2997	9897.82	<0.0001
	66+	1	0.0009	0.1%	0.0024	-0.0038	0.0056	0.15	0.7032
	25–65	0	0	0	0	0	0		
Rated driver gender	Male	1	-0.0276	-2.7%	0.0019	-0.0313	-0.0239	215.78	<0.0001
	Unknown	1	-0.2999	-25.9%	0.0059	-0.3114	-0.2883	2599.33	<0.0001
	Female	0	0	0	0	0	0		

Appendix A: Illustrative regression results — collision frequency									
Parameter		Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	P-value
Rated driver marital status	Single	1	0.2326	26.2%	0.0020	0.2286	0.2366	12975.20	<0.0001
	Unknown	1	0.1491	16.1%	0.0056	0.1381	0.1601	703.94	<0.0001
	Married	0	0	0	0	0	0		
Registered vehicle density	0–50	1	-0.3240	-27.7%	0.003	-0.3298	-0.3181	11810.20	<0.0001
	51–100	1	-0.2548	-22.5%	0.0032	-0.2611	-0.2485	6301.96	<0.0001
	101–250	1	-0.0495	-4.8%	0.003	-0.0554	-0.0435	265.56	<0.0001
	251–500	1	-0.1713	-15.7%	0.0028	-0.1769	-0.1658	3625.03	<0.0001
	501–1,000	1	-0.1116	-10.6%	0.0027	-0.1169	-0.1063	1702.59	<0.0001
	>1,000	0	0	0	0	0	0		
Vehicle type	luxury cars	1	0.4324	54.1%	0.0041	0.4243	0.4404	11076.60	<0.0001
	luxury SUVs	1	0.2498	28.4%	0.0046	0.2408	0.2587	2976.05	<0.0001
	nonluxury cars	1	0.314	36.9%	0.0027	0.3088	0.3192	13935.20	<0.0001
	nonluxury SUVs	1	0.093	9.7%	0.0029	0.0874	0.0986	1061.64	<0.0001
	pickups	0	0	0	0	0	0		
Unemployment		1	-0.0565	-5.5%	0.0032	-0.0628	-0.0503	314.04	<0.0001
Temperature range	00–31	1	0.0234	2.4%	0.0068	0.0102	0.0367	12.03	0.0005
	32+	0	0	0	0	0	0		
Precipitation		1	0.0545	5.6%	0.0037	0.0473	0.0617	220.75	<0.0001
State	Nebraska	1	-0.2146	-19.3%	0.0093	-0.2329	-0.1964	530.50	<0.0001
	Utah	1	-0.1868	-17.0%	0.0069	-0.2003	-0.1733	734.79	<0.0001
	Wyoming	1	0.0166	1.7%	0.0075	0.0018	0.0313	4.85	0.0276
	Colorado	0	0	0	0	0	0		
Legislation status		1	-0.0400	-3.9%	0.0052	-0.0502	-0.0298	58.89	<0.0001
Month index		1	-0.0067	-0.7%	0.0002	-0.0072	-0.0062	747.10	<0.0001
Month index x state	Nebraska	1	0.0056	0.6%	0.0003	0.0051	0.0062	439.07	<0.0001
	Utah	1	0.0068	0.7%	0.0002	0.0064	0.0072	958.16	<0.0001
	Wyoming	1	0.0054	0.5%	0.0003	0.0048	0.0061	269.78	<0.0001
	Colorado	0	0	0	0	0	0		
Month	January	1	-0.0051	-0.5%	0.0048	-0.0145	0.0042	1.15	0.2828
	February	1	0.0230	2.3%	0.0058	0.0116	0.0345	15.49	<0.0001
	March	1	-0.1057	-10.0%	0.0073	-0.1200	-0.0914	210.35	<0.0001
	April	1	-0.1616	-14.9%	0.0069	-0.1752	-0.1480	542.55	<0.0001
	May	1	-0.1537	-14.2%	0.0069	-0.1671	-0.1402	500.76	<0.0001
	June	1	-0.0999	-9.5%	0.0072	-0.1141	-0.0857	191.17	<0.0001
	July	1	-0.1521	-14.1%	0.0070	-0.1658	-0.1384	471.91	<0.0001
	August	1	-0.1458	-13.6%	0.0068	-0.1591	-0.1324	457.65	<0.0001
	September	1	-0.1693	-15.6%	0.0067	-0.1824	-0.1562	641.07	<0.0001
	October	1	-0.1794	-16.4%	0.0067	-0.1925	-0.1663	719.29	<0.0001
	November	1	-0.0754	-7.3%	0.0066	-0.0884	-0.0624	129.56	<0.0001
	December	0	0	0	0	0	0		
State type x legislation status		1	0.1178	12.5%	0.0066	0.1050	0.1307	323.06	<0.0001

Appendix B

Based on review and feedback of the 2017 HLDI study, several changes were made to the modeling methodology that was used in that study. This appendix summarizes the changes made and the impact they had on results.

