Received: 9 March 2021 | Revised: 7 April 2022 | Accepted: 15 May 2022

DOI: 10.1002/hec.4553

RESEARCH ARTICLE

Health Economics WILEY

Medical cannabis and automobile accidents: Evidence from auto insurance

Cameron M. Ellis[1] | **Martin F. Grace**[1] | **Rhet A. Smith**[2] | **Juan Zhang**[3]

[1]Fox School of Business, Temple University, Philadelphia, Pennsylvania, USA

[2]University of Arkansas at Little Rock, Little Rock, Arkansas, USA

[3]College of Business, Eastern Kentucky University, Richmond, Kentucky, USA

Correspondence
Cameron M. Ellis, Fox School of Business, Temple University, Philadelphia, PA, USA.
Email: Cameron.Ellis@temple.edu

Abstract

While many states have legalized medical cannabis, many unintended consequences remain under-studied. We focus on one potential detriment–the effect of cannabis legalization on automobile safety. We examine this relationship through auto insurance premiums. Employing a modern difference-in-differences framework and zip code-level premium data from 2014 to 2019, we find that premiums declined, on average, by $22 per year following medical cannabis legalization. The effect is more substantial in areas near a dispensary and in areas with a higher prevalence of drunk driving before legalization. We estimate that existing legalization has reduced health expenditures related to auto accidents by almost $820 million per year with the potential for a further $350 million reduction if legalized nationally.

KEYWORDS
auto safety, automobile insurance, Cannabis, dispensary, insurance pricing

JEL CLASSIFICATION
G22, G28, I18, K42, P37

1 | INTRODUCTION

The legal status of cannabis has changed dramatically over the past 2 decades. Although illegal at the federal level, the approval of Proposition 215 in California in 1996 started a trend that has seen cannabis legalized for medical purposes in 36 states. State medical cannabis laws provide legal protection to the Cannabis market and are associated with greater cannabis consumption (Choi et al., 2019). While most Americans favor legalized medical cannabis (Daniller, 2019), much of the potential public detriment remains under-studied. In this article, we focus on one potential detriment–the effect of increased cannabis access on auto safety. Cannabis is a psychoactive drug that impairs psychomotor skills and negatively affects driving ability.[1] Thus, traffic safety may be adversely affected as more states implement medical cannabis laws.

However, the effect of medical cannabis laws on traffic safety is complicated by the relationship of cannabis to other intoxicating substances. For instance, alcohol is the most commonly detected substance in traffic crashes, and the dangers of drunk driving are well documented. If cannabis and alcohol are economic substitutes, as suggested by Chaloupka and Laixuthai (1997) and Anderson et al. (2013), lowering the absolute price of cannabis by reducing legal restrictions could reduce alcohol-related crashes and lead to net improvements in traffic safety.[2] Medical cannabis laws also reduce travel incentives by restricting cannabis consumption to a private residence. Some cannabis dispensaries also offer delivery services, further reducing the incentives for cannabis consumers to travel. Reduced travel limits the exposure to the risk of being involved in a traffic crash. Thus, traffic conditions may improve following medical cannabis legalization due to diminished travel incentives among cannabis consumers (Cook et al., 2020).

Because of data availability, the extant literature on the effects of cannabis liberalization on traffic safety primarily focuses on fatal crashes. Using fatality data is a significant shortcoming. In 2016, only 37,461 of the approximately 7,277,000 auto accidents reported to the police involved a fatality (NHTSA, 2016). The existing literature misses over 99.5% of auto crashes. We instead approach the question through a different avenue–the direct effect of medical cannabis legalization on auto insurance premiums. Auto insurers cover 67% of all medical and property damage from automobile accidents (Blincoe et al., 2015). Through this lens, we paint a more comprehensive picture.

We use three identification strategies to estimate the effect of medical cannabis legalization on auto insurance premiums. Our first specification uses zip code-level data on auto insurance premiums. We exploit the variation in medical cannabis dispensary presence at the state level and estimate a modern difference-in-differences model. Our second strategy combines our zip code-level premium data with hand-collected data on the location and opening dates of medical cannabis dispensaries. We estimate a heterogeneous treatment difference-in-differences model where we classify zip codes near a dispensary as our "heavily-treated" group, zip codes in states that legalize but are far from dispensaries as our treated group, and zip codes in states that never legalize as of 2019 as our control group. Our final identification source lies in a quirk of medical cannabis laws (but not recreational)–one needs to be a resident of the state in order to acquire a medical cannabis card.[3] This creates a sharp geographic discontinuity in policy at the state border that coincides with a sharp geographic discontinuity in auto insurance rate setting while maintaining a similar driving environment.[4] We exploit this geographic discontinuity by comparing paired collections of zip codes near the state border in a difference-in-differences design.[5]

Consistent with an improvement in traffic safety, we find that the legalization of medical cannabis leads to a decrease in auto insurance premiums on average of $22 per policy per year. The effect is stronger in areas directly exposed to a dispensary, suggesting increased access to cannabis drives the results. In addition, we find relatively large declines in premiums in areas with relatively high drunk driving rates prior to medical cannabis legalization. This latter result is consistent with substitutability across substances that is argued in the literature.

This paper contributes to the growing literature on the positive spillover effects of medical cannabis legalization and provides an additional channel through which medical cannabis laws reduce medical expenses. For instance, Sabia et al. (2017) suggest a medical cannabis law-induced savings on obesity-related medical expenses of $58 to $115 per person, while Bradford and Bradford (2018) estimate the savings from reduced prescription drug use among Medicare Part D enrollees could be as high as $639 million annually by 2015. Likewise, Choi et al. (2019) argue the substitution away from tobacco following medical cannabis legalization generates savings in tobacco-related healthcare spending of $4.6 to $6.9 billion per year. While the aggregate effect on auto insurance premiums is not as large as some of the aforementioned studies, the savings are nontrivial. For policyholders in our switching states, we estimate an annual reduction in premiums of $500 million. Using a ratio of attributable expenses from premiums, the annual savings attributable to reduced medical expenses is roughly $220 million.[6]

We also contribute to a greater understanding of the factors influencing auto safety and insurance pricing. Our focus on auto insurance can examine the effect on a majority of auto accidents, rather than the 0.5% that result in fatalities. We find that the legalization of medical cannabis leads to a decrease in auto accident premiums primarily through the reduced cost of accidents. While our policy level impacts are quite small, the scale of the auto insurance industry means they have a large economic impact. For context, our estimates are about half of the estimated impact of handheld-device bans (Karl & Nyce, 2017) and about 25% of the impact of repealing no-fault insurance laws (Heaton, 2017).

2 | INSTITUTIONAL DETAILS

The prohibition of cannabis in the United States dates back to the 1930s. The classification of cannabis as a Schedule I drug in the Controlled Substances Act of 1970 reinforced the illegality of the drug and influenced cannabis-related legislation and policies for the next 50 years.[7] State medical cannabis laws contradict the federal prohibition by legally allowing patients to possess cannabis with doctor approval. The first states to enact such laws were primarily on the west coast in the late 1990s. While these early laws provided legal protection for patients with qualifying medical conditions, they did not ensure access to medical cannabis. In many states, inadequate access and a lack of dispensaries stymied the growth of the legal market.

In 2009, the US Department of Justice issued new guidance to US Attorneys in states where cannabis was legal. The new guidance, called the Ogden Memorandum, facilitated the expansion of the legal cannabis market.[8] It stated that federal funds would not be used to prosecute those in compliance with state medical cannabis laws. Multiple counties and states witnessed their first dispensaries at this time (Anderson & Rees, 2014; Smith, 2020). Similarly, Smart (2015) documents the low number of registered medical cannabis patients before 2009 and the subsequent growth in the patient levels following the Ogden Memorandum.

As a follow up to the Ogden Memorandum, the Cole Memorandum in 2013 solidified the role of dispensaries in legal cannabis markets.[9] This more recent federal memorandum specified that enforcement of federal cannabis prohibition would not be a priority in state markets where regulations were in place to prevent diversion, distribution to minors, or revenue to criminal enterprises. Therefore, if a dispensary operates within the provisions set forth by the state, it can operate unperturbed by law enforcement. All medical cannabis laws passed after 2013 include provisions concerning dispensaries and how the drug may be acquired or distributed.

The timing between medical cannabis law enactment and dispensary opening can vary considerably across states. For example, states such as Arkansas and Maryland passed medical cannabis laws after the issuance of the 2013 Cole Memorandum but did not provide a structure for dispensaries to open. Maryland, whose medical cannabis law passed in 2014, did not begin registering patients until 2017, when the first dispensary was scheduled to open.[10] Similarly, nearly 3 years after Arkansas passed its medical cannabis law in 2016 (and shortly after the first Arkansas dispensary opened), only 9830 patients were registered and able to legally consume the drug.[11] Therefore, dispensaries are a critical feature in late-adopting medical cannabis laws.

Absent of dispensaries, cannabis can only be acquired through caregivers, self-cultivation, or gray market transactions. Each of these alternatives is associated with additional non-pecuniary costs such as search, safety, and quality concerns borne by the consumers. Therefore, because dispensaries provide immediate access to cannabis and are associated with increased cannabis consumption (Freisthler & Gruenewald, 2014; Pacula et al., 2015), we focus on the variation in exposure to medical cannabis dispensaries when examining the effect of cannabis liberalization on traffic safety.

We define a state as "legalized" when it both has a medical cannabis dispensary in operation and medical cannabis is legally allowed.[12] Table 1 shows the timeline of medical cannabis laws in the United States. Our identification is based on the states in bold, which are the switching states in our analysis that legalized medical cannabis from 2016 to 2019.

Prohibition is a supply-side constraint that increases the non-pecuniary costs of a good (Thornton, 2007). Medical-use cannabis laws and dispensary access relax this constraint, leading to a decrease in absolute price (Anderson et al., 2013) and an increase in consumption (Cerdá et al., 2012; Choi et al., 2019; Chu, 2014; Pacula et al., 2015; Wen et al., 2015). Liberalization potentially affects traffic safety because cannabis impairs cognitive and psychomotor skills, and acute usage can significantly increase the risk of motor vehicle collisions in controlled trials (Bondallaz et al., 2016; Ramaekers et al., 2004). Thus, by decreasing non-pecuniary costs, increased access to cannabis should increase the risk of traffic crashes, *ceteris paribus* (Asbridge et al., 2012; Hartman and Huestis, 2013).

