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Can Anti-Vaping Policies Curb Drinking Externalities? Evidence from E-Cigarette Taxation and Traffic Fatalities

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ABSTRACT

Teenage drinking is a top public health concern, generating social costs of over $28 billion per year, including substantial external costs associated with alcohol-related traffic fatalities. At the same time, the high rate of electronic cigarette ("e-cigarette") use among teenagers has become a public health concern, with state and local policymakers turning to e-cigarette taxes as a tool to curb consumption. This paper is the first to explore the spillover effects of e-cigarette taxes on teenage drinking and alcohol-related traffic fatalities. Using data from five nationally representative datasets (the state and national Youth Risk Behavior Surveys, the Behavioral Risk Factor Surveillance Survey, the National Survey on Drug Use and Health, and the Fatality Analysis Reporting System) spanning the period 2003-2019, and a difference-in-differences approach, we find that a one-dollar increase in e-cigarette taxes is associated with a 1-to-2 percentage-point reduction in the probability of teenage binge drinking, and a 0.4 to 0.6 decline in the number of alcohol-related traffic fatalities per 100,000 16-to-20-year-olds in a treated state-year. A causal interpretation of our estimates is supported by (1) event-study analyses that account for heterogeneous and dynamic treatment effects, and (2) null effects of e-cigarette taxes on non-alcohol-related traffic fatalities.

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1. Introduction

Alcohol misuse imposes substantial costs on the United States. Each year, more than 140,000 Americans die from alcohol-related causes (Centers for Disease Control and Prevention 2022a) and alcohol-related healthcare, workforce, crime, and traffic accident costs exceed $315 billion (Sacks et al. 2015).[1] While some of these costs are private (e.g. established risks of future health conditions associated with alcohol use such as liver disease [O'Shea et al. 2010] or injuries to the individual attributable to alcohol-related accidents such as falls [Chikritzhs and Livingston 2021]), other costs are external in nature (e.g. alcohol-related motor vehicle accidents) or represent "internalities," wherein future costs of alcohol addiction are given insufficient weight in making current consumption decisions due to time-inconsistent preferences (Gruber and Kozsegi 2001). Given these high costs, reducing alcohol misuse has been listed a national health objective for the United States in each *Healthy People* report since the inception of this initiative in 1979 (CDC 2022b).[2]

Many of the external costs of alcohol misuse are generated by teenagers and young adults. While possession of and sales of alcohol to those under age 21 is illegal in the U.S., millions of teenagers continue to both use and misuse alcohol each year. In 2019, 20 percent of U.S. teenagers ages 16-to-18 drank in the last month and ten percent reported engaging in binge drinking[3] (NIAAA 2021). Annually, there are over 650,000 alcohol-related emergency department episodes involving teenagers (Naeger 2017) and more than 4,000 teen fatal alcohol poisonings (Lipari et al. 2017). One in ten teens reports drinking and driving (which translates to 2.4 million impaired driving episodes each month), and teens are estimated to be 17 times more likely to die in a traffic accident if they have a blood-alcohol content of 0.08 or higher; one teenager dies from drunk driving every 15 minutes (CDC 2012) and teen drivers account for 15 percent of passenger deaths of all ages (Insurance Institute for Highway Safety 2022). In total, the social costs of teenage alcohol misuse in the U.S. are estimated to be approximately $28 billion per year (CDC 2022d).[4]

In addition, standard cost-of-illness estimates of the effects of teenage drinking often exclude other important (sometimes difficult-to-measure) economic outcomes that may be adversely

[1] Inflated by the authors to 2022 dollars using the Consumer Price Index.
[2] The *Healthy People* Initiative is a set of health priorities for the nation that is released by the U.S. Department of Health and Human Services each decade. The Initiative "…identifies science-based objectives with targets to monitor progress and motivate and focus action." Please see https://www.cdc.gov/nchs/healthy_people/index.htm (last accessed 8/22/2022) for details.
[3] Binge drinking is defined as drinking five (four) or more drinks in one drinking session among males (females) (NIAAA N/D).
[4] Moreover, while teenagers under age 18 comprise just six percent of the population, they reflect nine percent of the total costs of alcohol misuse to the country (CDC 2022c).

affected by teenage drinking. For example, human capital development is impeded by alcohol misuse: drinking interferes with educational attainment through reduced attendance, impairment, and withdrawal symptoms ("hangovers"), and lack of motivation (Cook and Moore 1993; Grossman et al. 1994; DeSimone 2009; Sabia 2010). Risk-taking is developmentally normal for this age group, which further increases teens' vulnerability to impulsive and reckless behaviors such as alcohol misuse and associated actions (Steinberg 2010). Indeed, studies show that teenage drinking is linked with school violence (Markowitz 2007), crime (Carpenter 2005a, 2007; Carpenter and Dobkin 2015), suicidal behaviors (Carpenter 2004; Carpenter and Dobkin 2009), risky sexual behaviors and pregnancy (Dee 2001; Carpenter 2005b; Markowitz et al. 2005), and the use of harder substances (Kirby and Barry 2012), outcomes that often generate both external and internal costs.

The costs of teenage drinking may accelerate over the life course. Problem drinking-induced declines in human capital acquisition may harm employment trajectories and family formation (Becker 1964) even if alcohol misuse reflects a transitory behavior that teens "outgrow." Moreover, alcohol use disorder, a chronic condition that affects 15 million individuals ages 12-and-older (NIAAA 2022), emerges most often during an individual's teenage and young adult years and is often a lifetime condition that generates substantial socioeconomic costs (Rehm et al. 2009). Teenagers may fail to account for these future costs of youth alcohol use as the prefrontal cortex region of the brain — the region of the brain linked to rational decision-making and impulse control — continues to develop through one's early 20s; alcohol use can permanently alter its development (Squeglia et al. 2015; Pfefferbaum et al. 2018).

Addiction experts show that among young adults, those who begin drinking by age 15 are 5.6 times more likely to have alcohol use disorder than those who initiated drinking after age 20 (or did not drink) (NIAAA 2021) and economic research suggests that policies designed to curb teenage drinking can have long-run and positive impacts on life course alcohol use and associated consequences (Kaestner and Yarnoff 2011). Understanding and leveraging factors that increase or decrease teenagers' propensity to engage in alcohol misuse may therefore have potentially large social welfare effects, both immediately and in the longer term.

While teenage alcohol misuse and its associated consequences have been well-documented for decades, a new area of significant public health concern has arisen in recent years: high rates of teenage e-cigarette use (or electronic nicotine device systems, "ENDS"). ENDS are devices in which nicotine and other ingredients such as flavors are heated into a vapor and inhaled ("ENDS use" or "vaping"). ENDS were first imported into the United States in 2006 and by 2014 they overtook

cigarettes as the most commonly used tobacco product among teenagers. Coinciding with the popularity of JUUL, ENDS use rates among high-school students rose from less than 1.5 percent in 2011 to 11.7 percent in 2017 and then 28 percent in 2019, before falling following the onset of the COVID-19 pandemic in 2020.[5] While increased access to ENDS products has been documented to produce some tobacco-related public health benefits — including aiding in cigarette smoking cessation (Saffer et al. 2020; Dave et al. 2019a) and providing a less unhealthy alternative to combustible tobacco product use (National Academies of Sciences, Engineering, and Medicine 2018) — leading U.S. public health officials nonetheless remain concerned about high rates of teenage ENDS use. In 2018, the U.S. Surgeon General classified ENDS use among teens as an "epidemic."[6]

In response to surging ENDS use among youth, state and local governments have adopted policies aimed at reducing use, including prohibitions on sales to teenagers[7] and the most recent (and increasingly popular) policy lever to curb teenage vaping: taxation of ENDS.[8] Minnesota was the first state to adopt such a tax (2010) with more states adopting this policy in 2015-2016 (Louisiana, North Carolina, Pennsylvania, Washington DC, and West Virginia) and 2017-2019 (California, Connecticut, Delaware, Illinois, Kansas, New Jersey, New Mexico, New York, Ohio, Vermont, Washington, and Wisconsin) (Public Health Law Center 2022). Two large counties also adopted ENDS taxes over this time period: Cook County, Illinois in 2016 and Montgomery County, Maryland in 2015. By June 2022, 30 states and Washington DC tax these products (Public Health

[5] These rates are based on past 30-day use from the National Youth Tobacco Survey (NYTS). Current prevalence declined to 19.6 percent in 2020. Data collection for the 2020 NYTS took place from mid-January through mid-March, being truncated earlier due to school closures associated with the COVID-19 pandemic. The prevalence rate in 2021 fell to 11.3 percent, though methodological changes that took effect during the COVID-19 pandemic preclude comparisons of the 2021 data with the earlier surveys.

[6] The effect that ENDS use may have on youth public health remains a contested area of inquiry. The Surgeon General cited concerns that nicotine vaping itself is harmful to teens and that vaping may re-ignite teen smoking. However, the National Academies of Sciences, Engineering, and Medicine (2018) concluded, for instance, that ENDS contain far fewer toxicants than cigarettes. Rates of teen smoking declined by over 100 percent between 2011 and 2020 (CDC 2022c), which is at odds with "gateway effect" concerns (CDC 2016). Quasi-experimental research meanwhile suggests ENDS have contributed to driving down teen cigarette use rates. For example, several studies indicate that ENDS taxes increase cigarette consumption among teenagers (Abouk et al. 2021; Pesko and Warman 2022), young adults (Friedman and Pesko 2022), adults in general (Pesko et al. 2020), and pregnant women (Abouk et al. 2022), which suggests that ENDS and cigarettes are substitutes for many users. Thus, it is fair to conclude that public health concern over teen ENDS use is particularly acute for those teens who would not have otherwise used combustible tobacco products such as cigarettes.

[7] This culminated in the Food and Drug Administration ban, effective August 8, 2016, of ENDS sales to teens under the age of 18, and subsequently the federal law raising the minimum legal sales age to 21 for all tobacco products, including ENDS, on December 20, 2019.

[8] Stricter regulations on restricting ENDS are also supported by a majority of Americans (61 percent), across all party affiliations (Saad 2022).

Law Center 2022) (and 20 states had no tax). Among adopting states, ENDS tax rates vary substantially, with some states taxing standard ENDS pods[9] less than a nickel and others taxing ENDS more than cigarettes (Cotti et al. 2021). Several recent studies show that taxing ENDS has an intended public health effect of reducing teenage and adult ENDS use (Anderson et al. 2020; Abouk et al. 2021; Pesko et al. 2020), but also find that ENDS taxes increase cigarette use (Pesko et al. 2020; Abouk et al. 2021; Friedman and Pesko 2022), which clearly undermines the policy's tobacco-related public health goals, casting doubt on the efficacy of these taxes.

Despite the large social costs of teenage and young adult alcohol misuse, no study has explored the relationship between the taxation of ENDS, which is the most commonly used tobacco product among youth and whose taxes vary substantially across states, on alcohol-related behaviors. If the adoption of ENDS taxes causes a sizable reduction in the number of ENDS users, such a policy shock could generate important changes in alcohol use, which may include drinking-related externalities with substantial social costs. Understanding the general equilibrium effects of public health policies targeting ENDS use is necessary to document the full costs and benefits to society. Given its high costs, teenage and young adult alcohol misuse is a critical outcome to consider in such welfare calculations.

This study is the first to study the effects of ENDS taxes on teenage and young adult drinking and alcohol-related traffic fatalities. We combine difference-in-differences methods, including newly developed estimators that account for heterogeneous treatment effects over time, with five nationally representative datasets (the state and national Youth Risk Behavior Surveys, the Behavioral Risk Factor Surveillance Survey, the National Survey on Drug Use and Health, and the Fatality Analysis Reporting System) over the period enveloping ENDS introduction and ENDS taxation adoption in the U.S.

We document several key findings. First, we confirm that ENDS taxation reduces teen ENDS use, a one-dollar increase in ENDS taxes reduces teen vaping by 5.4 percentage points (or approximately 24 percent), a substantial effect. Then, drawing data on alcohol use, measured on both the intensive and extensive margins, we find that a one-dollar increase in ENDS taxes leads to a 1-to-2 percentage point reduction in the probability of teenage and young adult binge drinking. The effects are concentrated among those below the minimum legal drinking age (MLDA) for alcohol, ages 16-to-20, and appear larger when examining the intensive margin of drinking behavior

[9] A pod is a re-chargeable battery unit that can be refilled with vaping liquid.