Single state analysis

In the 2017 study, model year was used as a covariate. The current study uses vehicle age instead. Vehicle age was calculated as the difference between the calendar year and model year. Many manufacturers release new models in the calendar year prior to a vehicle's model year. For example, a vehicle's 2008 model year may be released during the 2007 calendar year. For the purposes of this analysis, such a vehicle is considered to have an age of -1 in calendar year 2007, 0 (zero) in calendar year 2008, 1 in calendar year 2009, etc. Vehicle age was determined to be a more appropriate and intuitive covariate than model year, particularly in studies that do not involve comparisons at the vehicle level.

In the 2017 study, a binary state type variable was used to differentiate between the study state and control states. This approach effectively combines all the control states together and treats them as a single entity. A single mean collision claim frequency and trend line is estimated for all the control states combined. However, differences (such as speed limits, laws, road conditions, etc.) between the control states still exist that may affect claim frequencies and are not controlled for by the other covariates in the model. To account for these differences, the current study uses discrete state values instead of the binary state type variable. This effectively allows each state in the analysis to have its own mean collision claim frequency estimate, and the interaction of state and month index allows each state its own trend line estimate.

The final methodology change in the single state analysis was made when comparing the study state with a single control state (i.e., Washington vs. Idaho or Washington vs. Montana). The approach of the 2017 study was to run separate models for each control state (i.e., a split sample approach). This approach only uses a subset of the data and allows all the covariate estimates to differ between the models for the same study state. The approach of the current study is to run a single model with all control states included. This approach leverages all the data available for a study state and its control states and results in a single estimate for each covariate.

Combined analysis

The model used in the current study adds a term for the interaction of month index and state. This effectively allows each state its own trend line estimate, instead of a single trend line used for all states.

Figures B1–B4 compare the results from the original study with results using the new methodology over the same time period as the original study (i.e., loss data through October 2016). Overall the results using the new methodology are consistent with the 2017 study over the same time period and do not change the primary findings of that study.

Figure B1: Estimated effect of marijuana sales in Colorado through October 2016

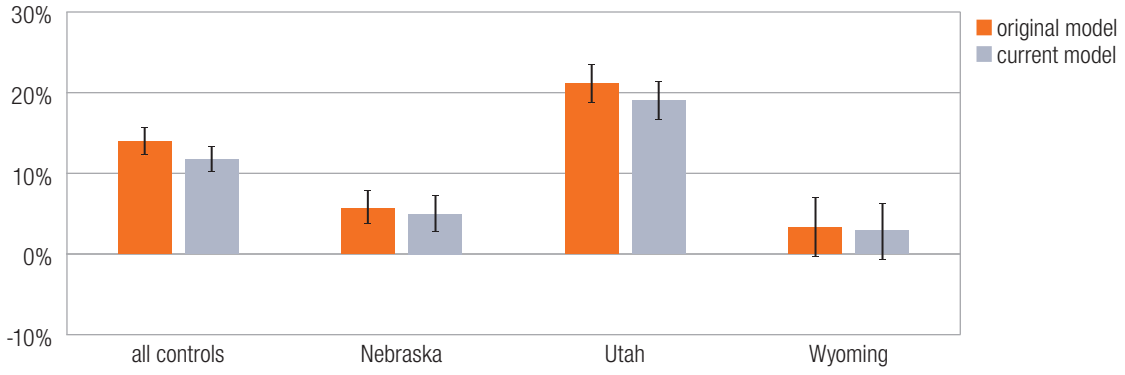


Figure B2: Estimated effect of marijuana sales in Washington through October 2016