Life is not *ceteris paribus*. In our case, this is due to the relationship between cannabis and other factors that affect traffic safety. The real effect of medical cannabis laws on traffic safety is theoretically ambiguous for a number of reasons. First, medical Cannabis laws restrict consumption to a private residence, thus reducing travel and limiting exposure to the risk of being involved in a traffic crash. Cook et al. (2020) argue this mechanism is a significant contributor to traffic safety improvement following medical cannabis legalization. Further, Santaella-Tenorio et al. (2017) find that states which enact medical cannabis laws are associated with lower traffic fatality rates than states without medical cannabis laws, with immediate reductions occurring in fatality rates for those aged 15–24 and 25–44.[13]

Second, cannabis consumption may be a substitute for other intoxicating substances. For instance, Baggio et al. (2020) and Anderson et al. (2013) find that legalization of medical cannabis directly lowers the demand for alcohol. Anderson et al. (2013) further show that medical cannabis laws are associated with fewer alcohol-related deaths. Similarly, Smart (2015) argues that greater cannabis access decreases traffic crash mortality in the aggregate but increases traffic fatalities caused by drivers aged 15–20 who cannot drink alcohol legally. In addition to alcohol, recent literature also suggests a substitution effect between cannabis and opioids (McMichael et al., 2020; Powell et al., 2018). Kim et al. (2016) find reductions in opioid-positive test rates of deceased drivers following the implementation of medical cannabis laws. Thus, the substitutability of cannabis for other substances could lead to a net improvement in traffic safety.

Last, driving simulation studies suggest safety is a complement to driving under the influence (DUI) of cannabis. Cannabis-impaired drivers tend to employ compensatory strategies such as decreasing speed and allowing for greater headway distances (Sewell et al., 2009).[14] The opposite is true of alcohol, however, and the combination of cannabis and alcohol can have additive or multiplicative effects on impairment (Chihuri et al., 2017; Ramaekers et al., 2004; Sewell et al., 2009). If cannabis and alcohol are economic complements, as suggested by Wen et al. (2015), then medical cannabis legalization could adversely affect traffic safety. Therefore, the real effect of medical cannabis legalization on traffic safety is *ex-ante* ambiguous and primarily determined by the relationship of cannabis to other factors in the accident production function.

TABLE 1 Timeline of medical cannabis laws

State	Law passed	Law beginning	First dispensary opened	State	Law passed	Law beginning	First dispensary opened
Alabama	-	-	-	Montana	2004	2004	2009
Alaska	1998	1999	2016[a]	Nebraska	-	-	-
Arizona	2010	2010	2012	Nevada	2000	2001	2009
Arkansas	**2016**	**2016**	**2019**	**New Hampshire**	**2013**	**2013**	**2016**
California	1996	1996	1996	New Jersey	2010	2010	2012
Colorado	2000	2001	2005	New Mexico	2007	2007	2009
Connecticut	2012	2012	2014	**New York**	**2014**	**2014**	**2016**
District of Columbia	2010	2010	2013	North Carolina	-	-	-
Delaware	2011	2011	2015	**North Dakota**	**2016**	**2016**	**2019**
Florida	**2016**	**2017**	**2016**[b]	**Ohio**	**2016**	**2016**	**2019**
Georgia	-	-	-	**Oklahoma**	**2018**	**2018**	**2018**
Hawaii	2000	2000	2019	Oregon	1998	1998	2009
Idaho	-	-	-	**Pennsylvania**	**2016**	**2016**	**2018**
Illinois	2013	2014	2015	Rhode Island	2006	2006	2013
Indiana	-	-	-	South Carolina	-	-	-
Iowa	-	-	-	South Dakota	2020	2021	-
Kansas	-	-	-	Tennessee	-	-	-
Kentucky	-	-	-	Texas	-	-	-
Louisiana	**2016**	**2016**	**2019**	Utah	2018	2018	2020
Maine	1999	1999	2011	Vermont	2004	2004	2013
Maryland	**2014**	**2014**	**2017**	Virginia	-	-	-
Massachusetts	2012	2013	2015	Washington	1998	1998	2009
Michigan	2008	2008	2009	West Virginia	2017	2019	-
Minnesota	2014	2014	2015	Wisconsin	-	-	-
Mississippi	2020	2021	-	Wyoming	-	-	-
Missouri	2018	2018	2020				

Note: For each state, we describe the year a medical cannabis law was passed, the year it went into effect, and the year the first known dispensary opened in the state. Switching states are in bold. Alaska, the District of Columbia, and Hawaii are excluded from the analysis throughout this paper.

[a]The first legal and active dispensary opened in Alaska after the state legalized recreational use.

[b]Florida dispensaries first opened in July 2016 under a "right-to-try" law for terminally ill patients.

3 | DISCUSSION OF DATA

We use two levels of automobile insurance data. Our analysis is primarily based on zip code-level survey data on auto insurance premiums from the S&P Global Market Intelligence database. We also use auto insurers' financial data at the firm-state level from the National Association of Insurance Commissioners (NAIC) for additional analysis in the Appendix.

3.1 | Survey and dispensary data

Our primary dataset is a yearly market research survey conducted by Nielsen and available through the S&P Global Market Intelligence Platform. The zip code-level survey data contain the average annual premium per household for automobile insurance in the zip code, the number of households with automobile insurance, and the number of households purchasing auto insurance from each of the top 17 major auto insurers.[15] The survey also contains a number of demographic variables calculated from the American Community Survey.[16] For the geographic discontinuity approach, we obtain pairs of near zip-codes that cross the state borders for switching states.[17] Our zip code-level sample spans from 2014 to 2019, and we examine the switching states that legalized medical cannabis from 2016 to 2019.

Table 2 provides the univariate summary statistics. The first column covers the full sample. The second column subsets the data to zip codes in the period before they legalize. The third column subsets the data to zip codes in the period they legalize. The fourth column reports the difference and statistical significance of the second and third columns.

The first observation is that, in a univariate setting, the average auto insurance premium increases by around $20 after zip codes legalize medicinal cannabis–the opposite direction of our multivariate results. We are also concerned if any of our control variables seem to move in tandem with legalization. While we find a number of our control variables statistically and significantly different pre- and post-expansion, most are minor economic differences. In particular, the average age decreases after legalization. Absent other effects, this would lead to an increase in auto insurance premiums and may explain the univariate increase.

The timeline of medical cannabis laws for each state is obtained from ProCon.org (2020). Within each medical cannabis state, we rely on previous literature to first identify state-level dispensary presence in early-adopting states (Pacula et al., 2015; Smith, 2020). Because all medical cannabis laws enacted after 2013 include provisions for dispensary operations, all dispensaries that open during our sample period are subject to state-level licensing and regulations.[18] This "legal and active" definition is important as it limits measurement error in the dispensary variable and maintains consistency with other studies (Pacula et al., 2015; Powell et al., 2018). We use three sources to identify the year when the first licensed dispensary opened in each state: (1) online news articles, (2) Appendix Table A1 provided by Powell et al. (2018), and (3) Table 1 of Lebesmuehlbacher and Smith (2021). We allow for partial treatment in the year of opening. In other words, if the first dispensary in a state opens in March, the treatment variable for that year would be 0.75.

While state-level variation allows us to compare across-state effects of medical cannabis legalization, it does not account for within-state changes in exposure to a dispensary. We match our zip code-level insurance survey data with hand-collected data on medical cannabis dispensary locations to exploit the within-state variation in dispensary access. Dispensary information is obtained from a web scraping of dispensary listings registered on Weedmaps.com as of 2019.[19] Weedmaps.com helps consumers locate cannabis businesses by providing dispensaries a cost-free way to advertise business name and location, product availability, contact information, and hours of operations. The registry is cross-referenced with state registries when possible. Because there is no official national registry of cannabis dispensaries, there is potential for measurement error from incorrect opening dates or dispensaries that may have closed. However, measurement error in the dispensary variable is mitigated by the strict licensing requirements needed for a dispensary to open during our sample period and the availability of state official sources to corroborate dispensary presence observed in the Weedmaps.com directory. Moreover, because it is more likely that dispensary operations are missed rather than non-dispensary areas being classified as "treated," any measurement error in the dispensary variable would bias the results toward zero and make our estimated effects on traffic safety conservative.

TABLE 2 Summary statistics: All zips

	(1)		(2)		(3)		(4)	
	Full sample		Pre-treatment		Post-treatment		Difference = (3) − (2)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Diff.	t
Unemployment rate	8.07	4.61	8.04	3.84	8.24	4.81	0.20	3.61
Average age	41.49	6.48	42.38	6.39	41.99	6.79	−0.39	−4.49
Population density	53,618	21,448	61,858	23,100	59,147	23,527	−2711	−8.83
Average income	1294	5154	2319	8530	2088	7282	−231.38	−2.17
Average premium	1245	142.35	1310	150.17	1331	152.82	21.53	9.23
Num. Under 25	632.25	932.85	620.94	823.14	639.70	866.39	18.76	1.44
Num. Insured	3789	5117	4063	5235	4048	5304	−15.03	−0.19
log(Registered patients)	2.66	4.74	4.29	4.04	6.11	5.20	1.82	30.39
N	268,879		9457		14,591		-	

Note: This table presents summary statistics for all of the zip codes in our data. Additionally, the latter columns subset the treated zip codes by pre-treatment versus post-treatment.

3.2 | Other data

The size and structure of legal cannabis markets vary significantly across states. To account for this heterogeneity, we also hand-collected the number of medical cannabis registered patients from 2013 to 2019. A registered patient is a person who has applied and been approved by a doctor to purchase and consume cannabis for medical purposes legally.[20] We searched for patients' statistics on each state's medical cannabis program page, which is often under the state's department of health website. These programs provide medical cannabis statistics reports weekly, monthly, or annually; we look for the number of qualifying patients as of the latest date of the year.[21]

To capture the changes in driver alcohol usage and in DUI after medical cannabis legalization, we use the count of DUI arrests from the Federal Bureau of Investigation's (FBI) Uniform Crime Reports (UCR) that are available from 2009 to 2016 (Federal Bureau of Investigation, 2009-2016).[22] UCR reports provide the county-level, monthly data on the number of arrests due to DUI offenses. While widely used in crime literature, the UCR data are limited in that arrest counts are not equivalent to offenses, and not all agencies participate in the UCR database. Still, we believe that this administrative data provide a reliable proxy for the level of drunk driving in a given zip code before medical cannabis legalization.