(i.e. number of drinks consumed among drinkers and multiple binge drinking episodes). Event-study analyses, including those generated from both two-way fixed effects and stacked difference-in-differences approaches, are consistent with common pre-treatment trends and a causal impact of ENDS taxes on teen and young adult alcohol use. We find little evidence that alcohol use among those ages 21-and-older are affected by ENDS taxes. Next, we turn to an important external cost of teenage and young adult alcohol misuse: alcohol-related traffic fatalities. Our results indicate that a one-dollar increase in ENDS taxes results in a 0.4 to 0.6 decline in the number of alcohol-related traffic fatalities per 100,000 16-to-20-year-olds in a treated state-year. We find no evidence that ENDS taxes are related to teenage traffic fatalities that do not involve alcohol, consistent with the hypothesis that alcohol use is an important mechanism through which ENDS taxes reduces traffic fatalities. In summary, our results suggest that alcohol and ENDS are economic complements among teenagers and young adults, and that taxing ENDS generates important, policy relevant, and beneficial alcohol-related spillovers.

This paper is organized as follows. Section 2 provides background on alcohol and ENDS use. Data are outlined in Section 3 and Section 4 describes our methods. Our main results, robustness checking, and extensions are reported in Section 5. Finally, Section 6 offers a discussion.

2. Background

2.1 The Impact of Public Policies on Teenage and Young Adult Alcohol Use

While the importance of teenage alcohol misuse is well-established (Carpenter and Dobkin 2011), the ability of standard alcohol policy levers to meaningfully curtail teen drinking is unclear. The MLDA (age 21) has been shown to be effective at curbing underage alcohol misuse and alcohol-related mortality (Dee 1999a; Cook and Moore 2001; Carpenter and Dobkin 2009, 2011, 2017; Carpenter et al. 2016). For example, Dee (1999a) finds that exposure to a MLDA of 18 years (vs. 21 years) increases teen drinking by 3.7 percent. However, this policy has remained unchanged since the 1980s and there are few policymakers proposing increases in the MLDA.

Further, federal taxes (with some exceptions) on alcohol were set in 1991 and have remained unchanged; the tax rates are $0.58, $1.07, and $13.50 per gallon of beer, wine, and spirits, respectively (Saffer et al. 2022). While these taxes were (arguably) high when set over four decades ago, through inflation their potential impact has declined substantially. All states tax alcohol, but these rates have also remained (for all but a few states) relatively stable in nominal terms (thus, declining in real terms) since the mid-2000s (Saffer et al. 2022). The limited variation over time in

alcohol taxes likely leads to heterogenous findings across studies that seek to estimate the impact of such taxes on teen alcohol misuse (Cawley and Ruhm 2011). However, Carpenter et al. (2007) use the Monitoring the Future dataset, covering a long period of time – 1976 to 2003, and find that higher beer taxes do reduce teen drinking propensities. Taxes are a classic approach to correcting both market externalities and internalities (DeCicca et al. 2022), which suggests that the lack of recent policy action may allow over-consumption of alcohol (relative to the socially optimal level). This lack of policy activity to correct externalities is of particular relevance for teens who generally face tighter budget constraints and are potentially more price-sensitive than older individuals.

Economists have studied the impact of other policy levers designed to curtail teen alcohol misuse. For example, social host laws (Dills 2010), keg registration laws (Yoruk and Xu 2021), zero tolerance drunk driving laws (Carpenter et al. 2007), and scanner ID laws (Yoruk 2014; 2018; Zheng 2018; Nesson and Shrestha 2021). Social host laws (which hold adults legally liable for hosting underage drinking parties) have been shown to reduce teen alcohol-related traffic fatalities by nine percent (Dills 2010). Similarly, keg registration laws (which require retailers of alcoholic beverages to record the personal information of consumers purchasing kegs and apply warning labels to kegs) reduce the probability of past-month binge drinking among teens by eight percent (Yörük and Xu 2021). Zero-tolerance laws prohibit drivers under 21 years from consuming any alcohol when operating a motor vehicle (i.e., teens must have a blood alcohol content [BAC] of zero). These laws have been shown to reduce traffic fatalities among those 18-to-20-years of age (Carpenter 2004; Chang et al. 2012). For example, Carpenter (2004) demonstrates that zero-tolerance laws lead to a 13 percent reduction in underage heavy episodic drinking for male teens ages 18-to-20-years. Since 1988, all states have implemented zero tolerance laws, setting a limit of 0.02 percent BAC or lower (equivalent to about one drink for the average person) for drivers under the minimum legal drinking age of 21, indicating very little to no room on this front for further policy action to reduce alcohol-impaired driving among teens. Findings for scanner ID laws – these laws require restaurants, bars, and retailers of alcoholic beverages to use electronic scanners, which read birth date information stored in bar codes on the ID cards to confirm that those purchasing alcohol are of the MLDA – are decidedly mixed with some studies documenting that such laws reduce teen alcohol misuse (Yörük 2014, 2018; Nesson and Shrestha 2021) and others showing no effect (Zheng 2018).

2.2 ENDS Taxes and ENDS Use

A growing economics literature finds that ENDS taxes are effective at reducing ENDS use. This finding has been established using retail sales data (Allcott and Rafkin 2021; Cotti et al. 2022), survey data on adults and youth (Pesko et al. 2020; Abouk et al. 2021; Friedman and Pesko 2022), and birth record data on pregnant women (Abouk et al. 2022). For example, using the Nielsen Retail Scanner Database 2013 to 2019, Cotti et al. (2022) show that a one-dollar increase in the ENDS tax rate (which is a large increase as the mean tax rate is $0.18) leads to a 52 percent decline in ENDS sales at retail stores in the U.S., suggesting that ENDS and cigarettes are economic substitutes.[10]

More directly related to our study, two recent studies examine the impact of ENDS taxation on teen ENDS use (Abouk et al. 2021; Pesko and Warman 2022). These two studies document non-trivial declines in ENDS use and increases in cigarette use post-ENDS tax, again suggesting economic substitution among teens. For example, Abouk et al. (2021) establish that a one-dollar increase in the ENDS tax rate leads to a 12.5 percent ($\varepsilon = 0.08$) to 33.3 percent ($\varepsilon = -0.16$) reduction in current teen ENDS use.[11]

In addition, there is evidence that some adults, particularly younger adults may be impacted by ENDS taxes. Using survey data on adults drawn from the National Health Interview Survey and Behavioral Risk Factor Surveillance Survey over the period 2014 to 2018, Pesko et al. (2020) show that a one-dollar increase in the ENDS tax leads to a 0.5 percentage point (15.5 percent) decline in adult daily ENDS use, with effects driven by younger adults. In a recent study using the 2010-2019 Tobacco Use Supplements to the Current Population Survey, Friedman and Pesko (2022) document that a one-dollar increase in the ENDS tax leads to a 2.5 percentage point decline (57 percent) in current ENDS use among young adults (ages 18-to-25 years). Saffer et al. (2020) find that the first-in-the-nation ENDS tax in Minnesota increases smoking and reduces cessation among adults.

2.3 Relationships Between Alcohol and Cigarettes

Despite the long-standing interest in both alcohol and tobacco products, there is limited evidence as to whether these two substances are economic complements or substitutes. In a comprehensive review of the literature on smoking, DeCicca et al. (2022) argue that the relationship

[10] The authors show that ENDS taxes are passed on to consumers in terms of higher prices: the "pass-through" rate of taxes to prices is estimated to be 0.90, which implies that prices rise substantially post-tax (Cotti et al. 2022).
[11] Economic studies have also examined the impact of a broader set of ENDS policies on ENDS and cigarette use outcomes. For example, minimum legal sales ages reduce ENDS use (Abouk and Adams 2017; Dave et al. 2019b) and increase cigarette use (Friedman 2015; Pesko et al. 2016; Dave et al. 2019b; Pesko and Currie 2019). Laws that limit or prohibit ENDS use in public places have not been found to affect ENDS use (Friedman 2021; Nguyen and Bornstein 2021; Cheng et al. 2022).

between tobacco and alcohol (e.g. whether tobacco taxes "can induce substitution") is "…a burgeoning area of much importance that would benefit from more research by economists."

The majority of studies produced to date focus largely on adults. Indeed, a review of this literature suggests an indeterminate relationship between alcohol and tobacco products, with some finding evidence of economic substitutes (Goel and Morey 1997; Koksal and Wohlgenant 2016; Burton, 2022), others economic complements (Cameron and Williams 2001; Bask and Melkersson 2004; Adams and Cotti 2008; Pierani and Tiezzi 2009; Tauchmann et al. 2013; Ukert 2017), and still others no relationship (Decker and Schwartz 2000; Picone et al. 2004). Studies have also examined the impact of smoking bans in bars on alcohol-related traffic fatalities. For example, Adams and Cotti (2008) find that these bans increase alcohol-related traffic fatalities. While seemingly counter-intuitive, the findings suggest that smokers drive longer distances to localities without such a ban, and accidents occur when (intoxicated) drivers return home.

Studies examining youths also have generated mixed findings. Pacula (1998) leverages variation in the beer tax and finds that alcohol and cigarettes are economic complements among young adults.[12] Dee (1999b) and Shang (2015) using the MLDA and cigarette taxes, and indoor bans on smoking in bars (where alcohol is often consumed) as sources of variation respectively also find evidence of economic complementarity among teens and young adults. Markowitz and Tauras (2009) use variation in prices (not taxes) and document that alcohol and cigarettes are economic substitutes. In a study that uses variation attributable to the Master Settlement Agreement, a legal agreement in which several large tobacco companies were required to pay substantial funds to states to account for public health insurance costs of smoking within those states, Shrestha (2018) finds mixed evidence on this question. Some specifications suggest economic complementarity among teens and young adults and other specifications provide support for economic substitution. Finally, Dave et al. (2019b) explore the effects of the ENDS minimum legal sales age (MLSA) on teenage alcohol use. While coefficient estimates on binge drinking are suggestive of a decline, in association with the ENDS MLSA laws, they are not statistically significant.[13]

[12] Pacula's main focus is on marijuana and cigarettes, not alcohol and cigarettes.

[13] Dave et al. (2019b) study the state laws which predated the federal ENDS MLSA law at age 18 in August of 2016. The implied elasticity of the state MLSA laws on ENDS use, from this study, is substantially lower than that of ENDS taxation found in the other studies (for instance, Abouk et al. 2021), which may explain the weak spillover effects on binge drinking in addition to potential heterogeneity in the effects due to the localized age margin that is being impacted by these MLSA laws.

3. Data

Our empirical analysis draws data from five nationally representative datasets spanning the years 2003 through 2019 to study the spillover effects of ENDS taxes on youth and young adult (we use the term "teenagers" for brevity) binge drinking and traffic fatalities.[14] These datasets include the state (and, occasionally, national) Youth Risk Behavior Surveys (YRBS), the Behavioral Risk Factor Surveillance Survey (BRFSS), the National Survey on Drug Use and Health (NSDUH), and the Fatality Analysis Reporting System (FARS). Each dataset has advantages that complement the others, which we describe below.

3.1 Youth Risk Behavior Surveys (YRBS)

The primary survey data we use are drawn from a pooled cross-section of state YRBS surveys, spanning the years 2003 through 2019. These biennial surveys are coordinated by the Centers for Disease Control and Prevention (CDC) and are distributed to U.S. high school students in grades nine through 12 by state education and health department officials. For the purposes of our research, the state YRBS is useful because it includes information on teenagers' ENDS and alcohol consumption.

The state YRBS is a pencil-and-paper, school-based survey that is designed (when weighted) to be representative of the health behaviors of each state's high school population. Additionally, when pooling state YRBS surveys across states, the sample of states can be made representative of (largely public) U.S. high school-aged students.[15] Because we analyze a *state* policy change, the use of survey data designed to generate population-based estimates of *state-level* trends in risky health behaviors of high school students is an important advantage.

One disadvantage of the YRBS data is that these are self-reported survey data. While the self-reports of alcohol use are likely to measure consumption with error, if such measurement error is uncorrelated with ENDS taxes, estimated treatment effects relative to the mean of the dependent variable (in terms of percent changes) should be unbiased. To further address this concern, we

[14] We utilize data up to 2019 in order to bypass confounding effects, and shifts in sampling design and data collection efforts, over the COVID-19 pandemic.

[15] Specifically, the person-specific sample weights we generate make the sample representative of all 14-to-18-year-olds in the U.S. Our person-specific sample weights are calculated as the product of the normalized state YRBS person weight (renormalized to sum to one in each state-year) and the state-by-year-by race/ethnicity-by gender population data on 14-to-18-year-olds from the National Cancer Institute's (NCI) Surveillance, Epidemiology, and End Results Program (SEER). We note that some states, in some years, include private high schools in the sample frame.

supplement our self-reported alcohol measures with more objective measures of drinking behaviors, including alcohol-involved traffic fatalities (discussed below). The state YRBS surveys were largely distributed in January through June of the school year. Thus, our state YRBS data allow us to identify the effects of ENDS taxes for 11 of 13 treatment states as well as two large counties (see Appendix Table 1).[16]

While the state YRBS data are our primary YRBS-based data source because the data are representative of state-level student behaviors, we supplement these data with estimates from the national YRBS. The national YRBS survey is coordinated by the CDC but is administered separately from the state YRBS survey. The national survey fields identical questions on ENDS and alcohol use as the state surveys, and, when weighted, is designed to be representative of all U.S. high school students attending both public and private schools. The national YRBS includes one additional state that does not contribute to identification in the state YRBS (Minnesota), but also excludes one state that is available in the state YRBS (Kansas). The most important disadvantage of the national YRBS survey for the purposes of this study is that the data are not designed to be representative of state-level trends in high school students' risky health behaviors. This may introduce measurement error when attempting to estimate the health effects of a state policy.[17]

Our YRBS-based analysis begins by drawing data on teen ENDS use, which is collected during the 2015, 2017, and 2019 survey waves. Respondents are asked:

> "The next questions ask about electronic vapor products, such as JUUL, Vuse, MarkTen, and blu. Electronic vapor products include e-cigarettes, vapes, vape pens, e-cigars, e-hookahs, hookah pens, and mods... During the past 30 days, on how many days did you use an electronic vapor product?"