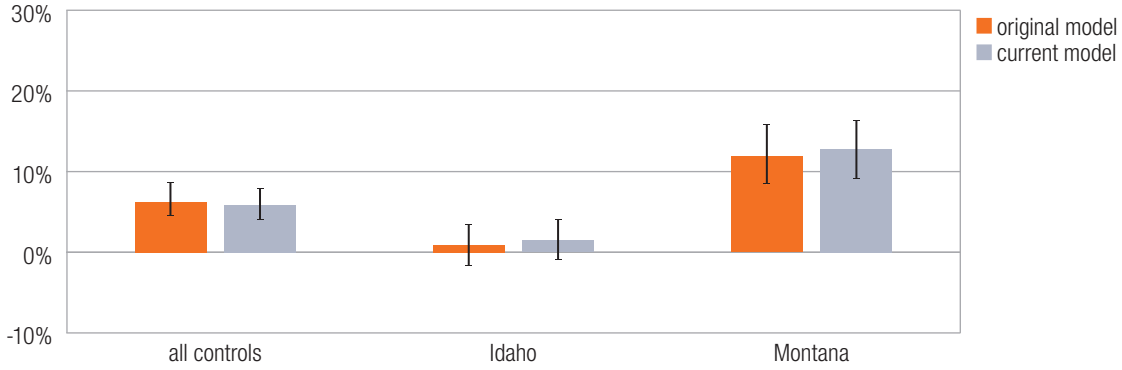


Figure B3: Estimated effect of marijuana sales in Oregon through October 2016

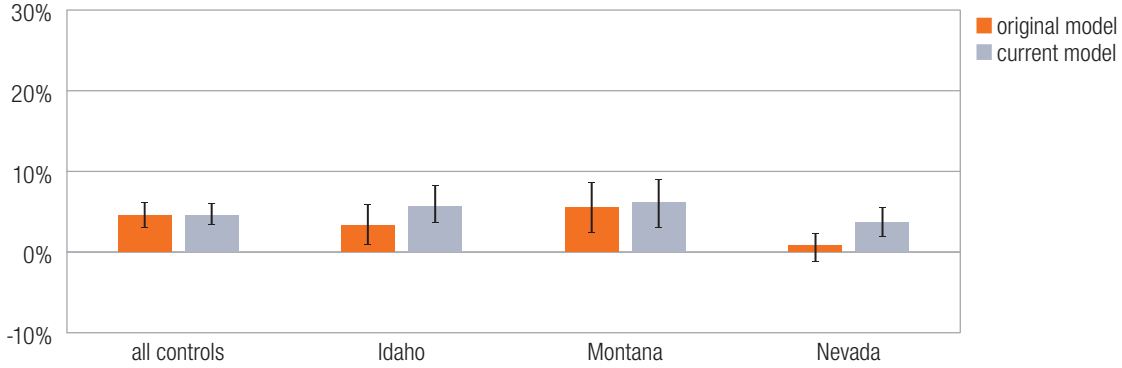
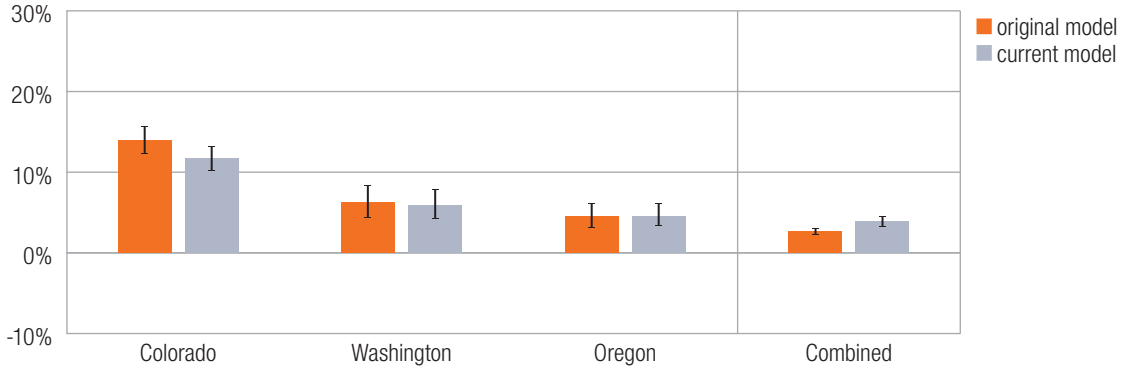


Figure B4: Estimated effect of marijuana sales through October 2016



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The Highway Loss Data Institute is a nonprofit public service organization that gathers, processes, and publishes insurance data on the human and economic losses associated with owning and operating motor vehicles. DW201804 NB