4 | METHODS AND RESULTS

4.1 | Full sample analysis

Our first approach uses a staggered difference-in-differences model for all zip codes in the contiguous United States. This identification is based on the treatment of Florida, New Hampshire, and New York in 2016; Maryland in 2017; Oklahoma and Pennsylvania in 2018, and Arkansas, Louisiana, North Dakota, and Ohio in 2019. Figure 1 shows the treatment year for each state. The switching states are colored based on their treatment year. The white states are those that legalized before 2016 (denoted by "Always Treated").[23] The white states with an asterisk are the states that have not legalized as of the end of 2019 (denoted by "Never Treated"). Consistent with modern difference-in-differences approaches, the always treated states are omitted from our analysis.

Recent work on two-way fixed effects style difference-in-differences has shown that a violation of the stable treatment effect assumption will bias the non-event study estimates (Goodman-Bacon, 2021). The bias stems from the model deriving identification from the comparison of switching units with always treated units. If the treatment effect is not stable, either growing or shrinking over time, then this dynamic effect will be interpreted as an underlying trend and will bias the results.

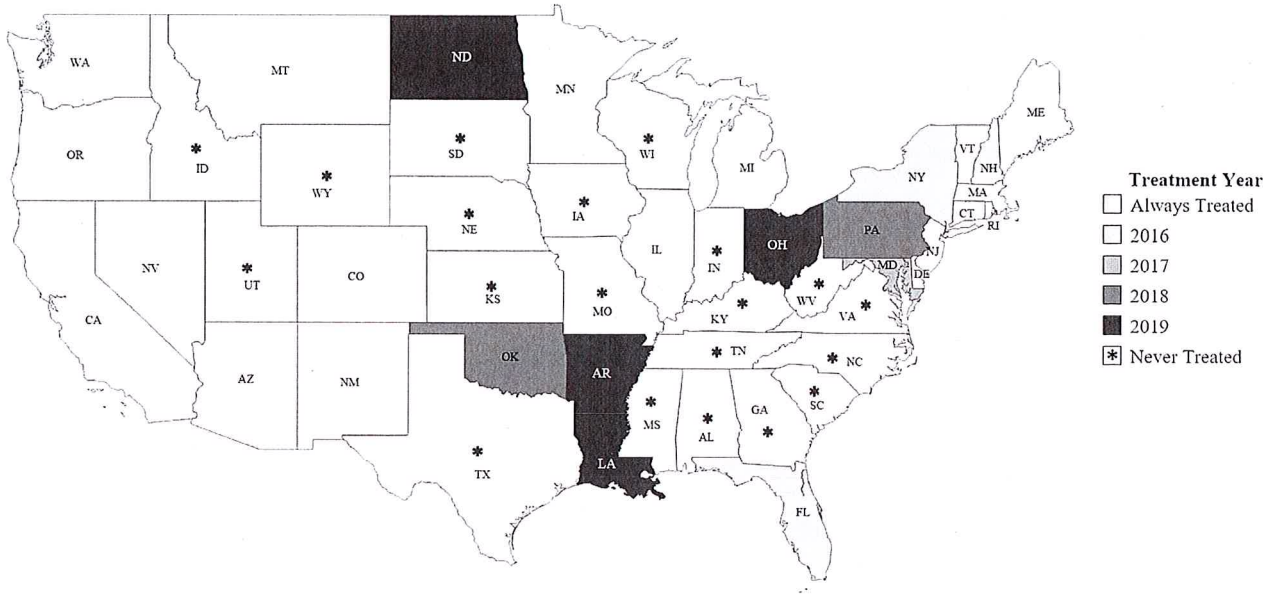

FIGURE 1 Map of medical cannabis legalized states. Only "Never Treated" states are used as our control group

Several recent papers have developed methods to overcome this limitation (Athey et al., 2021; Borusyak et al., 2021; Callaway & Sant'Anna, 2020; Gardner, 2021; Jakiela, 2021). A common feature of all of these approaches is limiting the identifying variation to only treated versus not treated units. To isolate this comparison, we use the two-stage difference-in-differences approach of Gardner (2021).[24] This approach consists of four steps: (1) Fit a two-way fixed effects model, without the treatment variables, on all of the untreated unit-years.[25] (2) Use the fitted model to predict the counterfactual, potential not-treated outcome for all of the treated unit-years $\left(\widehat{y_{zt}^0}\right)$. (3) Take the difference between the predicted outcome and the actual outcome to get unit-time specific treatment effects. (4) Regress the unit-specific treatment effects on the treatment variables. Specifically, we estimate:

$$y_{zt}^0 = x_{zt}'\alpha + \theta_z + \tau_t + State_s * t + \epsilon_{zt} \tag{1}$$

$$y_{zt}^1 - \widehat{y_{zt}^0} = \beta_1 Medical\_Cannabis_{st} + \nu_{zt} \tag{2}$$

$$y_{zt}^1 - \widehat{y_{zt}^0} = \beta_1 ln(Registered\_Patients_{st}) + \nu_{zt} \tag{3}$$

$$y_{zt}^1 - \widehat{y_{zt}^0} = \beta_1 Medical\_Cannabis_{st} + \beta_2 Medical\_Cannabis_{st} * DUI_{z,2013} + \nu_{zt} \tag{4}$$

$$y_{zt}^1 - \widehat{y_{zt}^0} = \beta_1 Medical\_Cannabis_{st} * Smoking_s + \beta_2 Medical\_Cannabis_{st} * (1 - Smoking_s) + \nu_{zt} \tag{5}$$

where Equation (1) is estimated using only the never-treated units, and Equations (2)–(5), which are estimated as separate regressions, are estimated using all of the units. The dependent variable y_{zt} is the average annual auto insurance premium for zip code z in year t, x_{zt} is a vector of zip code-level controls (inclusive of an intercept), $State_s * t$ are state-specific time trends, and θ_z and τ_t are zip code and year fixed effects. $Medical\_Cannabis_{st}$ is a "binary" treatment variable for when state s legalizes medical cannabis[26]; $ln(Registered\_Patients_{st})$ is a continuous treatment variable and is the log of the number of registered medical cannabis patients in state s in year t. In Equations (4) and (5) we examine whether the effects of medical cannabis legalization on auto insurance premiums differ in areas with higher rates of DUI arrests ($DUI_{z,2013}$) and whether the state allows smoking as a method of consumption ($Smoking_s$).[27] Last, ϵ_{zt} and ν_{zt} are the mean-zero error terms. Because our treatment is applied at the state level, standard errors for all models presented are clustered by state.

For zip code-level controls, we include demographic variables of the median age of the population (*Median Age*), the number of insured drivers in the zip code (*Number Insured*), the unemployment rate of the population aged 16 and over (*Unemployment*), and the median household income in dollars (*Median Household Income*). *Drivers Under 25 on Policy* is the number of households in each zip code whose auto insurance policy covers one or more drivers under the age of 25. Insurance firm prevalence controls are the number of households in each zip code whose primary auto insurance policy is through one of the major auto insurers.

The results of our all zip code analysis (Equations (2)–(5)) are presented in Table 3. The first column of Table 3, which uses the binary treatment variable, shows that legalizing medical cannabis reduces average annual auto insurance premiums by $22.[28] The second column of Table 3 uses the log of the number of registered patients as a continuous treatment. We find that increasing the number of registered users by 1% decreases auto insurance premiums by $2.00 per year. Because auto insurance premiums are largely driven by costs, these results imply that legalizing cannabis has a positive impact on auto safety.[29]

The third column of Table 3 interacts the binary treatment variable with the number of DUI arrests per capita in 2013. We find the negative effect of legalization on premiums is $10 higher in areas that had relatively more issues with drunk driving before legalization. In the fourth column of Table 3, we examine whether the effect is more pronounced in states with rules that allow for smoking as a method of consumption.

We find the effects are larger and more precisely estimated in states that allow for smoking. States that prohibit smoking as a method of consumption tend to have more medicalized and restrictive markets. These characteristics correlate with lower patient enrollment (Williams et al., 2016). Thus, the results in column (4) of Table 3 are consistent with the results in column (2) and suggest the effects in column (1) are largely driven by states that allow for smoking as a method of consumption.

TABLE 3 All zip models

	Dependent variable			
	Annual premiums			
	(1)	(2)	(3)	(4)
Medical Cannabis legalization	−22.409** (11.306)		−29.667 (21.800)	
ln(Registered patients)		−2.034** (1.026)		
Medical Cannabis legalization * $\ln(DUI_{2013}+1)$			−10.170* (6.087)	
Medical Cannabis legalization * smoking allowed				−54.483*** (18.535)
Medical Cannabis legalization * smoking not allowed				−0.561 (17.786)
Median age	−0.062 (0.728)	−0.062 (0.728)	−0.062 (0.728)	−0.062 (0.728)
Number insured	−0.006 (0.004)	−0.006 (0.004)	−0.006 (0.004)	−0.006 (0.004)
Unemployment	−2.421*** (0.150)	−2.421*** (0.150)	−2.421*** (0.150)	−2.421*** (0.150)
Median household income	−0.003 (0.008)	−0.003 (0.008)	−0.003 (0.008)	−0.003 (0.008)
Drivers under 25 on policy	0.013*** (0.004)	0.013*** (0.004)	0.013*** (0.004)	0.013*** (0.004)
Insurance firm prevalence controls?	Yes	Yes	Yes	Yes
Own zip fixed effects?	Yes	Yes	Yes	Yes
Zip pair fixed effects?	No	No	No	No
Year fixed effects?	Yes	Yes	Yes	Yes
State-specific trends?	Yes	Yes	Yes	Yes
Observations	113,178	113,178	100,764	113,178
Residual std. Error	24.587	24.587	24.634	24.567

Note: Standard errors, clustered by state, are in parentheses. This table presents the results from a difference-in-differences regression of annual auto insurance premiums (at the zip-code level). Identification is based on zip codes in states that legalized medicinal cannabis from 2016 to 2019, with zip codes in states that have not legalized as of the end of 2019 as the control group.

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

4.2 | Within-state variation in dispensary analysis

Our second specification is a heterogeneous treatment effect model. It defines zip codes near a dispensary in states that legalize from 2016 to 2019 as our "heavily-treated" group, zip codes in states that legalize from 2016 to 2019 but are far from dispensaries as our treated group, and zip codes in states that have not legalized as of the end of 2019 as our control group. If our story is correct, and our results are not driven by some other state-level phenomenon correlated with cannabis legalization, then the effect should be stronger near dispensaries. Moreover, this approach allows us to disentangle the effects of increased cannabis access from the effects of legality changes (in areas with no dispensaries). Figure 2 below shows the "heavily-treated" zip codes in black and the treated zip codes in gray. The never treated states are still in white and marked with an asterisk.