ENDS Use is set equal to one if the respondent reports using an electronic vapor product at least once in the past 30 days; it is set equal to zero otherwise. Weighted means show that 19.7 percent of U.S. high school students (as surveyed in the state YRBS) report ENDS consumption (see Appendix Table 2).

[16] Minnesota and the District of Columbia are the two treatment jurisdictions that do not contribute to identification in the state YRBS.

[17] In addition, following previous studies (see, for example, Abouk et al. 2021; and Rees et al. 2021), we generate an "augmented" combined YRBS dataset in which we augment the state YRBS with the national YRBS to maximize identifying variation. The results are qualitatively similar to those obtained when using the state YRBS survey.

Next, we turn to our alcohol consumption measures, which (with one exception) are available for a longer window than ENDS consumption variables, allowing us to explore trends in teenage alcohol consumption prior to the implementation of the first ENDS tax (in 2010 in Minnesota). Thus, we utilize data for the period 2003-2019 for these outcomes. *Any Alcohol Use* is generated using the following survey item:

> "During the past 30 days, on how many days did you have at least one drink of alcohol?"

Any Alcohol Use is set equal to one if the respondent reports any alcohol use in the last month and is set equal to zero otherwise. In the state (national) YRBS, we find that 35.7 percent (38.9 percent) of U.S. high school students report alcohol consumption.

In addition, during the period 2013 to 2019, respondents are asked about the maximum number of drinks they consume:

> "During the past 30 days, what is the largest number of alcoholic drinks you had in a row, that is, within a couple of hours?"

We generate an intensive margin of drinking, *Number of Drinks|Any Alcohol Use = 1*, set equal to the largest number of alcoholic beverages consumed by a drinker. Using the state YRBS data, we find that 4.5 drinks is the largest number of drinks consumed in a row by the average teenage drinker.

Turning to binge drinking, *Any Binge Drinking* is derived from responses to the following questionnaire item:

> "During the past 30 days, on how many days did you have four or more drinks of alcohol in a row, that is, within a couple of hours (if you are female) or five or more drinks of alcohol in a row, that is, within a couple of hours (if you are male)?"

Any Binge Drinking is set equal to one if a respondent reports having five or more drinks in a row at least one day during the prior month.[18] In addition, we also explore the more intensive margin of binge drinking. *Multiple Binge Drinking Episodes* is set equal to one if a respondent reports binge

[18] In 2017, this question was updated to account for differences in the definition of binge drinking by gender.

drinking two or more times in the prior month and zero otherwise. State YRBS data show that 19.9 percent and 13.0 percent of the respondents report binge drinking and multiple binge drinking episodes, respectively.[19]

Appendix Figure 1 shows trends in ENDS use, and Appendix Figure 2 shows trends in any alcohol consumption, binge drinking, and multiple binge drinking episodes over the sample periods under study. As Appendix Figure 1 demonstrates, ENDS use declined slightly between 2015 to 2017, at a time when a number of states adopted minimum legal purchasing ages of 18 for ENDS and ENDS taxes. However, the period 2017 to 2019 saw a substantial increase in ENDS use, most notably because sales of JUUL exploded in the tobacco market.

With respect to alcohol consumption the pattern shown in Appendix Figure 2 reflects that both any alcohol consumption and binge drinking fell steadily over the period 2003-2019. Binge drinking prevalence rates fell about 50 percent from approximately 26 percent in 2003 to 12 percent in 2019.

3.2 Behavioral Risk Factor Surveillance System (BRFSS)

To complement our YRBS-based analysis, which surveys U.S. high school students, we use the Behavioral Risk Factor Surveillance System (BRFSS) survey, which allows an examination of drinking behaviors among adults ages 18 and older. The BRFSS is a telephone survey designed to be representative of all U.S. adults. Until 2011, the BRFSS was conducted exclusively with landlines, but for the period 2011-2019, the survey samples individuals using both landlines and cellular phones (i.e., smartphones). Our main analysis sample for adult alcohol outcomes is drawn from the more homogeneous 2011-2019 sample, which includes respondents answering landlines and cellular phones.[20] Our analysis focuses on adults ages 18-to-20 (adults under the MLDA), younger adults ages 21-to-39 (at or over the MLDA), and older adults ages 40-and-older.[21]

First, like the YRBS, the BRFSS includes measures of ENDS consumption over a short window; in this case, the years 2016 through 2018.[22] BRFSS respondents are asked whether they currently "use e-cigarettes or other electronic vaping products" on "some days" "every day" or "not

[19] The rates are similar in the national YRBS, where 21.5 percent and 14.1 percent of the respondents report binge drinking and multiple binge drinking episodes, respectively.
[20] We note that this sample restriction only results in one state policy change out of 19 (Minnesota's ENDS tax enacted in 2010) being dropped as a source of identification. Our main estimated treatment effects are qualitatively similar if we include landline telephone data from 2009.
[21] The BRFSS data are available at: https://www.cdc.gov/brfss/ (last accessed 9/5/2022).
[22] The 2019 BRFSS does not include ENDS questions.

at all." *ENDS Use* is set equal to one if the respondent reports using ENDS or vaping products on "some days" or "every day" and zero otherwise. We find that 12.0 percent of adults ages 18-to-20, 7.2 percent of adults ages 21-to-39, and 2.7 percent of adults ages 40-and-older report current consumption of ENDS or other vaping products (see Appendix Table 3).

Over the broader analysis sample (2011-2019), BRFSS respondents are asked various questions about their alcohol consumption:

> "Did you drink any alcoholic beverages in past 30 days"

Any Alcohol Use is set equal to one if the respondent answers the above questionnaire item in the affirmative and zero otherwise. The mean rate of prior 30-day alcohol consumption for 18-to-20-year-olds over this sample period was 32.5 percent, 61.9 percent for 21-to-39-year-olds, and 50.0 percent for those ages 40-and-older (see Appendix Table 3). Respondents are also asked about their binge drinking behavior:

> "Considering all types of alcoholic beverages, how many times during the past 30 days did you have five or more drinks for men or four or more drinks for women on an occasion?"

Binge Drinking is a dichotomous variable set equal to one if the respondent reports binge drinking in the prior month. *Multiple Binge Drinking Episodes* is set equal to one if the respondent reports binge drinking at least three times in the last month. We find that 16.3 percent of 18-to-20-year-olds, 26.9 percent of 21-to-39-year-olds, and 11.6 percent of those ages 40-and-older report binge drinking in the last month. The respective rates of multiple binge drinking episodes among these age groups are 11.1 percent, 17.0 percent, and 7.5 percent, respectively.

In addition, we create measures of drinking on the intensive margin, including (1) the total number of drinks consumed in the last month by drinkers (*Number of Drinks |Any Alcohol Use=1*), and (2) an indicator for whether a respondent consumes 20 or more drinks in the last month (*20-or-More Drinks |Any Alcohol Use=1*) in the last month. The average number of drinks consumed by an 18-to-20-year-old drinker is 27.3; for 21-to-39-year-olds, the number is 24.0 and for those ages 40-and-older, the number is 22.2. We find that 11.6 percent of drinkers ages 18-20 and 21.7(16.9) percent of 21-to-39 (40-and-older) year-olds consume 20 or more drinks in the prior month.

3.3 National Survey on Drug Use and Health (NSDUH)

To supplement our use of the YRBS and BRFSS, we incorporate information on adult (ages 18-and-older) binge drinking and substance use using data from the 2003-2019 National Survey on Drug Use and Health (NSDUH). The NSDUH, administered by the Substance Abuse and Mental Health Services Administration (SAMSHA), is a household survey designed to be representative of the U.S. non-institutionalized population. The survey is administered in individuals' homes (including private homes, public housing, and non-institutional group quarters such as college dorms, rooming houses, shelters).[23] To address concerns of privacy and increase the likelihood of a truthful response, the survey is conducted via an individual audio computer-assisted self-administered interview.

Geocoded individual-level data are not easily available to researchers outside of SAMHSA (Balestra et al. 2021).[24] Thus, our analysis sample makes use of publicly available two-year overlapping state-by-year averages of binge drinking and illicit substance use. With respect to age, the publicly available data do not allow us to examine age cutoffs around the MLDA. Therefore, we draw data using the publicly available cutoff of age 26, focusing on those ages 18-to-25 and ages 26-and-older.

For the purposes of this study, a disadvantage of the NSDUH dataset is that it does not include questions about ENDS use. However, we can measure indicators of problem drinking behaviors including binge drinking and alcohol use disorder. First, *Binge Drinking* is defined as "drinking five or more drinks (for males) or four or more drinks (for females) on the same occasion (i.e., at the same time or within a couple of hours of each other) on at least one day in the past 30 days." We find that 39.7 percent of 18-to-25-year-olds and 22.5 percent of those ages 26-and-older report binge drinking in the prior month (see Appendix Table 4).

Alcohol use disorder is defined as meeting criteria for alcohol dependence or abuse based on definitions found in the 4th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV).[25] We find that under these criteria, 14.3 percent of 18-to-25-year-olds and 5.8 percent of those ages 26-and-older are classified as having an alcohol use disorder.

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[23] The NSDUH sample does not include residents of hospitals or homeless individuals not residing in shelters.
[24] At the time of writing, accessing the restricted use NSDUH data is difficult and cost-prohibitive (see Balestra et al 2021).
[25] See pages 44-45 of this CDC document for additional information: https://www.samhsa.gov/data/sites/default/files/reports/rpt32806/2019NSDUHsaeShortTermCHG/2019NSDUHsaeShortTermCHG/2019NSDUHsaeShortTermCHG.pdf (last accessed 9/5/2022).

3.4 Fatality Analysis Reporting System (FARS)

Finally, we draw administrative data from the Fatality Analysis Reporting System (FARS) to study traffic fatalities, with special attention to alcohol-related traffic fatalities. The FARS is a nationwide census of fatal injuries suffered in motor vehicle crashes on public roadways made available from the National Highway Traffic Safety Administration (NHTSA). Information on the conditions of each crash and the vehicles and persons involved is acquired from a variety of sources, including police crash reports, driver licensing files, vehicle registration files, state highway department data, emergency medical services records, medical examiners' reports, toxicology reports, and death certificates.[26]

We focus on the period from 2003-2019 and generate a state-by-year panel of traffic fatalities for those ages 18-to-20, ages 21-to-39, and 40-and-older. Given our interest in traffic fatalities involving alcohol, we make use of information collected on Blood Alcohol Content (BAC) of the driver as well as the timing of the accident given that the alcohol-related fatalities frequently occur on nights and weekends (Dee 1999a).[27,28]

Our main outcomes are *Total Traffic Fatalities*, *Traffic Fatalities with Driver BAC > 0*, *Traffic Fatalities with Driver BAC > 0.1, Traffic Fatalities with Driver BAC = 0, and Weekend* versus *Weekday Traffic Fatalities.* Appendix Table 5 reports descriptive statistics for the (1) count of traffic fatalities, and (2) rate of traffic fatalities per 100,000 population (each by age, BAC of driver, and day of accident). Over the 2003-2019 period, we estimate a traffic fatality rate (total fatal injuries suffered in motor vehicle accidents) among 16-to-20-year-olds to be 18.7 per 100,000 teenage population; for 21-to-39-year-olds 15.9 per 100,000 population ages 21-to-39; and for those ages 40-and-older, 13.0 per 100,000 population ages 40-and-older. For traffic fatalities where the BAC of the driver is reported, the rate of traffic fatalities involving 18-to-20-year-old drivers with a BAC > 0 was 4.5 per 100,000 population. For those ages 21-to-39 and 40-and-older, the numbers are 5.9 and 2.5, respectively.

[26] The FARS data are available here: https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars (last accessed 9/5/2022).

[27] Information on BAC of the driver is available for approximately 63 percent of all traffic fatalities over the 2003-2019 period. Information on the timing of the accident (weekday, weekend) is available for nearly all (99 percent) traffic fatalities.