Specifically, we estimate.

$$y^0_{zt} = x'_{zt}\alpha + \theta_z + \tau_t + State_s * t + \epsilon_{zt} \tag{6}$$

$$y^1_{zt} - \widehat{y^0_{zt}} = \beta_1 Medical\_Cannabis_{st} + \beta_2 Medical\_Cannabis_{st} * Dispensary_{zt} + \nu_{zt} \tag{7}$$

$$y^1_{zt} - \widehat{y^0_{zt}} = \beta_1 ln(Registered\_Patients_{st}) + \beta_2 ln(Registered\_Patients_{st}) * Dispensary_{zt} + \nu_{zt} \tag{8}$$

where $Dispensary_{zt}$ is a binary indicator equal to 1 if the zip code is within 25 miles of a zip code with an operating dispensary. The coefficients of interest are β_1 and β_2, and we include the same vector of control variables described in the previous models.

The results of this estimation are presented in Table 4. Column (1) provides the estimates from our binary definitions of heavily treated, while column (2) uses a continuous treatment approach based on the log of the number of registered medical cannabis patients. In the binary treatment case, the treatment effect is statistically larger in dispensary areas than in

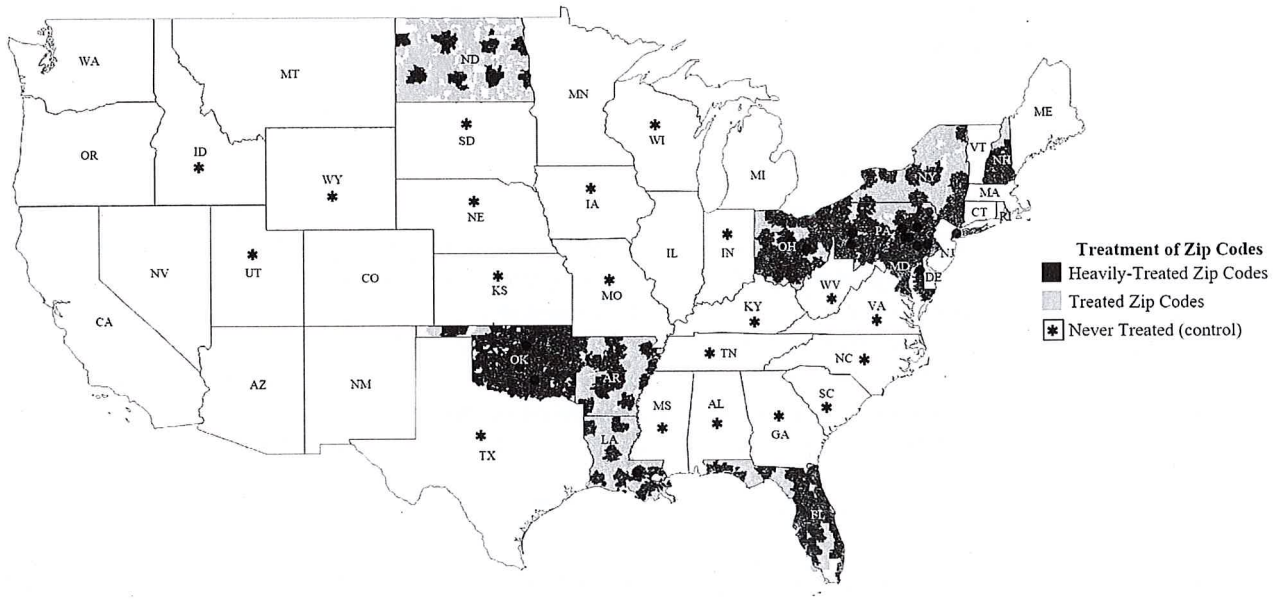

FIGURE 2 Map of zip codes close to dispensaries

TABLE 4 Dispensary models

	Dependent variable	
	Annual premiums	
	(1)	(2)
Medical Cannabis legalization	−10.855 (12.388)	
Medical Cannabis legalization * dispensary	−22.571* (13.465)	
ln(Registered patients)		−1.131 (1.059)
ln(Registered patients) * dispensary		−1.720 (1.104)
Median age	−0.062 (0.728)	−0.062 (0.728)
Number insured	−0.006 (0.004)	−0.006 (0.004)
Unemployment	−2.421*** (0.150)	−2.421*** (0.150)
Median household income	−0.003 (0.008)	−0.003 (0.008)
Drivers under 25 on policy	0.013*** (0.004)	0.013*** (0.004)
Insurance firm prevalence controls?	Yes	Yes
Own zip fixed effects?	Yes	Yes
Zip pair fixed effects?	No	No
Year fixed effects?	Yes	Yes
State-specific trends?	Yes	Yes
Observations	112,812	112,812
Residual std. Error	24.509	24.502

Note: Standard errors, clustered by state, are in parentheses. This table presents the results from a difference-in-differences regression of annual auto insurance premiums (at the zip-code level) for nearly all of the zip codes in the contiguous United States that legalized medical cannabis from 2016 to 2019, compared to zip codes in states that have not legalized as of the end of 2019. Dispensary is a binary variable for zip codes located within 25 miles of a zip code where a dispensary ever opens.

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

non-dispensary areas. In sum, these results provide further evidence that the negative effect of medical cannabis legalization on insurance premiums is driven by increased accessibility to the drug.

4.3 | Border zip analysis

Our third approach relies on a combination of difference-in-differences and geographic discontinuity. Unlike recreational cannabis, one has to physically live in the state to be qualified for purchasing medical cannabis.[30] Physical residence requirements create a hard discontinuity at the state border. We exploit the geographic discontinuity through paired zip codes across state borders where one state expands and the other never does. This geographic identification approach has precedent, though typically with counties as the geographic level of observation. For example, Gowrisankaran and Krainer (2011) examine ATM surcharges using differing laws in Minnesota and Iowa; Dube et al. (2010) use it to examine minimum wage effects on job growth; and Baggio et al. (2020) examine the effect of medical cannabis on alcohol demand.

In our analysis, we adapt the methodology of Dube et al. (2010) to the modern difference-in-differences setting, estimating.

$$y^0_{zpt} = x'_{zt}\alpha + \theta_z + \rho_p + \tau_t + State_s * t + \epsilon_{zpt} \tag{9}$$

$$y^1_{zpt} - \widehat{y^0_{zpt}} = \beta_1 Medical\_Cannabis_{st} + \nu_{zpt} \tag{10}$$

$$y^1_{zpt} - \widehat{y^0_{zpt}} = \beta_1 ln(Registered\_Patients_{st}) + \nu_{zpt} \tag{11}$$

where y_{zpt} is the average annual auto insurance premium for zip code z, in zip code pair p, and year t; ρ_p is a vector of pair-specific fixed effects; and the rest of the variables are the same as in Equations (2)–(5).

The standard errors for Equations (10) and (11) are more complicated. A single zip code may be in multiple pairs along a border. This induces a mechanical correlation across zip-code pairs along the same border segment.[31] To account for all of these sources of residual correlation, we follow Dube et al. (2010) and multi-way cluster the standard errors for Equations (10) and (11) by both state and border segment.

To understand the effect of access to cannabis on auto insurance premiums, we examine the effect using a sample that consists of all zip code pairs across borders of untreated and treated states as well as a sample of zip code pairs that are near a dispensary only. This means that β_1, for the dispensary only analysis, is identifying the average impact of legalization in zip codes near a dispensary. Figure 3 shows the bordering zip-code pairs near dispensaries that are used for our geographic discontinuity analysis.

The results of this estimation are presented in Table 5. The first and third columns of Table 5 use a binary treatment approach while the second and fourth columns of Table 5 use a continuous treatment (the log number of registered patients) approach. For the first two columns, which use all border zip codes, we fail to find a significant effect. However, when we limit to dispensary pairs, we find much stronger results for both the binary and the continuous treatment models. Relative to their non-expansion counterparts, zip codes that gain a dispensary in states that legalize medical cannabis experience a decline in auto insurance premiums by approximately $26.00 per policy per year following legalization.

In addition to providing evidence of improved traffic safety following medical cannabis legalization, the results in Table 4 and Table 5 shed light on important within-state variation in traffic safety and access to cannabis. We find significant declines in auto insurance premiums in areas most exposed to dispensaries, while the effects in areas without dispensaries are not distinguishable from zero for any specification.

4.4 | Economic significance

We estimate that legalizing medical cannabis reduces annual auto insurance premiums by $22 per household, a reduction of 1.7% for the average household.[32] While this reduction may be inconsequential to an individual policyholder, the aggregate effects are economically meaningful. For just the policyholders in our switching states, we estimate a combined annual reduction in premiums of $500 million. Extending our results to other states, we find that medical cannabis legalization has reduced auto insurance premiums by $1.5 billion in all states that have currently legalized, with the potential to reduce premiums by an

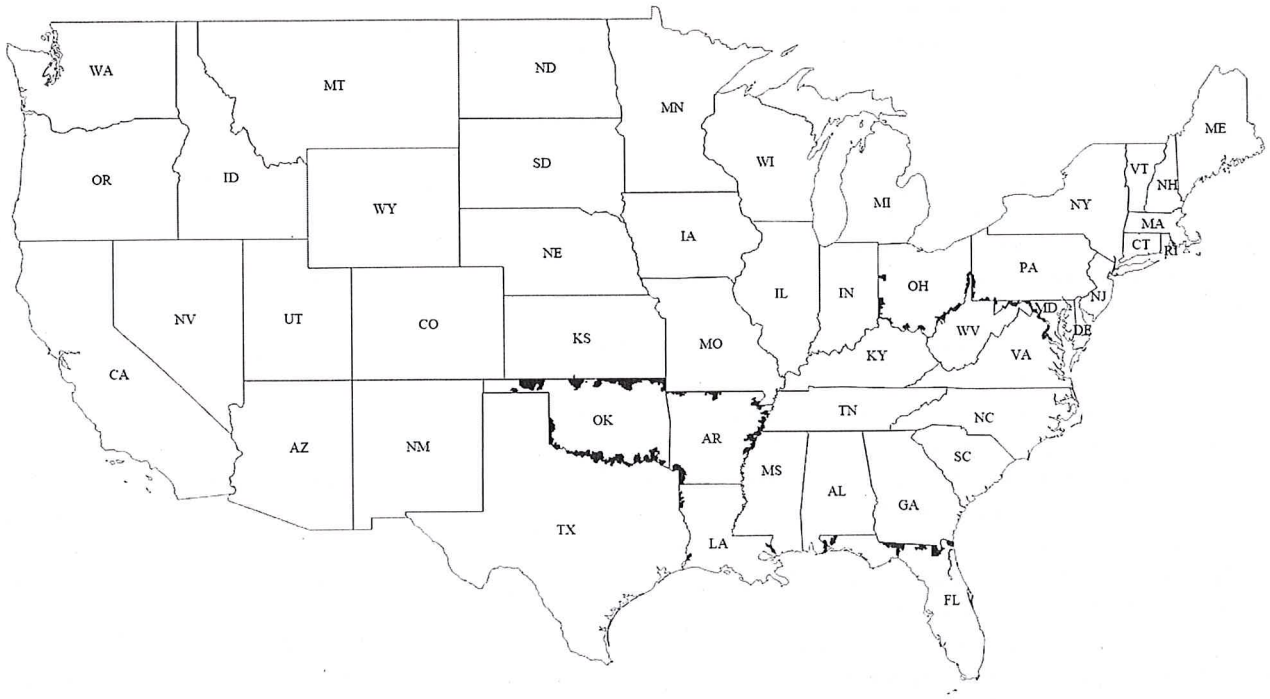

FIGURE 3 Map of bordering zip-code pairs with accessible dispensaries

TABLE 5 Cross-border paired zip models

	Dependent variable			
	Annual premiums			
	(1)	(2)	(3)	(4)
Medical Cannabis legalization	−7.216 (11.852)		−26.048* (14.071)	
ln(Registered patients)		−0.616 (1.065)		2.225* (1.245)
Median age	4.334* (2.587)	4.334* (2.587)	5.975** (2.827)	5.975** (2.827)
Number insured	0.013 (0.010)	0.013 (0.010)	0.019** (0.009)	0.019** (0.009)
Unemployment	−1.826*** (0.239)	−1.826*** (0.239)	−2.091*** (0.373)	−2.091*** (0.373)
Median household income	0.022* (0.012)	0.022* (0.012)	0.023* (0.014)	0.023* (0.014)
Drivers under 25 on policy	0.020*** (0.004)	0.020*** (0.004)	0.003 (0.022)	0.003 (0.022)
Pairs:	All	All	Dispenary only	Dispenary only
Insurance firm prevalence controls?	Yes	Yes	Yes	Yes
Own zip fixed effects?	Yes	Yes	Yes	Yes
Zip pair fixed effects?	Yes	Yes	Yes	Yes
Year fixed effects?	Yes	Yes	Yes	Yes
State-specific trends?	Yes	Yes	Yes	Yes
Observations	21,504	21,504	14,904	14,904
Residual std. Error	20.808	20.808	20.500	20.500

Note: Standard errors, clustered by state and border segment, are in parentheses. This table presents the results from a difference-in-differences regression of annual auto insurance premiums (at the zip-code level) for zip-code pairs across the border of a treated state (legalized medicinal cannabis from 2016 to 2019) and a never treated state (has not legalized as of the end of 2019). The right two columns further restrict to zip-code pairs that are located within 25 miles of a zip code where a dispensary ever opens.

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

additional $900 million if the remaining states were to legalize. Because auto insurance premiums are directly tied to property damage and health outcomes, we find evidence of a *positive* social impact of medical cannabis on auto safety.

We further estimate the cost savings just in terms of health expenditures. To disentangle the premium tied to medical outcomes from the premium tied to property damage, we rely on the data from National Association of Insurance Commissioners (2020, 2021) Auto Insurance Database Reports. Auto insurance coverage for bodily injuries differs by third-party and first-party medical costs and tort systems. Bodily Injury Liability (BI) coverage pays damages for injuries to third parties when the insured driver is at fault. This payment can include economic damages, such as medical, rehabilitation, funeral expenses, and non-economic damages, such as pain and suffering. In a traditional tort system, the insured driver can purchase Medical Payment (MedPay) coverage to cover their own medical and funeral expenses (i.e., first-party medical costs) regardless of fault.

In a no-fault system, the accident victim is restricted from suing for "small" auto injuries, that is, injuries below a specified dollar amount or severity level. Instead, the injured person receives compensation for economic damages from their own insurer without regard to fault. In the no-fault states, Personal Injury Protection (PIP) coverage replaces the limited MedPay coverage and covers the medical expenses of the insured regardless of who is at fault.[33]

Another type of medical cost arises from an Uninsured/Underinsured Motorist (UM/UIM) who does not purchase liability insurance or does not purchase enough insurance to cover their liability in a severe accident. A policyholder can purchase UM/UIM coverage to cover their own bodily injuries caused by a negligent uninsured or underinsured motorist. Hit-and-run accidents are included in UM/UIM coverage.

The NAIC Auto Insurance Database Reports provide state-level average premium for various auto coverage types from 2014 to 2017. The average premium is the total premiums divided by the total exposures measured by the number of car-years. Table 6 shows the average premium per vehicle per year for each of the four types of medical-related coverage–BI, PIP, MedPay, and UM/UIM.[34] The state-level premium is separately averaged across all states, states that legalized prior to 2016 ("Always Treated"), switching states ("Switchers"), and states that have not yet legalized as of the end of 2019 ("Never Treated").

TABLE 6 Disentangled auto insurance premiums

	Average premium (per car-year)						
	BI	**PIP**	**MedPay**	**UM/UIM**	**Total medical – related**	**Combined premium**	**% Medical**
2014							
All states	205.89	143.66	31.83	68.14	449.53	946.32	48%
Always treated	234.35	190.83	35.62	78.96	539.76	1013.79	53%
Switchers	215.82	120.31	28.91	80.95	445.99	1017.85	44%
Never treated	173.71	64.55	29.99	51.72	319.97	849.82	38%
2015							
All states	209.99	142.91	33.16	68.39	454.46	972.84	47%
Always treated	238.58	191.33	37.49	79.50	546.90	1039.53	53%
Switchers	219.34	117.36	30.81	80.92	448.43	1045.50	43%
Never treated	177.99	64.91	30.52	51.86	325.28	876.50	37%
2016							
All states	217.83	143.51	34.16	69.82	465.31	1016.18	46%
Always treated	246.59	190.58	39.17	81.32	557.67	1082.83	52%
Switchers	228.22	119.67	32.19	82.89	462.97	1093.27	42%
Never treated	185.11	65.64	30.71	52.65	334.10	917.65	36%
2017							
All states	229.82	147.37	36.38	74.25	487.82	1077.94	45%
Always treated	258.47	194.91	43.86	85.79	583.03	1144.32	51%
Switchers	240.89	123.71	33.38	86.62	484.60	1156.54	42%
Never treated	196.84	67.96	31.27	57.40	353.47	978.90	36%

Note: This table provides the average auto insurance premium for medical-related coverage. BI is bodily injury insurance; PIP is personal injury protection; MedPay is medical payment coverage; and UM/UIM is uninsured and underinsured motorist coverage. Combined Premium is the total average auto premium for all coverage, including liability, collision, and comprehensive.

We aggregate the average premium for BI, PIP, MedPay, and UM/UIM coverage to obtain the total premium for medical-related expenses. The Combined Premium is the total auto premium for all coverage, including liability, collision, and comprehensive. By dividing the aggregate medical-related premium by the combined premium, we obtain the percentage of the auto insurance premium that covers the medical expenses (% Medical). Based on this breakdown, we estimate that medical cannabis has reduced health expenditures by at least $220 million per year in our switching states; by $600 million in states that legalized prior to 2016; and, if implemented, would reduce medical costs by $350 million in the states that have yet to legalize.

5 | CONCLUSIONS

Our results indicate that the legalization and access to medical cannabis positively impacts auto safety. Other literature on this topic (which mainly finds null or negative results) has been limited by the reliance on data that only involve fatal accidents. We conduct a more comprehensive analysis by focusing on the direct effect on auto insurance prices. We find the decline in premiums are more significant in areas closer to a dispensary and in areas with higher drunk driving levels prior to cannabis legalization. Further, we find premium reductions are larger in states with greater patient enrollment and in states that allow smoking. There are other differences in laws (such as the allowance for home growth) that could be exploited for future research. Additionally, the question of who is "driving" the effect (those using cannabis legally vs. illicitly) is another excellent avenue for future research.

Our results indicate the increase in auto safety is due, at least partially, to a decrease in DUI of alcohol. However, we caution against interpreting this as direct evidence of an alcohol/cannabis substitution effect. Another plausible explanation is that legalizing medical cannabis does not change the quantity of alcohol consumption but instead changes the location of consumption. Bar-equivalents do not typically exist for cannabis, and current medical cannabis laws stipulate that consumption occurs in a private residence. Thus, joint consumption of cannabis and alcohol is likely to take place in the home. We do not examine recreational laws because our identification techniques do not apply. Thus, we would advise policy-makers against extending our results on medical cannabis toward recreational use since consumption habits may differ under the two regimes.

ACKNOWLEDGMENT

The authors have no relevant financial interests to disclose. The authors would like to thank David Eckles, Meghan Esson, Chuck Nyce, Lars Powell, David Sjoquist, Sarah Stith and seminar participants at the American Risk and Insurance Association (Chicago, August 2018), the Southern Economics Association (Washington D.C., November 2018), the Risk Theory Society (Tuscaloosa, April 2019), and the American Society of Health Economists (Washington D.C., June 2019).

CONFLICT OF INTEREST

The authors have no conflicts of interest to report.

DATA AVAILABILITY STATEMENT

The zip code survey data that support the findings of this study are available from S&P Global. Restrictions apply to the availability of these data, which were used under license for this study. Data are available https://www.capitaliq.spglobal.com/ with the permission of S&P Global. The Insurance Company Financial data that support the findings of this study are available from The NAIC. Restrictions apply to the availability of these data, which were used under license for this study. Data are available upon request to the authors with the permission of the NAIC. The dispensary location data are not shared. The timing of medical Cannabis laws that support the findings of this study are available from the corresponding author upon reasonable request. The UCR data that support the findings of this study are openly available in at https://www.fbi.gov/services/cjis/ucr.