[28] Because BAC of drivers is likely measured with error (for instance, because some states expend more resources to collect this information) (Eisenberg 2003), we supplement our analysis by exploring crashes that occur on weekends, which are more likely to include alcohol-related fatalities.

Appendix Figure 3 shows trends in traffic fatality rates for 16-to-20-year-olds (panel a), 21-to-39-year-olds (panel b), and those ages 40-and-older (panel c) over the period 2003-2019. We find that traffic fatality decreases rapidly for young adults from 7.2 to 2.1 per 100,000 population during 2003-2019. For adults ages 21-to-39, the decline in traffic fatalities is less rapid, from 7.1 per 100,000 population in 2003 to 4.4 in 2019. Lastly, among adults older than 40, the traffic fatality rate is smallest and declines only slightly from 2.7 to 2.1 during the same period (Berning and Smither 2014).

3.5 ENDS Taxes

Our main policy variable of interest is the state or local ENDS tax rate. State ENDS taxes are levied either through an ad valorem tax on wholesale prices, as excise tax per unit or fluid mL of liquid, or as a special sales tax. To generate a comparable ENDS tax measure across states and over time, Cotti et al. (2021) produce a standardized tax per fluid mL measure, which we use in this study.

Figure 1 and Appendix Table 1 shows the rollout of ENDS taxes in the U.S. between 2010 and 2019, along with the magnitude of these increases. Minnesota was the first state to enact a statewide ENDS tax in 2010; by late 2019, 17 states, the District of Columbia, two large counties (Cook County, Illinois and Montgomery County, Maryland) and one large city (Chicago, Illinois) had enacted ENDS taxes.[29] By June 2022, 30 states had adopted ENDS taxes (Public Health Law Center 2022).

4. Methods

4.1 Primary Difference-in-Differences Regressions

We begin by drawing data from the state YRBS, national YRBS, and BRFSS and estimate two-way fixed effects (TWFE) "difference-in-differences" regressions of the following form via ordinary least squares (OLS):

$$Y_{ist} = \gamma_0 + \gamma_1 ENDS\ Tax_{st} + \boldsymbol{X}_{st}\boldsymbol{\beta} + \boldsymbol{Z}_{it}\boldsymbol{\kappa} + \alpha_s + \theta_t + \varepsilon_{ist}, \quad (1)$$

where Y_{ist} is an indicator for whether respondent *i* residing in state *s* in survey wave *t* engaged in the risky behavior described above (ENDS use, alcohol use, binge drinking, drinking-and-driving).

[29] We incorporate local taxes at the state-level based on the share of the population residing in the localities.

The primary independent variable of interest, $ENDS\ Tax_{st}$, measures the standardized ENDS tax per mL of fluid (adjusted to 2019 dollars). Our control variables include $\mathbf{X}_{st}$, a vector of state-specific, time-varying controls, including macroeconomic conditions (unemployment rate and poverty rate), other tobacco control policies (the presence of an ENDS MLSA, per pack state excise tax on cigarettes, an indicator of whether there is a state indoor ENDS use restriction in restaurants, bars, or workplaces, an indicator for whether there is an indoor smoking restriction in restaurants, bars, or workplaces, and statewide Tobacco-21 laws), and alcohol and marijuana control policies (beer tax per gallon, medical marijuana laws, and recreational marijuana laws) [30]; $\mathbf{Z}_{it}$, a vector of individual demographic controls (in the YRBS: gender, age, race/ethnicity, and grade; in the BRFSS: gender, age, educational attainment, race/ethnicity); α_s, a time-invariant state effect; and θ_t, a state-invariant survey wave effect.

In addition, we explore the sensitivity of our key policy parameter of interest, γ_1, to the inclusion of treatment state-specific linear time trends and census region-specific year effects:

$$Y_{ist} = \gamma_0 + \gamma_1 ENDS\ Tax_{st} + \boldsymbol{X}_{st}\boldsymbol{\beta} + \boldsymbol{Z}_{it}\boldsymbol{\kappa} + \alpha_s + \theta_t + \pi_e * t + \varepsilon_{ist}, \quad (2a)$$

$$Y_{ist} = \gamma_0 + \gamma_1 ENDS\ Tax_{st} + \boldsymbol{X}_{st}\boldsymbol{\beta} + \boldsymbol{Z}_{it}\boldsymbol{\kappa} + \alpha_s + \theta_{rt} + \varepsilon_{ist}, \quad (2b)$$

where $\pi_e * t$ is a treatment-state-specific linear time trend.[31] θ_{rt} is a region-specific year fixed effect (subscript *r* here represents one of four Census regions). With regard to the treatment-state-specific linear time trends, their purpose is to reduce potential omitted variable bias caused by unobserved state (linear) trends. However, we note that this control could introduce bias in the estimated treatment effect by obscuring (true) dynamic treatment effects (see, for example, Wolfers 2006; Meer and West 2016) or isolating identifying variation that is correlated by other spurious factors (Neumark et al. 2014).

[30] The source for ENDS taxes is Cotti et al. (2021). State cigarette taxes are obtained from the CDC STATE system, state beer taxes are obtained from the Tax Foundation, demographic shares of state populations are obtained from the Surveillance, Epidemiology, and End Results Program (SEER), poverty rates are obtained from University of Kentucky Poverty Research Center, unemployment data from the Bureau of Labor Statistics, effective dates for recreational and medical marijuana legalization are obtained from Anderson and Rees (2021), the Prescription Drug Abuse Policy System (PDAPS), and ProCon.org. State Tobacco-21 laws are obtained from Hansen et al. (2021). State clean indoor air laws are obtained from the CDC STATE system. The minimum legal sales ages for ENDS and cigarette MLSAs are always identical; therefore, we control for just the presence of an ENDS MLSA since we separately control for the cigarette MLSA age.

[31] Subscript *e* here is an indicator coded as one for states that adopt an ENDS tax by 2019; otherwise, it is zero.

Similarly, region-specific year effects are included (in equation 2b) to control for unmeasured common shocks faced by states within census regions. These controls effectively limit counterfactuals for treatment states to be located within the same census region ("close controls"). This could reduce bias in estimated treatment effects if geographically proximate states are more credible counterfactuals but could also exacerbate bias if they are not (Neumark et al. 2014). Given these tradeoffs, our approach is to examine the sensitivity of the estimate of γ_1 across the specifications described in equations (1), (2a), and (2b).

We then turn to the NSDUH data, which are provided at the state-by-(two) year-level, to estimate the following TWFE regression via OLS:

$$Y_{st} = \gamma_0 + \gamma_1 ENDS\ Tax_{st} + \mathrm{X}_{st}\beta + \alpha_s + \theta_t + \pi_e * t + \epsilon_{st}, \qquad (3)$$

where Y_{st} denotes the prevalence rate of the outcome of interest (binge drinking, alcohol use disorder) for adults in state *s* and year(s) *t*. Because the NSDUH data are provided in two-year averages, each of our right-hand side variables is also a two-year average. In addition, the vector $\mathbf{X}_{st}$ includes state-level demographic controls, including the share of the state population that was female, Black, Hispanic, and college educated. As above, we explore the sensitivity of our estimated treatment effect to controls for a treatment state-specific linear time trend ($\pi_e * t$).

Finally, we turn to the FARS data, which are provided at the state-by-year level, and estimate the following regression via OLS:

$$\ln \lambda_{st} = \gamma_0 + \gamma_1 ENDS\ Tax_{st} + \boldsymbol{X_{st}\beta} + \alpha_s + \theta_t + \pi_e * t + \mu_{st}, \qquad (4)$$

where λ_{st} is the age-specific traffic fatality rate (number of traffic fatalities per 100,000 population) in state *s* and year *t*. In robustness checks, we also add an extended set of controls to the vector X_{st} to capture policies related to traffic laws such as seat belt laws and 0.08 BAC laws.[32] Moreover, we also explore the robustness of our findings to changes in the functional form of the specification (i.e., using levels rather than logs of the traffic fatality rate), treatment of zero fatality counts, which account for 2.3 percent of all observations (i.e., dropping zero fatalities versus recoding them as one or 0.1), and use of a fixed effects Poisson specification.

[32] Most states had a BAC of 0.08 by 2003 (when we begin our analysis), but four states adopted this policy in the early years (Colorado, Delaware, Minnesota, and West Virginia).

The key policy parameter of interest in equations (1) through (4), γ_1, captures the partial effect of a one-dollar (in 2019 dollar) increase in ENDS taxes on alcohol-related outcomes. γ_1 is identified from state-specific changes in ENDS taxes. Between 2010 and 2019, 17 states, the District of Columbia, and two large counties adopted ENDS taxes. Appendix Table 1 lists the effective dates of these policies, the magnitude of the tax, and whether the state contributed to identification in each of the datasets examined in this study.

The common trends assumption underlying our identification strategy may be violated if ENDS taxes are adopted in response to trends in risky behaviors or if state-specific time-varying unobservables are correlated with the ENDS taxes and the outcomes under study. We undertake a number of strategies to assess the validity of the common trends assumption. First, we estimate event-studies to explore the estimated treatment effect over time. We employ the approach developed by Schmidheiny and Shiegloch (2019) and Rees et al. (2021) for specifying an event-study analysis for a continuous treatment and estimate the following regression (first, using the YRBS and then analogously for the other datasets):

$$Y_{ist} = \gamma_0 + \sum_{j=\underline{J}}^{-1} \pi_j D_{st} + \sum_{j=0}^{\bar{J}} \emptyset_j D_{st} + \boldsymbol{X}_{st}\boldsymbol{\beta} + \boldsymbol{Z}_{it}\boldsymbol{\kappa} + \alpha_s + \theta_t + \varepsilon_{ist}, \quad (5)$$

where *t* represents survey years, *j* represents event time, π represents the effects of an ENDS tax increase on the outcome Y_{ist}, and D_{st} represents the state-by-year variables equal to the difference in ENDS taxes between year *t* and *t-1*. Event time *j* = -1 is omitted to normalize the estimates of π_j to zero in that wave. If the estimates of π_j are small and statistically indistinguishable from zero, this pattern of results would tend to support the common trends assumption.

Second, recent developments in the difference-in-differences literature suggest that in the presence of heterogeneous and dynamic treatment effects, estimates of γ_1 from equation (1) and π_j from equation (5) may be biased (Goodman-Bacon 2021; Sun and Abraham 2021). For example, such bias could be introduced if (1) earlier-adopting (ENDS tax) states are poor controls for later-adopting states due to dynamic treatment effects across adoption timing, or (2) heterogeneity in adoption timing gives greater (less) weight to jurisdictions that enact ENDS taxes around (away from) the mid-point of the panel.[33] To expunge these potential biases, we turn to a stacked

[33] A total of 32 states are "never-adopters" of ENDS taxes over our sample period.

difference-in-differences approach (Cengiz et al. 2019), which, in the context of our "natural experiment" involving a continuous treatment, has the advantage of allowing us to account for not only the presence of the tax, but also the magnitude of the tax (Abouk et al. 2021).

To implement this approach, we select a common event window around the adoption of an ENDS tax.[34] We then create a cohort for each treatment state (one that implemented an ENDS tax) that includes control states that never implemented ("never adopters") and have not-yet adopted an ENDS tax ("not-yet-adopters"). This selection of counterfactuals ensures that two-way comparisons of "later versus earlier" adopting states are eliminated from the estimated treatment effect. The common event window for each treatment cohort mitigates concerns related to differential treatment variance weights given to each treated unit in the standard difference-in-differences estimation. We note that states which implemented different tax rates (even at the same time) are treated as unique cohorts. We then stack each treatment state cohort and estimate the following regression (first in the YRBS, and then subsequently with the remaining datasets):

$$Y_{icst} = \gamma_0 + \gamma_1 ENDS\ Tax_{st} + \boldsymbol{X}_{st}\boldsymbol{\beta} + \boldsymbol{Z}_{it}\boldsymbol{\kappa} + \alpha_{cs} + \theta_{ct} + \mu_c + \varepsilon_{icst}, \qquad (6)$$

where *c* denotes the cohort (each treatment state and its controls) μ_c is a cohort fixed effect, α_{cs} is a cohort-specific state effect, and θ_{ct} is a cohort-specific survey year effect. In addition to obtaining the overall treatment effect, we also re-estimate event-study coefficients (originally produced in equation 5) using this stacked difference-in-differences approach.

5. Results

Our main findings appear in Tables 1 through 10 and Figures 2 through 5. Supplemental analyses are presented in the appendix tables. All regressions are weighted[35] and standard errors are clustered at the state level (Bertrand et al. 2004).

5.1 Adolescent ENDS and Alcohol Use

[34] In the YRBS, this event window is three waves prior to the tax and one wave following the tax. For state-level datasets (i.e., FARS), the event window is four years prior to the tax and one year following the tax.