ORCID

Cameron M. Ellis https://orcid.org/0000-0002-2794-6299
Rhet A. Smith https://orcid.org/0000-0003-3426-1228

ENDNOTES

[1] See Lenné et al. (2010) and Hartman and Huestis (2013).

[2] Anderson et al. (2013) is especially relevant to our study as they specifically find medical cannabis laws are associated with fewer alcohol-related fatal traffic crashes.

[3] Although certain states allow for reciprocity, these laws are limited in scope and often require medical authorization from the individual's home state.

[4] Bradford and Bradford (2017) note a geographical component to the spread of medical cannabis laws, in particular for neighboring states. This is further reason to use our border approach as neighboring states, in general, will have a similar consumer demand for medical cannabis than states that are further apart.

[5] This approach has precedent (though typically with counties). See Gowrisankaran and Krainer (2011), Dube et al. (2010), and Baggio et al. (2020) for example,

[6] The potential savings documented in this paragraph are not exhaustive and may be offset (heightened) by other types of medical expenses (savings) that relate to greater cannabis access.

[7] There are five categories of controlled substances based on their medical usefulness and abuse potential. Schedule I drugs are considered to have no currently accepted medical usefulness and a high potential for abuse.

[8] The 2009 Ogden Memorandum is available at https://www.justice.gov/archives/opa/blog/memorandum-selected-united-state-attorneys-investigations-and-prosecutions-states.

[9] A previous Cole Memorandum was issued in 2011 to curtail the initial expansion after 2009. This memo did not address the inconsistency between state and federal law. The 2013 Cole Memorandum was issued in response to recreational cannabis laws in Washington and Colorado and laid out the legal market operation guidelines. See the 2013 Cole Memorandum at https://www.justice.gov/opa/pr/justice-department-announces-update-marijuana-enforcement-policy.

[10] Similar patterns were observed in many early-adopting states. The time between a state legalizing medical cannabis and the first dispensary opening can be quite long; Maine, Oregon, and Washington took more than 10 years to open their first dispensary.

[11] Patient number was obtained from the state's medical cannabis program website. Another extreme example is West Virginia. West Virginia passed a medical cannabis law in 2017 but expect the first dispensary to open in the first quarter of 2022.

[12] We interchangeably use the words "legalize" and "expand." Both mean that the state has opened a dispensary and medical cannabis is legal. We allow for "partial" treatment and let our treatment variable represent the percent of the year that the state has legalized.

[13] In the short time following legal recreational sales, Hansen et al. (2020b) fail to find any evidence of recreational cannabis laws increasing fatal traffic crashes.

[14] This further exacerbates the issue of limiting analyses to fatal accidents as crashes may become less severe if they occur at lower speeds.

[15] The 17 major auto insurers are Auto Club (AAA), Allstate, American Family, Erie, Esurance, Farm Bureau, Farmers or Zurich, GEICO, Hartford, Liberty Mutual, Mercury, MetLife, Nationwide, Progressive, State Farm, Travelers, and USAA. However, we do not include Esurance or Mercury, as they did not report data in 2014 or 2015. The data also contain several other survey items that we do not use, such as "did you switch plans" and "how many claims have you had in the past three years."

[16] The 2017–2019 ACS control variables are projected by the survey.

[17] Each zip code is paired with every zip code across the state border within 25 miles. The same zip code can be in several pairs. We account for this through multi-way clustered standard errors, which are described in the next section. The distances between zip codes are obtained from the NBER database at http://www.nber.org/data/zip-code-distance-database.html.

[18] States that experienced dispensary or dispensary-like operations prior to the sample period are considered always treated and are omitted from the analysis.

[19] We are grateful to Thomas Lebesmuehlbacher for updating and sharing the dispensary data. See Lebesmuehlbacher and Smith (2021) for further details on data construction and accuracy of data relative to known official sources.

[20] Patient registry usually starts after medical cannabis law becomes effective and before the first medical cannabis dispensary opens. A qualifying patient's certification card is re-certified every year conditional on the re-evaluation of the patient's medical condition by a health practitioner.

[21] Some states report the medical cannabis statistics on a fiscal-year basis, for example, Minnesota. In this case, the number of registered patients is as of June 30.

[22] DUI is defined in UCR Handbook (Federal Bureau of Investigation, 2004) as "driving or operating a motor vehicle or common carrier while mentally or physically impaired as the result of consuming an alcoholic beverage or using a drug or narcotic." The vast majority of DUIs are due to alcohol.

[23] Although Michigan, Montana, and Nevada implement dispensary provisions after 2014, each state was already exposed to dispensary-like operations prior to these laws and before our sample period began. Therefore, we consider these states always treated.

[24] In Appendix A, we examine the robustness of this method through using Callaway and Sant'Anna's (2020) method and find very similar results. We do not use Callaway and Sant'Anna (2020) for our primary analysis because it does not allow for treatment effects to be heterogeneous across individuals, only across time.

[25] Because we include a trend variable, we must observe our switching states for at least 2 years before treatment.

[26] Recall, we allow for partial treatment in the year of opening. In other words, if the first dispensary in a state opens 3 months into the year, the treatment variable for that year would be 0.75.

[27] It is possible that states may switch to allowing smoking (or vice versa), but we cannot find any examples during our data's timeframe.

[28] Results from two-way fixed effects models were qualitatively similar, but smaller in magnitude. In addition, estimates of the effect of medical cannabis law enactment using our preferred model in Equation (2) were significantly smaller and not distinguishable from zero. These results are available upon request.

[29] In prior-approval states, premium changes are legally mandated to be driven by costs. This is also the case when markets are competitive.

[30] Hansen et al. (2020a) and Hao and Cowan (2020) both document the cross-border impact of recreational cannabis laws. We only use borders with never-treated states.

[31] A border segment is a state-pair specific border, such as the Pennsylvania - New York border.

[32] The average annual premium is $1245.

[33] PIP coverage may also be offered in tort states as an "add-on" to the existing tort system.

[34] The Earned Premium for UM/UIM coverage is an aggregate of bodily injury and physical damage. We use their incurred losses to allocate the Earned Premium and obtain the average premium for UM/UIM-BI.

[35] It is also possible that rate regulation leads to the delay since, in many states, insurers must directly show the cost reduction before they are allowed to lower premiums.

[36] Incurred losses also include incurred loss adjustment expenses. The three private auto insurance lines are: private passenger auto no-fault liability, other private passenger auto liability, and private passenger auto physical damage.

[37] We are grateful to Greg Leung for sharing the law enactment dates and sources for many of these traffic laws.

REFERENCES

Abouk, R., & Adams, S. (2013). Texting bans and fatal accidents on roadways: Do they work? Or do drivers just react to announcements of bans? *American Economic Journal: Applied Economics*, *5*(2), 179–199. https://doi.org/10.1257/app.5.2.179

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. https://doi.org/10.1086/668812

Anderson, D. M., & Rees, D. I. (2014). The role of dispensaries: The devil is in the details. *Journal of Policy Analysis and Management*, *33*(1), 235–240. https://doi.org/10.1002/pam.21733

Anderson, D. M., & Rees, D. I. (2015). Per Se drugged driving laws and traffic fatalities. *International Review of Law and Economics*, *42*, 122–134. https://doi.org/10.1016/j.irle.2015.02.004

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. *BMJ*, *344*, e536. https://doi.org/10.1136/bmj.e536

Athey, S., Bayati, M., Doudchenko, N., Imbens, G., & Khosravi, K. (2021). Matrix completion methods for causal panel data models. *Journal of the American Statistical Association*, *116*(536), 1–15. https://doi.org/10.1080/01621459.2021.1891924

Avraham, R. (2019). *Database of state tort law reforms (6.1)*. U of Texas Law, Law and Econ Research. Paper No. e555. Available at SSRN: https://ssrn.com/abstract=902711

Baggio, M., Chong, A., & Kwon, S. (2020). Marijuana and alcohol evidence using border analysis and retail sales data. *Canadian Journal of Economics*, *53*(2), 563–591. https://doi.org/10.1111/caje.12437

Blincoe, L., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015). *The economic and societal impact of motor vehicle crashes, 2010 (revised), technical report (report No. DOT HS 812 013)*. National Highway Traffic Safety Administration.

Bondallaz, P., Favrat, B., Chtioui, H., Fornari, E., Maeder, P., & Giroud, C. (2016). Cannabis and its effects on driving skills. *Forensic Science International*, *268*, 92–102. https://doi.org/10.1016/j.forsciint.2016.09.007

Borusyak, K., Jaravel, X., & Spiess, J. (2021). *Revisiting event study designs: Robust and efficient estimation*. arXiv preprint arXiv:2108.12419.

Bradford, A. C., & Bradford, W. D. (2017). Factors driving the diffusion of medical marijuana legalisation in the United States. *Drugs: Education, Prevention & Policy*, *24*(1), 75–84. https://doi.org/10.3109/09687637.2016.1158239

Bradford, A. C., & Bradford, W. D. (2018). The impact of medical Cannabis legalization on prescription medication use and costs under medicare part d. *The Journal of Law and Economics*, *61*(3), 461–487. https://doi.org/10.1086/699620

Callaway, B., & Sant'Anna, P. H. (2020). Difference-in-differences with multiple time periods. *Journal of Econometrics*, *225*(2), 200–230. https://doi.org/10.1016/j.jeconom.2020.12.001

Cerdá, M., Wall, M., Keyes, K. M., Galea, S., & Hasin, D. (2012). Medical marijuana laws in 50 states: Investigating the relationship between state legalization of medical marijuana and marijuana use, abuse and dependence. *Drug and Alcohol Dependence*, *120*(1), 22–27. https://doi.org/10.1016/j.drugalcdep.2011.06.011

Chaloupka, F. J., & Laixuthai, A. (1997). Do youths substitute alcohol and marijuana? Some econometric evidence. *Eastern Economic Journal*, *23*(3), 253–276.