[35] In analyses of state and national YRBS, we use weights provided by the CDC. Population weights are used in analyses of the NSDUH and FARS.

Panel I of Table 1 presents "first stage" estimates of the effect of ENDS taxes on ENDS use among U.S. high school students using the state YRBS data. Controlling for state fixed effects, wave fixed effects, and individual demographic characteristics (age, gender, race/ethnicity, grade in school), we find that a one-dollar increase in the ENDS tax is associated with a statistically significant 3.4 percentage-point decline in prior-month ENDS use among U.S. high school students (column 1). The inclusion of socioeconomic controls (state unemployment rate, state poverty rate) has very little impact on the estimated treatment effect (column 2). However, the inclusion of controls for other tobacco policies (Tobacco-21 laws, MLSA laws for ENDS, state cigarette excise taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions), increases the absolute magnitude of the estimated treatment effect to 5.4 percentage-points. In our preferred specification (column 4), which also includes controls for alcohol and marijuana policies (medical and recreational marijuana laws and beer taxes), we find that a one-dollar increase in ENDS taxes is associated with a statistically significant 5.4 percentage-point decline in ENDS use. This corresponds to a 24 percent decline in ENDS use relative to the pre-treatment mean of youth ENDS use in the treatment states.[36]

While data on ENDS use is only available in three waves of the YRBS (2015, 2017, 2019) thereby precluding a formal event-study analysis, in column (1) of Appendix Table 6, we descriptively explore whether the decline in youth ENDS use precedes rather than follows the enactment of an ENDS tax. We include a dummy variable for the period prior to the adoption of an ENDS tax. There is no evidence that that ENDS use fell before the adoption of the tax.

In panel II, we present results using the national YRBS. Across specifications, the pattern of results continues to show that ENDS taxes are an effective policy tool to reduce youth ENDS use. TWFE estimates consistently show that a one-dollar increase in ENDS taxes leads to a 3.7-to-6.9 percentage-point decline in prior-month ENDS use among U.S. high school students.[37] Results from both state and national YRBS are largely consistent with those reported by Abouk et al. (2021).

Establishing the first stage effect of how ENDS taxes have impacted ENDS use is important for framing what the maximal effect would potentially be if there are spillover responses into alcohol

[36] The implied ENDS participation tax elasticity, based on the mean participation and tax rate for the treated units, is -0.234; this is consistent with YRBS estimates from Abouk et al. (2021).

[37] In unreported results available upon request, we show estimates from a sample in which we combine the state and national YRBS datasets and apply the approximated sample weights estimated by Abouk et al. (2021) and Rees et al. (2021). This approach only adds one additional state to contribute to identification relative to the individual state and national YRBS. In the combined YRBS, we continue to show that ENDS taxes are associated with statistically significant and economically meaningful declines in ENDS use among youths, on the order of 7.2 percentage-points.

consumption given that these teens (those who shift their ENDS consumption in response to the taxes) represent the affected group. Effects on drinking behaviors that we estimate are an intention-to-treat (ITT) effect. Most youth in the population would not be affected by ENDS taxes, and thus the estimated reduced-form drinking response is an average across two groups – those who are potentially affected by ENDS taxes and those who are not.

Thus, having confirmed a first stage effect of ENDS taxes on teen ENDS use, we now turn to our primary outcome of interest, teen alcohol consumption. In panel I of Table 2, we find that ENDS taxes are negatively, but insignificantly related to alcohol consumption on the extensive margin, behavior that includes both lighter or experimental drinking and alcohol misuse. However, the results shown in the remaining panels suggest that ENDS taxes may have important effects on (1) drinking behavior on the intensive margin, as well as (2) heavier drinking episodes.

First, in panel II, we find that a one-dollar increase in ENDS taxes leads to a 0.29 to 0.34 fewer average drinks per sitting among those youth who consume alcohol. This finding corresponds to a 6.5 to 7.6 percent reduction in the average number of drinks consumed, suggesting a potentially important effect on the intensive margin of youth alcohol use.

Moreover, in panels III and IV of Table 2, we find strong evidence that ENDS taxes are associated with a reduction in youth binge drinking. A one-dollar increase in ENDS taxes is associated with a 2.2-to-2.3 percentage-point reduction in prior-month binge drinking and a 1.1-to-1.4 percentage-point reduction in prior-month multiple binge drinking episodes among U.S. high school students. Relative to pre-treatment means in these outcomes, these effects correspond to 10-to-11 percent and 8-to-10 percent reductions, respectively. These results are consistent with the hypothesis that heavier drinking and ENDS use are complementary behaviors among teens.

Importantly, with respect to our binge drinking results, we note that the estimated marginal effects from our preferred specifications (column 4 of panels III and IV) show an effect size that is 60 to 70 percent smaller than the "first stage" effect on ENDS use (column 4, panel I, Table 2).[38]

[38] To frame the spillover effects on binge drinking in context, we can use the first stage analyses (Table 1) to calculate a back-of-the-envelope treatment-on-the-treated (TOT) effect. The first-order effects of ENDS taxes on ENDS use (Table 1) indicated approximately a five to seven percentage point decline; using these magnitudes to rescale the reduced-form effects on binge drinking (Table 2) implies a TOT of about 0.33 to 0.42. In other words, about two out of every five teens, who on the margin reduce their ENDS use in response to higher taxes, also reduce their binge drinking behavior. These estimates should be interpreted with caution and are meant to be suggestive since TOT estimates rescaled in this way can be sensitive to relatively small changes in the underlying first stage estimates. Nevertheless, that this "marginal propensity" of complementary changes in binge drinking, induced by tax-driven changes in ENDS use, is very much in line with the observed "average propensity" of 0.4 (about 40 percent of ENDS users in the YRBS binge drink) adds a degree of credibility to the magnitudes of the second-order binge drinking effects.

And from a social welfare perspective, more frequent and heavier drinking may be more important margins of behavior with which to be concerned, as heavier drinking is more closely linked to negative externalities (and internalities) than light or experimental drinking.

In Appendix Table 7, we repeat the above analysis using the national YRBS sample. The pattern of findings is qualitatively similar to what we report for the state YRBS: ENDS taxes are negatively related to binge drinking, consistent with a complementary relationship. Moreover, in Appendix Table 8, we restrict the state YRBS analysis sample to the 2015-2019 period (to replicate the window over which we measured ENDS consumption) and find a similar pattern of results to those shown in Table 2. We also detect evidence of ENDS tax-induced statistically significant declines in youth alcohol use, as measured on the extensive margin (Panel I).

One concern with the above alcohol estimates is that they could be contaminated by differential pre-treatment trends in youth alcohol use in treatment versus control states. In columns (2) through (4) of Appendix Table 6, we find no evidence that youth alcohol use declined more in treatment versus control states in the year prior to ENDS tax adoption.

Figure 2 shows formal event-study analyses for our binge drinking outcomes, where our panel is sufficiently long to measure pre-treatment and post-treatment trends. Reassuringly, an examination of pre-treatment trends for binge drinking and multiple binge drinking episodes supports the common trends assumption, including in models without (panels a and c) and with (panels b and d) treatment state-specific linear time trends. We find that divergence in binge drinking rates between treatment and control states occurs after the adoption of an ENDS tax increase.

As noted above, one concern with our TWFE estimates of the treatment effect is that they may be biased in the presence of heterogeneous and dynamic treatment effects (Goodman-Bacon 2021). In Table 3, we present findings from stacked difference-in-differences estimates where we select an approximately balanced event time window (three waves prior to tax adoption and at most two waves following adoption) and limit the set of counterfactual states to those that had never adopted an ENDS tax by 2019 or not-yet adopted an ENDS tax within the event time window. We continue to find that ENDS taxes reduce the number of drinks consumed by drinkers and binge drinking behaviors. For instance, in our fully specified model (column 4, Table 3), we find that a one-dollar increase in ENDS taxes is associated with 0.36 fewer drinks among youth drinkers, a 2.3 percentage-point decline in binge drinking, and a 0.35 percentage-point decline in multiple episodes of binge drinking. An examination of event-study analyses of our binge drinking outcomes using

stacked difference-in-differences estimators (Figure 3) continues to support the common trends assumption, with pre-treatment coefficients that are statistically indistinguishable from zero.

In Table 4, we explore the sensitivity of our estimated treatment effects in Table 2 to the inclusion of controls for spatial heterogeneity. Specifically, we examine whether controlling for region-specific time shocks — which forces treatment states to have geographically proximate counterfactuals ("close controls") — significantly impacts our estimated treatment effects. While the ENDS tax effects are less precisely estimated, the pattern of findings is qualitatively similar (column 2 vs column 1). In addition, the inclusion of additional controls for treatment state-specific linear time trends to control for differential trends of the tax-adopting states as compared to never adopting states also generally shows a consistent pattern of results (column 3 vs column 1). We therefore conclude that unmeasured spatial heterogeneity is not an important source of bias in the estimated effects of ENDS taxes.

We next explore whether ENDS taxes reduce joint ENDS use and binge drinking. Indeed, Table 5 provides consistent evidence that ENDS taxes are associated with a decline in dual use of ENDS products and alcohol (in binge drinking form). In our preferred specification (column 4), we find that a one-dollar increase in ENDS taxes is associated with a 2.8 percentage-point reduction in ENDS use *and* binge drinking (panel I) and a 2.0 percentage-point reduction in ENDS use *and* multiple binge drinking episodes.

Finally, in Table 6, we explore heterogeneity in the effects of ENDS taxes by gender (columns 1 and 2), age (columns 3 and 4), and race/ethnicity (columns 5 through 8). In the main, our results show that the estimated spillover effects of ENDS taxes persist among each of the demographic groups under study with the exception of one: for number of drinks consumed among drinkers, we find that our overall reductions in alcohol use on the intensive margin are driven largely by non-Hispanic Whites.

5.2 Adult Alcohol Use

In Table 7, we explore the effects of ENDS taxes on ENDS and alcohol use among adults, with particular attention to those younger and older than the MLDA (age 21). First, we again establish a strong first stage. We find that a one-dollar increase in ENDS taxes is associated with a 2.2 percentage-point decline in prior-month ENDS use for those ages 18-to-20 (column 1), which translates to a 16.6 percent decline relative to the pre-treatment mean. Similarly, for adults ages 21-to-39 (panel II), we find that a one-dollar increase in ENDS taxes is associated with an albeit smaller

and marginally significant 0.32 percentage point (4.6 percent) reduction in ENDS use. However, we find no evidence that ENDS taxes are effective at reducing ENDS use among those ages 40 and older, the population with a 77 percent lower rate of baseline ENDS use than 18-to-20-year-olds. Thus, the first stage effects appear concentrated among younger adults ages 18-to-39, and in particular younger adults below the MLDA. In the main, these findings are consistent with those of Pesko et al. (2020).

Turning to spillover effects on drinking-related outcomes among adults, we find that ENDS taxes are associated with significant declines in both alcohol consumption and binge drinking, but only among those age groups whose ENDS use is responsive to taxation. Notably, a one-dollar increase in ENDS taxes is associated with a 2.4 percentage-point decline in the probability of any alcohol use in the last month among 18-to-20-year-olds, 1.9 percentage-point decline in the probability of binge drinking (panel I, column 3) and a 1.5 percentage-point (approximately 12 percent) decline in the probability of multiple episodes of binge drinking (panel I, column 4). Consistent with our YRBS-based results, the magnitudes of these spillover effects are around 30 to 60 percent smaller than those obtained for ENDS use, suggesting spillover effects that are of plausible magnitude. We also find that ENDS taxes affect the intensive margin of consumption, reducing the average number of drinks consumed by young adult drinkers (columns 5 and 6). For example, we find that a one-dollar increase in ENDS taxes is associated with a 1.6 percentage-point reduction in the probability that an 18-20-year-old drinker consumes 20-or-more drinks in the last month. In contrast to young adults under age 21, for those ages 21-to-39 and 40-and-older, we find no evidence of important spillover effects on any alcohol use or binge drinking; this is validating given that there does not appear to be any significant or substantial first stage effect on their ENDS use to generate any downstream spillover effects.

In Figure 4, we show event-study analyses of the effect of ENDS taxes on binge drinking for 18-to-20-year-olds using TWFE (panel a) and stacked difference-in-differences (panel b) estimators. Our results provide evidence that supports both the common trends assumption and the hypothesis that ENDS taxes drive declines in binge drinking, with null estimated treatment effects in the pre-treatment period and significant declines materializing only following tax enactment, particularly in the shorter-run.[39]

[39] In Appendix Table 9, we take the alternate approach of including a dummy for the year prior to the enactment of an ENDS tax. Consistent with the event-studies, the pattern of findings is consistent with the hypothesis that treatment and control states did not differ in (conditional) pre-treatment levels of ENDS use or binge drinking among 18-to-20-year-olds.