Chihuri, S., Li, G., & Chen, Q. (2017). Interaction of marijuana and alcohol on fatal motor vehicle crash risk: A case–control study. *Injury Epidemiology*, *4*(1), 1–9. https://doi.org/10.1186/s40621-017-0105-z

Choi, A., Dave, D., & Sabia, J. J. (2019). Smoke gets in your eyes: Medical marijuana laws and tobacco cigarette use. *American Journal of Health Economics*, *5*(3), 303–333. https://doi.org/10.1162/ajhe_a_00121

Chu, Y.-W. L. (2014). The effects of medical marijuana laws on illegal marijuana use. *Journal of Health Economics*, *38*, 43–61. https://doi.org/10.1016/j.jhealeco.2014.07.003

Cook, A. C., Leung, G., & Smith, R. A. (2020). Marijuana decriminalization, medical marijuana laws, and fatal traffic crashes in US cities, 2010-2017. *American Journal of Public Health*, *110*(3), 363–369. https://doi.org/10.2105/ajph.2019.305484

Daniller, A. (2019). *Two-thirds of Americans support marijuana legalization*. Pew Research Center. http://pewrsr.ch/2E9u3hd

Dee, T. S., Grabowski, D. C., & Morrisey, M. A. (2005). Graduated driver licensing and teen traffic fatalities. *Journal of Health Economics*, *24*(3), 571–589. https://doi.org/10.1016/j.jhealeco.2004.09.013

Dube, A., Lester, T. W., & Reich, M. (2010). Minimum wage effects across state borders: Estimates using contiguous counties. *The Review of Economics and Statistics*, *92*(4), 945–964. https://doi.org/10.1162/rest_a_00039

Federal Bureau of Investigation. (2004). Uniform crime reporting handbook. https://ucr.fbi.gov/additional-ucr-publications/ucr_handbook.pdf

Federal Bureau of Investigation. (2009-2016). Uniform crime reporting program data: Arrests by age, sex, and race, United States. https://www.icpsr.umich.edu/web/NACJD/series/57

Freeman, D. G. (2007). Drunk driving legislation and traffic fatalities: New evidence on BAC 08 laws. *Contemporary Economic Policy*, *25*(3), 293–308. https://doi.org/10.1111/j.1465-7287.2007.00039.x

Freisthler, B., & Gruenewald, P. J. (2014). Examining the relationship between the physical availability of medical marijuana and marijuana use across fifty California cities. *Drug and Alcohol Dependence*, *143*, 244–250. https://doi.org/10.1016/j.drugalcdep.2014.07.036

Gardner, J. (2021). *Two-stage differences in differences*. Working Paper.

Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics*, *225*(2), 254–277.

Gowrisankaran, G., & Krainer, J. (2011). Entry and pricing in a differentiated products industry: Evidence from the ATM market. *The RAND Journal of Economics*, *42*(1), 1–22. https://doi.org/10.1111/j.1756-2171.2010.00123.x

Grace, M. F., & Leverty, J. T. (2012). How tort reform affects insurance markets. *Journal of Law, Economics, and Organization*, *29*(6), 1253–1278. https://doi.org/10.1093/jleo/ews026

Hansen, B., Miller, K., & Weber, C. (2020a). Federalism, partial prohibition, and cross-border sales: Evidence from recreational marijuana. *Journal of Public Economics*, *187*, 104159. https://doi.org/10.1016/j.jpubeco.2020.104159

Hansen, B., Miller, K. S., & Weber, C. (2020b). Early evidence on recreational marijuana legalization and traffic fatalities. *Economic Inquiry*, *58*(2), 547–568. https://doi.org/10.1111/ecin.12751

Hao, Z., & Cowan, B. W. (2020). The cross-border spillover effects of recreational marijuana legalization. *Economic Inquiry*, *58*(2), 642–666. https://doi.org/10.1111/ecin.12764

Hartman, R. L., & Huestis, M. A. (2013). Cannabis effects on driving skills. *Clinical Chemistry*, *59*(3), 478–492. https://doi.org/10.1373/clinchem.2012.194381

Heaton, P. (2017). How does tort law affect consumer auto insurance costs? *Journal of Risk & Insurance*, *84*(2), 691–715.

Jakiela, P. (2021). *Simple diagnostics for two-way fixed effects*. arXiv preprint arXiv:2103.13229.

Karl, J. B., & Nyce, C. (2017). How cellphone bans affect automobile insurance markets. *Journal of Risk & Insurance*, *86*(3), 567–593. https://doi.org/10.1111/jori.12224

Kim, J. H., Santaella-Tenorio, J., Mauro, C., Wrobel, J., Cerdà, 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. https://doi.org/10.2105/ajph.2016.303426

Lebesmuehlbacher, T., & Smith, R. A. (2021). The effect of medical Cannabis laws on pharmaceutical marketing to physicians. *Health Economics*, *30*(10), 2409–2436. https://doi.org/10.1002/hec.4380

Lenné, M. G., Dietze, P. M., Triggs, T. J., Walmsley, S., Murphy, B., & Redman, J. R. (2010). The effects of Cannabis and alcohol on simulated arterial driving: Influences of driving experience and task demand. *Accident Analysis & Prevention*, *42*(3), 859–866. https://doi.org/10.1016/j.aap.2009.04.021

McCartt, A. T., Kidd, D. G., & Teoh, E. R. (2014). Driver cellphone and texting bans in the United States: Evidence of effectiveness. *Annals of Advances in Automotive Medicine*, *58*, 99–114.

McMichael, B. J., Van Horn, R. L., & Viscusi, W. K. (2020). The impact of Cannabis access laws on opioid prescribing. *Journal of Health Economics*, *69*, 102273. https://doi.org/10.1016/j.jhealeco.2019.102273

National Association of Insurance Commissioners. (2020). *Auto insurance database report 2016/2017*. https://content.naic.org/publications

National Association of Insurance Commissioners. (2021). *Auto insurance database report 2017/2018*. https://content.naic.org/publications

NHTSA. (2016). 2016 data: Summary of motor vehicle crashes. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812580

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. https://doi.org/10.1002/pam.21804

Powell, D., Pacula, R. L., & Jacobson, M. (2018). Do medical marijuana laws reduce addictions and deaths related to pain killers? *Journal of Health Economics*, *58*, 29–42. https://doi.org/10.1016/j.jhealeco.2017.12.007

ProCon.org. (2020). Legal medical marijuana states and DC. Retrieved February 18, 2020, from. https://medicalmarijuana.procon.org/legal-medical-marijuana-states-and-dc/

Ramaekers, J. G., Berghaus, G., van Laar, M., & Drummer, O. H. (2004). Dose related risk of motor vehicle crashes after Cannabis use. *Drug and Alcohol Dependence*, *73*(2), 109–119. https://doi.org/10.1016/j.drugalcdep.2003.10.008

Sabia, J. J., Swigert, J., & Young, T. (2017). The effect of medical marijuana laws on body weight. *Health Economics*, *26*(1), 6–34. https://doi.org/10.1002/hec.3267

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. https://doi.org/10.2105/ajph.2016.303577

Sewell, R. A., Poling, J., & Sofuoglo, M. (2009). The effect of Cannabis compared with alcohol on driving. *American Journal on Addictions*, *18*(3), 185–193. https://doi.org/10.1080/10550490902786934

Smart, R. (2015). *The kids aren't alright but older adults are just fine: Effects of medical marijuana market growth on substance use and abuse*. Working paper. Available at SSRN: https://ssrn.com/abstract=2574915

Smith, R. A. (2020). The effects of medical marijuana dispensaries on adverse opioid outcomes. *Economic Inquiry*, *58*(2), 569–588. https://doi.org/10.1111/ecin.12825

Thornton, M. (2007). *The economics of prohibition*. Ludwig von Mises Institute.

Wen, H., Hockenberry, J. M., & Cummings, J. R. (2015). The effect of medical marijuana laws on adolescent and adult use of marijuana, alcohol, and other substances. *Journal of Health Economics*, *42*, 64–80. https://doi.org/10.1016/j.jhealeco.2015.03.007

Williams, A. R., Olfson, M., Kim, J. H., Martins, S. S., & Kleber, H. D. (2016). Older, less regulated medical marijuana programs have much greater enrollment rates than newer 'medicalized' programs. *Health Affairs*, *35*(3), 480–488. https://doi.org/10.1377/hlthaff.2015.0528

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Ellis, C. M., Grace, M. F., Smith, R. A., & Zhang, J. (2022). Medical Cannabis and automobile accidents: Evidence from auto insurance. *Health Economics*, 1–20. https://doi.org/10.1002/hec.4553

APPENDIX A: DIFFERENCE-IN-DIFFERENCES ROBUSTNESS

In this appendix, we present the results of using Callaway and Sant'Anna's (2020) method for staggered difference-in-differences for our main analysis. In particular, we are interested in the dynamic effects of our estimate, which are more easily calculated with Callaway and Sant'Anna (2020). Table A1 presents the overall estimated averaged treatment effect on the treated (ATT) and further splits this effect into dynamic estimates. Figure A1 presents the same coefficients in visual form.

We find that the overall ATT is very similar (-$25 vs. -$22) to the ATT estimated using the Gardner (2021) method, which gives us further confidence that our overall results are robust. We next examine the dynamic effects. The "pre-treatment" effects allow for a check of the parallel trends assumption. The only coefficient that gives us pause is on the period immediately prior to treatment. While this coefficient is significantly, and economically, below zero, it is less than half of our estimated treatment effect. This implies that non-parallel pre-trends can not account for our estimated treatment effect. Finally, we examine the post-treatment variables. Interestingly, we find a delayed reaction. This could be due to either a delay in treatment onset

TABLE A1 Callaway and Sant'Anna (2020) results

	ATT	Std. Error	[95% Conf. Int.]	
Overall ATT				
	−25.60	3.34	−32.14	−19.06
Dynamic effects				
−4.00	4.56	0.62	2.95	6.17
−3.00	3.17	0.61	1.58	4.76
−2.00	−5.48	2.49	−11.96	1.00
−1.00	−11.78	1.04	−14.49	−9.06
0.00	−4.02	1.33	−7.49	−0.56
1.00	−20.25	2.52	−26.80	−13.70
2.00	−52.53	8.67	−75.10	−29.95

Note: This table provides the results of our main analysis using the method of Callaway and Sant'Anna (2020). This analysis uses a binary treatment variable instead of the continuous one used in the main analysis. Here we define treatment as the year a dispensary first opens.

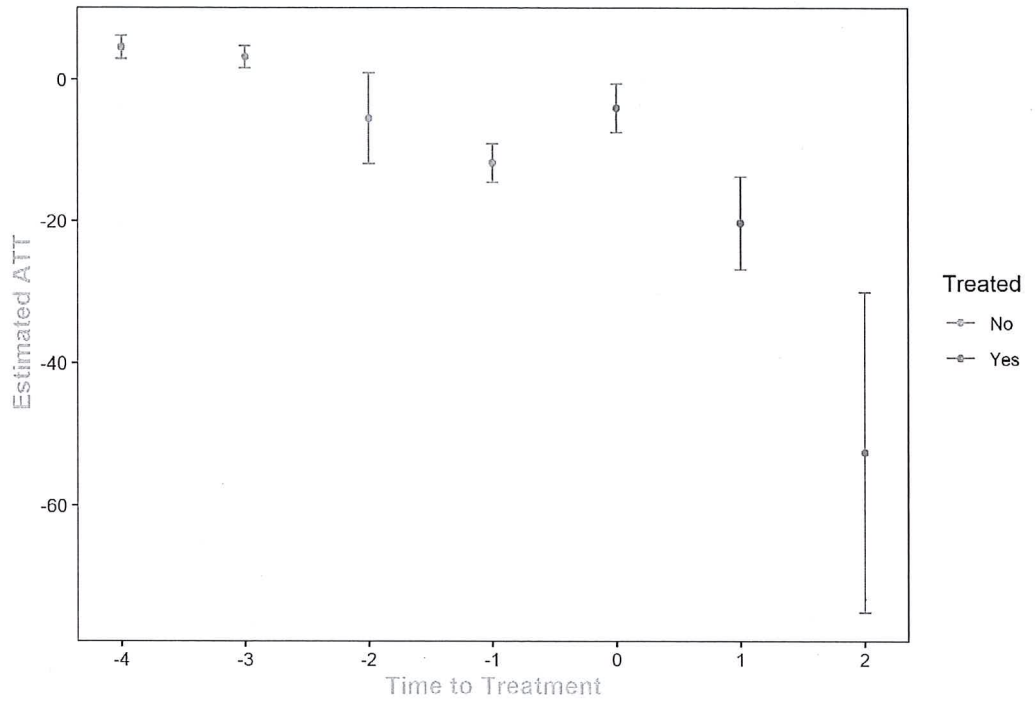

FIGURE A1 Callaway and Sant'Anna parallel trends

(i.e., a dispensary opening late in the year) or a delay in effect, since insurers may not have anticipated the drop in costs in the treatment year.[35]

APPENDIX B: SUPPLY VERSUS DEMAND (FIRM-LEVEL) ANALYSIS

B.1 | NAIC data

The NAIC data (1993–2019) contain the financial operations of virtually all of the automobile insurers operating in the United States. The "State Pages" of the financial report provide the dollar amount of premiums earned (*Premiums*) and incurred losses (*Losses*) by a given auto insurer, in a given state, during a given year, and for a given product line. We use the data on three private auto insurance lines only.[36] We then divide *Losses* by *Premiums* to obtain the *Loss Ratio*. The *Loss Ratio* is a commonly used (*ex-post*) measure of the inverse underwriting profit per dollar of losses incurred (e.g., Grace & Leverty, 2012).

Our analysis hinges on any potential demand-side effects being orthogonal to the medical cannabis-based supply-side effects that we are trying to identify. The *Loss Ratio* allows us to check this. In our main analysis, we find premiums fall in response to medical cannabis legalization. If the *Loss Ratio* is also going down, then premiums are falling slower than costs, and we are under-estimating the real effect. If the *Loss Ratio* is going up, then premiums are falling faster than costs, and our estimate is biased away from zero. If the *Loss Ratio* is unchanging, then premiums and costs are moving hand-in-hand, and our estimate is free from confounding demand-side factors.

For control variables, we obtain insurers' total admitted assets, group affiliation, organizational form, and the number of states where the firm operates from the NAIC data. We merge this with the A.M. Best Key Rating Guide, which provides an insurer's primary distribution system (marketing type) and financial strength rating. We then merge the combined data with state-level control variables that we collected from various sources. The Federal Highway Administration's Highway Statistics Series Publications provide the numbers of licensed drivers and young drivers aged 19 or under and the state gas tax rate. The state unemployment rate is from the Bureau of Labor Statistics, and the per-capita personal income is available through the Bureau of Economic Analysis. Our tort reform dummies come from the Database of State Tort Law Reforms (DSTLR 6.1; Avraham, 2019) and the American Tort Reform Association (ATRA) Tort Reform Record. The DSTLR (6.1) contains a detailed and comprehensive legal dataset of tort reforms in the U.S. from 1980 to 2018; we supplement tort reform changes (if any) in 2019 using the ATRA record.

We also control for state-level traffic safety laws to isolate the effect of medical cannabis legalization on traffic safety. Per se drugged driving laws are obtained from Anderson and Rees (2015) and updated using the Prescription Drug Abuse Policy System. Seat belt enforcement laws, 70 miles per hour maximum speed limits, graduated driver licensing laws, and texting bans are obtained from the Centers for Disease Control and Prevention, the Insurance Institute for Highway Safety (IIHS), and previous literature (Abouk & Adams, 2013; Dee et al., 2005; McCartt et al., 2014). To control for alcohol-related policies such as zero tolerance alcohol laws, reducing the drunk driving legal blood alcohol concentration limit to 0.08, and administrative license revocation laws, we use enactment dates from IIHS, the National Highway Traffic Safety Administration, and the appendix of Freeman (2007).[37]

B.2 | Methods and results

Finally, to ensure that no demand-side effects are confounding our analysis, we turn to our firm-state-line level data and estimate:

$$Y^0_{lfst} = X'_{lfst}\alpha + \theta_f + \gamma_s + \tau_t + State_s * t + \epsilon_{lfst} \tag{A1}$$

$$Y^1_{lfst} - \widehat{Y^0_{lfst}} = \beta Medical\_Cannabis_{st} + \nu_{lfst} \tag{A2}$$

where Y_{lfst} is the *Loss Ratio* for policies in line l, written by firm f, in state s, and year t; X_{lfst} is a vector of line, firm, and state-level controls (inclusive of an intercept); θ_f is a vector of firm fixed effects; γ_s is a vector of state fixed effects; τ_t is a vector of year fixed effects; $State_s * t$ are state-specific time trends; and ϵ_{lfst} and ν_{lfst} are the mean-zero error terms. To align with our previous analysis, we also perform the analysis using only the states that legalized from 2016 to 2019.

Firm-level control variables include the log of total admitted assets (*Log(Assets)*), a dummy for stock organizational form (*Stock*), a dummy for group affiliation (*Group*), and a dummy for direct marketing/distribution channel (*Direct*). *Num. States* is the number of states where the firm operates for each of the three personal auto lines. We also include an insurer's market share of direct written premiums for a given line and a given state (*Market Share*). Other state-level control variables include the log of the number of total drivers (*Log(Num. Drivers)*), the log of the ratio of the number of drivers aging 19 and under to the number of total drivers (*Log(Youth Ratio)*), the log of the state gas tax rate (*Log(Gas Tax)*), the annual average unemployment rate (*Unemployment Rate*), and the log of per capita personal income (*Log(Per Capita Income)*). We also include controls for various state driving laws, four types of tort reform on auto liability, and financial strength rating dummy.

The results for this analysis are presented in Table B1. The first and second columns show the effect of legalizing medical cannabis on the *Loss Ratio*, and the effect is not statistically different from zero. Additionally, the estimate is very tightly estimated to be close to zero. Columns (3) – (5) subset the analysis by line, but with the exception of physical damage, the results are noisy nulls.

TABLE B1 Firm-level models

	Dependent variable				
	Loss ratio (%)				
	(1)	(2)	(3)	(4)	(5)
Medical Cannabis legalization	−0.013 (1.470)	0.469 (1.296)	−9.651 (6.591)	1.298 (1.894)	0.165 (1.248)
Stock	−5.413*** (1.194)	−6.275*** (1.265)	2.186 (4.748)	−5.964*** (1.584)	−6.410*** (1.459)
Group	3.198*** (0.932)	4.247*** (0.981)	4.668* (2.690)	5.140*** (1.214)	1.422 (1.108)
Direct	−0.068 (0.430)	−0.337 (0.444)	−0.096 (1.651)	−0.106 (0.515)	−0.119 (0.496)
Log(Assets)	0.567*** (0.207)	0.605** (0.244)	−0.041 (0.620)	0.672** (0.292)	1.110*** (0.260)
Num. States	−0.110*** (0.031)	−0.104*** (0.032)	−0.222 (0.177)	−0.198*** (0.042)	−0.076*** (0.025)
Log(Youth ratio)	−1.939*** (0.750)	−1.254* (0.685)	−6.800 (4.341)	−1.539 (1.106)	−1.453 (1.209)
Log(Num. Drivers)	−2.090 (4.011)	0.121 (4.208)	−13.333 (11.070)	1.706 (3.645)	−1.286 (6.015)
Log(Gas tax)	1.013 (1.288)	0.414 (1.449)	9.509* (4.855)	1.819 (1.768)	−0.945 (1.241)
Log(Per capita income)	1.312 (8.800)	−0.953 (9.676)	13.584 (11.504)	−6.381 (11.910)	5.803 (12.235)
Unemployment rate	−0.667*** (0.298)	−0.759** (0.344)	−0.508 (0.996)	−0.849*** (0.289)	−0.420 (0.518)

(Continues)

TABLE B1 (Continued)

	Dependent variable				
	Loss ratio (%)				
	(1)	(2)	(3)	(4)	(5)
Other priv. Auto liab. Line	−7.784*** (2.406)	−6.505*** (2.340)			
Physical damage line	−19.428*** (2.774)	−17.742*** (2.701)			
Treatment groups:	1992–2019	2016–2019	1992–2019	1992–2019	1992–2019
Line:	All	All	No fault	Other liability	Physical damage
State driving law controls?	Yes	Yes	Yes	Yes	Yes
Tort reform controls?	Yes	Yes	Yes	Yes	Yes
Rating controls?	Yes	Yes	Yes	Yes	Yes
Firm fixed effects?	Yes	Yes	Yes	Yes	Yes
State fixed effects?	Yes	Yes	Yes	Yes	Yes
Year fixed effects?	Yes	Yes	Yes	Yes	Yes
State-specific trends?	Yes	Yes	Yes	Yes	Yes
Observations	357,952	279,411	44,462	151,317	162,173
Residual std. Error	35.161	34.893	44.572	37.182	27.567

Note: This table represents multiple difference-in-differences regressions for the impact of legalizing medical cannabis on auto insurers' *Loss Ratio*. Column (1) uses all of the data from all 3 lines. Column (2) only uses the states that legalize from 2016 to 2019 and never-treated states. Columns (3)–(5) subset by line. Standard errors (in parentheses) are clustered at the state level.

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.