In Table 8, we bring in the NSDUH data into our analyses, which allow us to assess effects on a DSM-based measure of problem drinking (alcohol use disorder) as well as replicate the previously discussed effects on binge drinking for a different surveillance dataset. While publicly available data do not allow us to separate effects around the MLDA, we can explore the effect of ENDS taxes on binge drinking and alcohol use disorder separately among 18-to-25-year-olds and those ages 26-years-and-older. Consistent with the BRFSS based results, we find that a one-dollar increase in ENDS taxes is associated with a 1.0 percentage-point decline in binge drinking for 18-to-25-year-olds (column 1) and a 0.8 percentage-point decline in binge drinking for those ages 26-and-older (column 3). Each of these estimated effects is statistically distinguishable from zero at the ten percent level. We also find evidence of a negative relationship between ENDS taxes and alcohol use disorder (columns 2 and 4), suggesting that problem drinking may be curbed by ENDS taxes.

5.3 Traffic Fatalities Results

Together, our findings above point to strong evidence that ENDS taxes are negatively related to binge drinking and total number of drinks consumed among drinkers. The effects are most prominent among high school-aged teenagers and those ages 18-to-20. In Table 9, we explore the effect of ENDS taxes on an important social cost of teenage drinking: alcohol-related traffic fatalities.

Table 9 presents estimates of the effects of ENDS taxes on traffic fatalities among 16-to-20-year-olds, generated from equation (4). First, we find that ENDS taxes are essentially unrelated to total traffic fatalities among 16-to-20-year-olds (columns 1 and 2), though the estimated sign is negative. When we separate fatalities by whether the driver has a BAC = 0 (column 5) as compared to a BAC > 0 (column 3) or BAC > 0.10 (column 4), our results show consistent evidence of an ENDS tax-induced decline in alcohol-involved traffic fatalities. Specifically, for those 16-to-20 years, the age demographic for whom we found the largest declines in binge drinking in the YRBS and BRFSS, we find that a one-dollar increase in ENDS taxes is associated with a 10.4 percent decline in the number of traffic fatalities where the BAC of the driver is greater than zero (column 3) or greater than 0.1 (column 4).[40] In contrast, the effect estimates of the effect of ENDS taxes on traffic fatalities when the BAC of the driver is zero is smaller in absolute magnitude and statistically

[40] Note that over the sample period under study, a BAC > 0 for a driver ages 16-to-20 would violate the zero-tolerance drunk driving law enacted in each state.

indistinguishable from zero at conventional levels (column 5). This pattern of findings is consistent with an alcohol-driven traffic fatality decline, consistent with the decline in binge and problem drinking, rather than an effect driven by a shift in driving behavior per se.[41] Conservatively, if we take the difference between the estimate in column (3) and (5), "difference-in-difference-in-differences (DDD)" results imply an approximately 5-to-9 percent decline in alcohol involved traffic fatalities among 16-to-20-year-olds. This translates to approximately 2 fewer alcohol-related traffic fatalities per state-year for 16-to-20-year-olds.[42]

Given that BAC of the driver may be poorly measured, we also explore weekend (column 6) versus weekday (column 7) fatalities given that alcohol-related traffic fatalities disproportionately occur on weekends and that day-of-week data are available for 99 percent of all traffic fatalities (as compared to around 60 percent of all accidents that include results of BAC tests for drivers). Our results show that a one-dollar increase in ENDS taxes is associated with a 8.7 percent decline in weekend traffic fatalities (column 6). We find a small and statistically insignificant effect for the effect of ENDS taxes on weekday traffic fatalities.

In panel II, we augment our baseline controls with additional driving-related controls, including seat belt laws, MLDAs, and 0.08 BAC laws. The pattern of findings is very similar to that obtained with our baseline controls.

In panel III, we explore adding 0.01 to the count of traffic fatalities for observations that have zero fatality counts (which account for just two percent of the observations). The results continue to show that ENDS taxes are associated with a significant decline in the alcohol-related fatality rate for those ages 16-to-20. Here, the estimates suggest a 12.0 percent decline in traffic fatalities involving a 16-to-20-year-old with a BAC > 0. An examination of event-study analyses in Figure 5 shows a pattern of findings consistent with both the common trends assumption and with the hypothesis that ENDS taxes drive declines in alcohol-involved traffic fatalities.

Finally, in panel IV, we explore whether the estimates in panels I and II are biased due to heterogeneous and dynamic treatment effects by using a stacked difference-in-differences approach. We continue to find strong evidence that ENDS taxes are associated with a decline in alcohol, but

[41] In contrast, in their study of smoking bans in bars, Adams and Cotti (2008) find that the increase in alcohol-related traffic fatalities was due to smokers driving longer distances to frequent localities without such a ban, with accidents more likely than to occur when some of these (intoxicated) drivers return home.

[42] We use the coefficients for both traffic-related and non-traffic-related deaths to calculate the decrease in traffic fatalities count. We first compute the percentage change in BAC>0 relative to BAC=0 ((1-exp(-0.110)-(1-exp(-0.0547))), and then multiply it by the pre-treatment mean of alcohol-involved traffic fatalities (BAC > 0).

not non-alcohol-related traffic fatalities. The effects on traffic fatalities are approximately four percent points higher than those obtained from traditional TWFE estimates.

The range of our estimates in Table 9 suggest that a one-dollar increase in ENDS taxes reduces the teenage alcohol-related traffic fatality rate by approximately 0.4 to 0.6 fatalities per 100,000 population per state-year.[43] This corresponds to about 2.0 to 4.1 fewer alcohol-related traffic fatalities per state-year for a treated state.

For those at or older than the minimum legal drinking age (Table 10), we uncover no evidence of statistically significant traffic fatality declines following ENDS tax enactment. While the estimated effects for fatalities involving alcohol are uniformly negative, the absolute magnitude of the treatment effects is 56 to 78 percent smaller than for those ages 16-to-20.[44]

Together, the above findings provide strong evidence that the enactment of ENDS taxes generates important beneficial spillovers to public health through a reduction in binge drinking and alcohol-related traffic fatalities among teenagers and young adults.

6. Conclusions

This study offers the first causal evidence on the impact of ENDS taxes on teen alcohol misuse and alcohol-related traffic fatalities. ENDS use rates are high and ENDS taxes cause a sizable reduction in the number of ENDS users, thus providing us the ability to study the effect of ENDS taxes on an important secondary marketplace, alcohol, in order to provide a more complete understanding of general equilibrium effects of public health policies targeting ENDS. Increasingly more states are adopting ENDS taxes, though these policies are not without controversy as they appear to cause higher rates of both adult and teen smoking (Abouk et al. 2021; Cotti et al. 2022). Teen alcohol misuse remains high and imposes substantial costs on society — with estimated annual social costs of $28 billion dollars (CDC 2022c) — and policy action by state and federal governments has largely stagnated. State and federal alcohol tax rates have, in real terms, markedly declined over the past six decades because they are not indexed to inflation and raised through legislative action infrequently. There appears to be little appetite for raising alcohol taxes at the state

[43] This reflects the range of estimated treatment effects from column (3) and the more conservative estimates that represent the difference between the estimated treatment effects in column (3) and column (5).
[44] In results available in the appendix (Appendix Table 11), we find some evidence that ENDS taxes are negatively related to self-reported drinking and driving behavior, but the effects are imprecisely estimated and suggest larger effects for those ages 18-to-20 as compared to those ages 16-to-18.

or federal levels with a regulatory stance that may favor alcohol producers over consumers.[45] Consequently, as a share of average household income, one can of branded beer currently costs only about one-fifth of what it did in 1950, after accounting for inflation (Kerr et al. 2013). Moreover, other alcohol policy strategies that have been shown to be effective at curbing teenage drinking — such as zero tolerance drunk driving policies and MLDAs of 21 — have been universally adopted by all states since 1998, leaving little room on this front for further policy action, and evidence on the effectiveness of other targeted policies such as scanner ID laws is decidedly mixed. Therefore, in the context of limited policy action with respect to regulations that directly target problem alcohol use, it is important to consider how other substance use policies could be spilling over into the youth alcohol market.

We combine a quasi-experimental difference-in-differences research design, applied to five survey and administrative databases, to bring much needed evidence to bear on the relationship between ENDS taxes and teen alcohol misuse. Our results show that ENDS taxation has little impact at the extensive margin of teen drinking (any alcohol consumption), but curtails use on the intensive margin, in particular metrics of misuse that likely correlate with social costs. Specifically, we show that the probability of teen binge drinking declines by one to two percentage points following a one-dollar increase in the ENDS tax. We also document that alcohol-related traffic fatalities – a particularly costly externality associated with teen alcohol misuse – decline by 0.4 to 0.6 fatalities per 100,000 16-to-20-year-olds following a one-dollar hike in the ENDS tax. We apply estimators that are robust to corrections for bias from heterogeneity and dynamics in treatment effects identified from a staggered policy rollout and show that our results are not an artifact of differential pre-trends between states that do and do not adopt ENDS taxes. Moreover, placebo tests show that ENDS taxes do not impact non-alcohol-related traffic fatalities and our findings are robust to a range of alternative specifications. Collectively, we document, for the first time, that ENDS taxes causally reduce alcohol misuse and alcohol-related traffic fatalities among U.S. teens.

Interestingly, our findings suggest that experimental teen drinking (proxied by any alcohol use) and ENDS are unrelated activities, but measures of teen alcohol misuse (frequent and binge drinking and drinking and driving as proxied by fatal traffic accidents) and ENDS use are economic complements. Previous economic research (Dee 1999b) suggests that alcohol and tobacco products

[45] For instance, a recent report by the U.S. Department of Treasury on competition in the alcohol market essentially put forth recommendations to reduce regulatory barriers and promote growth of small businesses in the market, largely bypassing the public health perspective in regulating the industry and using taxes to correct for externalities (Alcorn 2022; U.S. Department of Treasury 2022).

are economic complements among teens, and this research shows that this relationship extends to ENDS for the first time.

Teens who experiment with alcohol, but do not transition to alcohol misuse, may differ in their preferences for tobacco products than teens who engage in alcohol misuse. In particular, polysubstance use and alcohol misuse may proxy underlying addiction risk, and teens who consume substances in either manner are more prone to heavily use substances in general. Moreover, the complementarity between youth ENDS use and heavier alcohol use may reflect the fact that both ENDS consumption and teen binge drinking have strong social elements (Rosenquist et al. 2010; Groom et al. 2021) and are often consumed together; a substantial fraction of teen ENDS users (40% in the state YRBS) also binge drink.

We use reduced form methods to study the effect of ENDS taxes on teen alcohol misuse. Thus, our causal chain relies on the hypothesis (which we provide evidence on, in addition to the existent literature) that increases in ENDS taxes lead to reductions in teen vaping, which in turn leads to a decline in teen drinking (this second-order effect is our unique contribution to the literature). Thus, our reduced form analysis captures the net effects of ENDS taxation on alcohol use through at least two mechanisms: first, a direct link between teen ENDS use and alcohol, and second, through relationships between teen smoking and alcohol use, as ENDS taxation has been shown to increase teen smoking (e.g. Abouk et al. 2021; Pesko and Warman 2021). Given the prior work suggesting that smoking and alcohol use are complements among teens (e.g. Dee 1999b), the smoking-induced potential increase in drinking could mute some of the complementary decrease in drinking driven by lower teen vaping. The extent to which these shifts, among the population of teens drinking and using ENDS, may impact our estimate of the impact of ENDS taxes on teen alcohol misuse is determined by the overlap in the sub-populations of teens who change their tobacco product use behavior due to the tax policy change.[46] Our reduced form estimates capture all reinforcing and counteracting channels, and our analyses provide robust evidence that the net effect of ENDS taxation leads to an overall decline in teen alcohol misuse.

We can use our estimates for alcohol-related traffic fatalities to conduct a back-of-the envelop cost savings associated with spillover effects to teen alcohol use from ENDS taxes. We select alcohol-related traffic fatalities for this exercise given the importance of this outcome from a

[46] A smoking-induced increase in drinking among teens could moderate some of the complementary decrease in drinking associated with lower ENDS use by teens, in response to higher ENDS taxes. On the other hand, the sub-population of teens that is induced to reduce vaping post-tax (and correspondingly drinking) may be different than the subset that is increasing drinking.

social cost perspective. Based on our conservative estimates, we document that a one-dollar increase in the ENDS tax rate leads to 2 fewer alcohol-related traffic fatalities per state-year for 16-to-20-year-olds (Table 9). If all states raised their ENDS tax by one-dollar, this policy change would imply 85 teen lives saved annually. Using the Federal Emergency Management Agency's value of a statistical life ($14.35 million)[47] (FEMA, 2020), the value of these saved lives is nearly $878 million dollars per year. While standard in economics, the value of a statistical life does not include other costs associated with a fatal crash (e.g., property damage). The National Safety Council (2022) estimates that the cost of a fatal traffic crash death (including a VSL estimate) is $13.1 million,[48] using this estimate suggests that a one-dollar increase in the ENDS tax rate would lead to nearly $1340 million in saving per year. Regardless of the specific value we use, alcohol-related traffic accident savings from a one-dollar increase in the ENDS tax are likely non-trivial. Further, the benefits of reduced teen drinking plausibly exceed those documented here, since alcohol-involved fatalities are just one component of the social costs of drinking (see Section 1).

We note, however, these benefits must be balanced alongside other costs and benefits associated with ENDS taxation. In particular, the documented increases in smoking among both teens and adults following ENDS taxation are concerning. Smoking is a leading cause of death in the U.S., contributing to 480,000 deaths per year according to the CDC (2016).

Together, our findings suggest that rapid emergence of a product initially designed to assist adult smokers struggling to quit their nicotine addiction entered youth markets and shaped consumption patterns across multiple substances. Given that ENDS taxation, and optimal ENDS policy more generally, is contentious and ongoing, considering general equilibrium effects is essential. Our results underline the importance of policymakers carefully weighing costs and benefits of anti-ENDS use efforts, both in terms of outcomes directly targeted by the policy as well as indirect effects on non-targeted outcomes.

[47] Inflated by the authors from $7.5 million in 2020 terms to 2022 dollars using the Consumer Price Index.
[48] Inflated by the authors from $11.2 million in 2020 terms to 2022 dollars using the Consumer Price Index.

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Figure 1. Geographic and Temporal Variation in ENDS Taxes

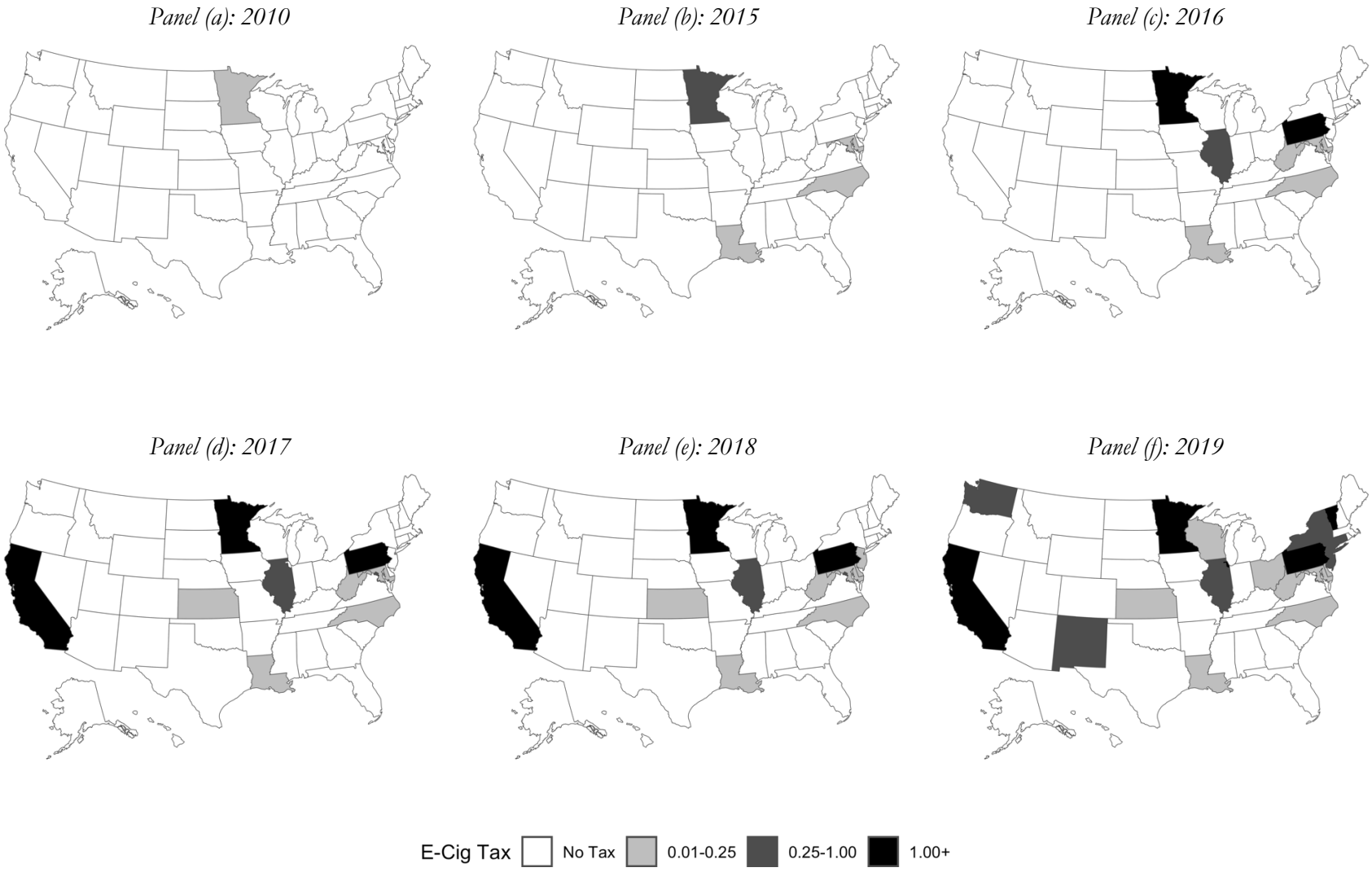
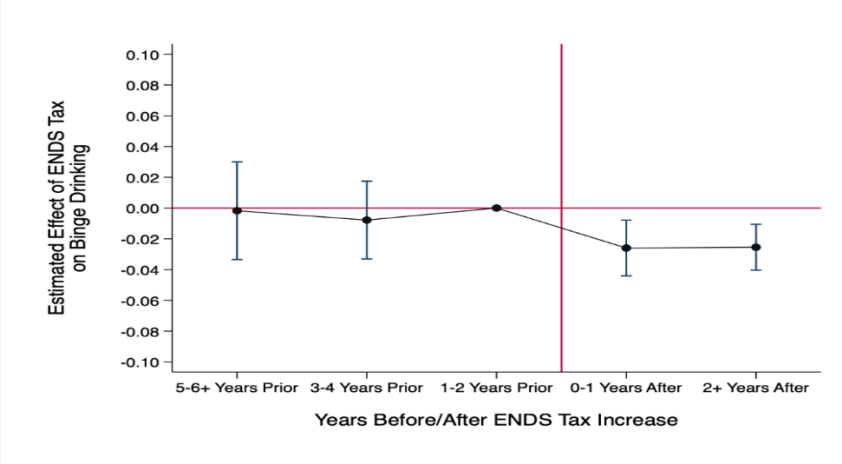
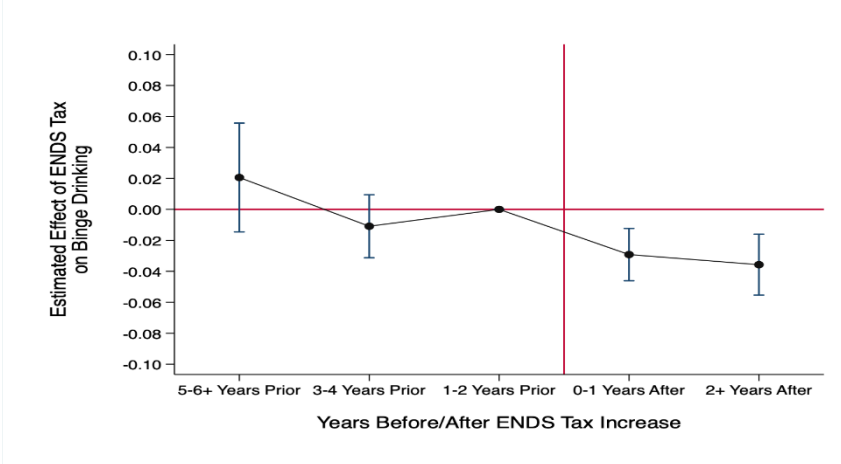


Figure 2. Event-Study Analysis of ENDS Taxes and Binge Drinking, Using TWFE Estimates

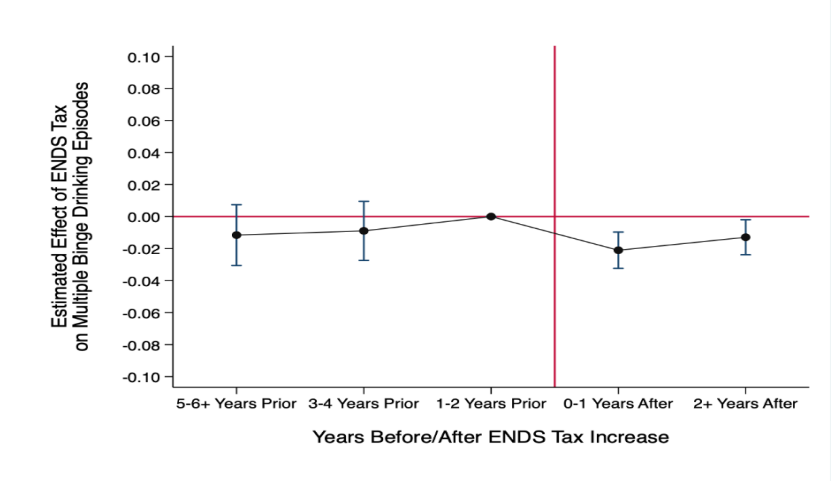
Panel (a): Binge Drinking, No Trends



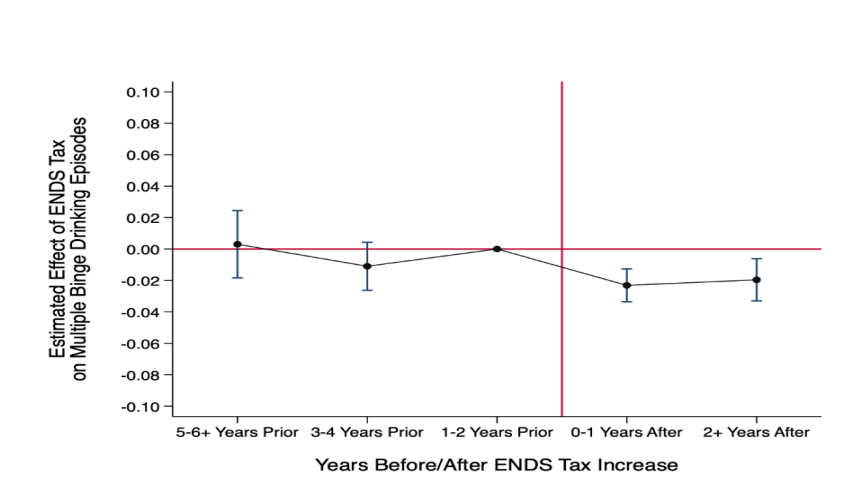
Panel (b): Binge Drinking, State Trends



Panel (c): Multiple Binge Drinking Episodes, No Trends



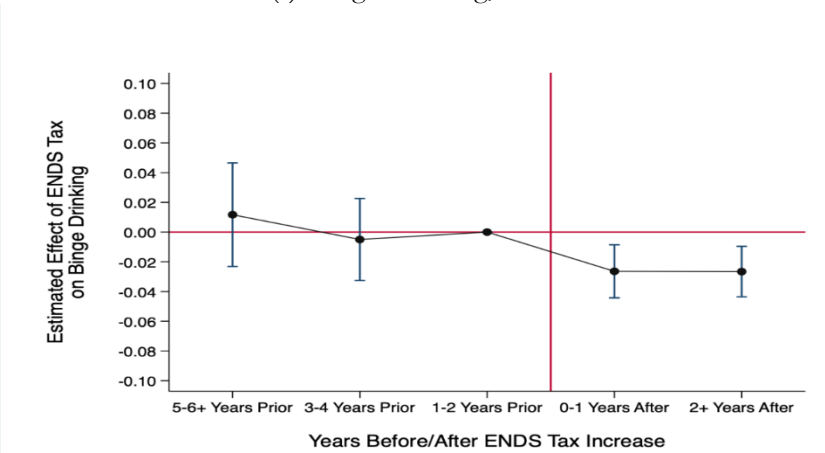
Panel (d): Multiple Binge Drinking Episodes, State Trends



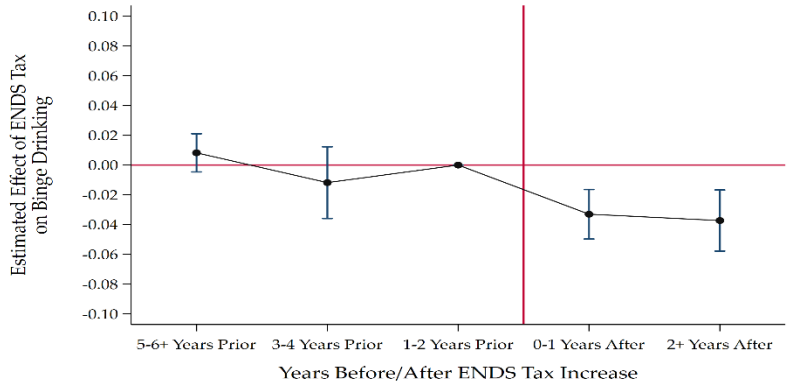
Note: Population weighted OLS estimates (with 95% CIs) from the event-study regression model described in equation (4) are shown. Regressions include state and year fixed effects and controls listed in Appendix Table 2. Panels (b) and (d) further include treatment state-specific linear time trends.

Figure 3. Event-Study Analyses of ENDS Taxes and Youth Binge Drinking, Using Stacked Difference-in-Differences Estimates

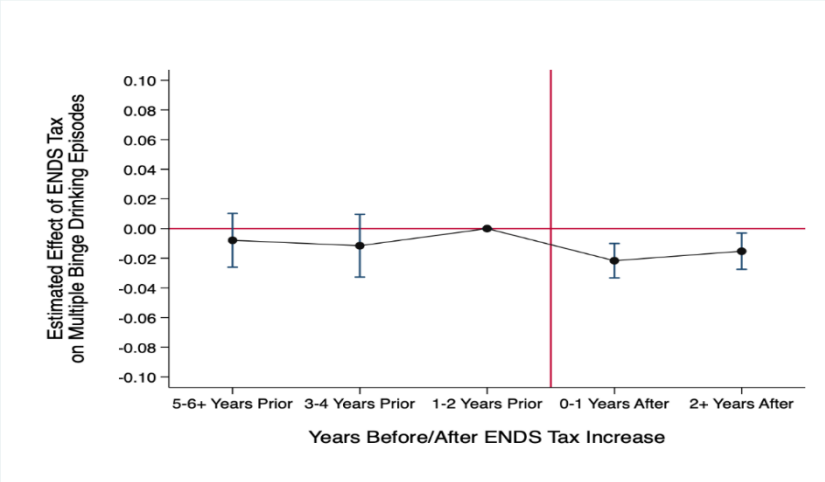
Panel (a): Binge Drinking, No Trends



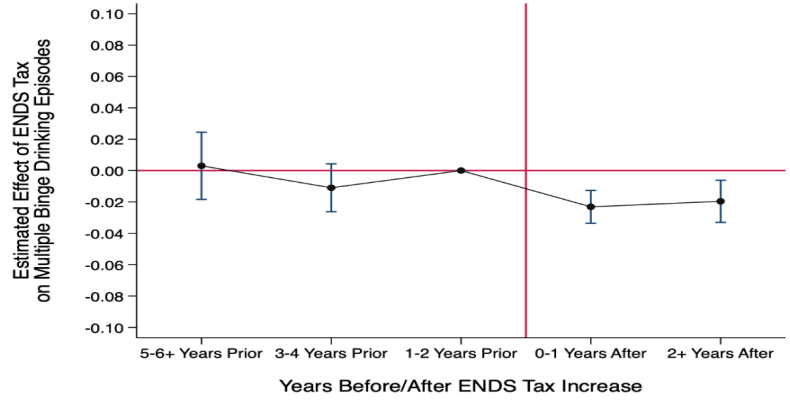
Panel (b): Binge Drinking, State Trends



Panel (c): Multiple Binge Drinking Episodes, No Trends



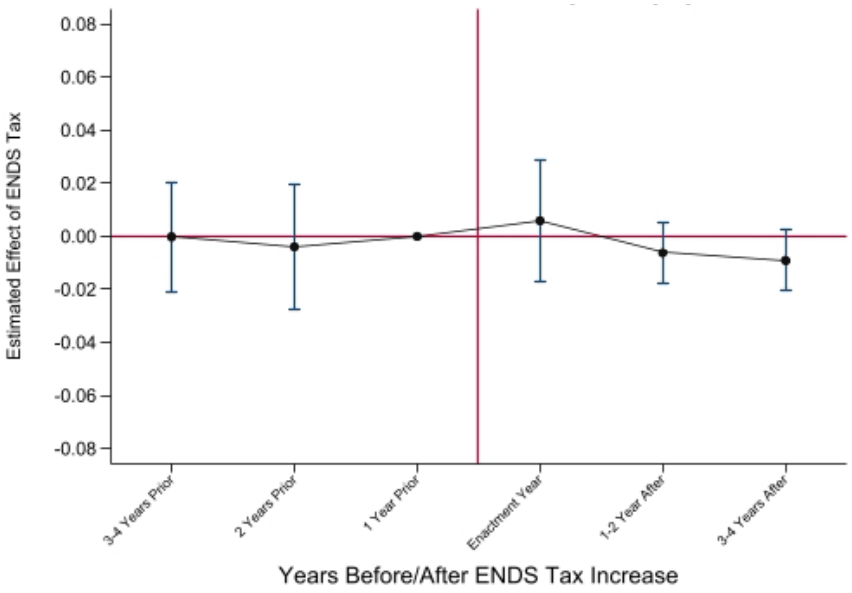
Panel (d): Multiple Binge Drinking Episodes, Trends



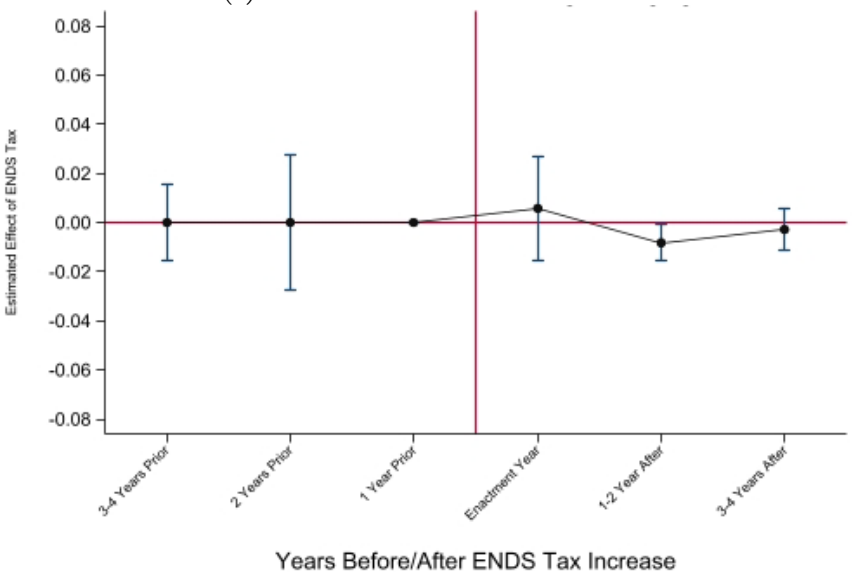
Note: Population weighted OLS estimates (with 95% CIs) from a stacked difference-in-differences regression over time are reported. Regressions include cohort, cohort-state, and cohort-year fixed effects and controls listed in Appendix Table 2. Panels (b) and (d) further include treatment state-specific linear time trends.

Figure 4. Event-study Analyses of ENDS Taxes and Binge Drinking Among Young Adults Ages 18-to-20

Panel (a): TWFE



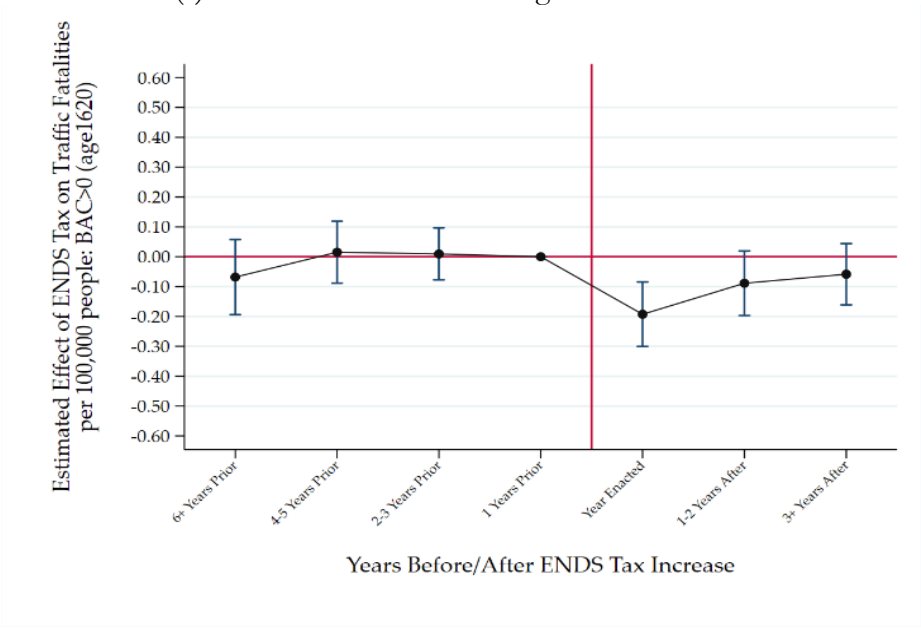
Panel (b): Stacked Difference-in-differences



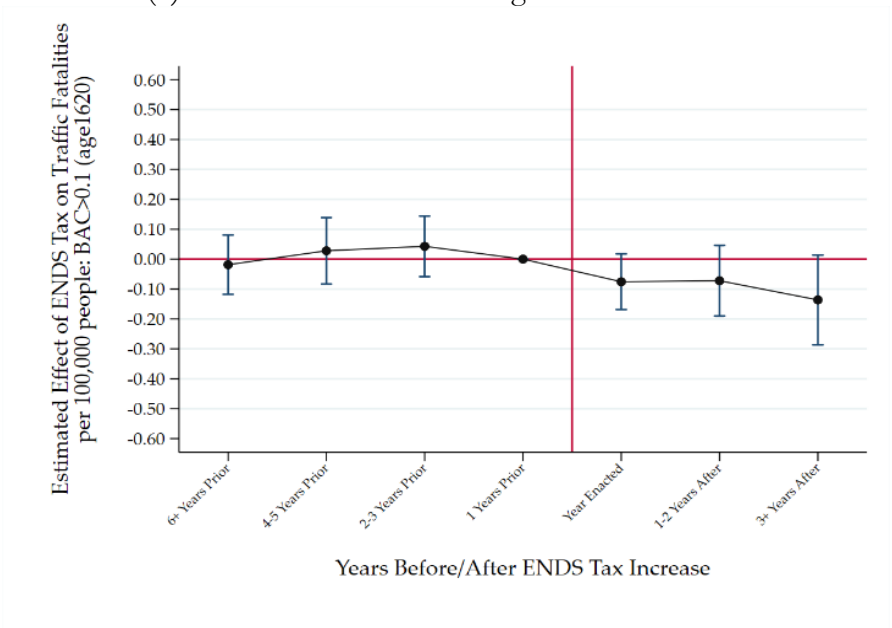
Note: OLS and Stacked estimates (with 90% CIs) are reported. Estimates include state and year fixed effects and the controls listed in Appendix Table 2.

Figure 5. Event-Study Analysis of ENDS Taxes and Traffic Fatalities Among 16-to-20-Year-Olds

Panel (a): Traffic Fatalities Involving Driver with BAC > 0



Panel (b): Traffic Fatalities Involving Driver with BAC > 0.1



Note: Population weighted OLS estimates (and their 95% CIs) from a regression model are shown. The included control variables are specified in the notes to Table 9.

Table 1. "First stage" Results: TWFE Estimates of Effect of ENDS Taxes on ENDS Use Among Youths, YRBS

	(1)	(2)	(3)	(4)
		Panel I: State YRBS		
ENDS Tax ($)	-0.0343***	-0.0345***	-0.0537***	-0.0536***
	(0.0055)	(0.0075)	(0.0072)	(0.0075)
N	499,839	499,839	499,839	499,839
Pre-Treatment Mean of Dep Variable	0.2269	0.2269	0.2269	0.2269
		Panel II: National YRBS		
ENDS Tax ($)	-0.0477**	-0.0371**	-0.0693***	-0.0667***
	(0.0196)	(0.0157)	(0.0160)	(0.0157)
N	39,153	39,153	39,153	39,153
Pre-Treatment Mean of Dep Variable	0.2628	0.2628	0.2628	0.2628
State and Year FE?	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes
Socioeconomic Controls?	No	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes
Alcohol and Marijuana Policy Controls?	No	No	No	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2015-2019 waves of the state (Panel I) and national (Panel II) Youth Risk Behavior Surveys. Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.

Table 2. TWFE Estimates of the Effects of ENDS Taxes on Alcohol Consumption among Youths, YRBS

	(1)	(2)	(3)	(4)
	Panel I: Any Alcohol Use			
ENDS Tax ($)	-0.0129	-0.0128	-0.0149	-0.0133
	(0.0104)	(0.0090)	(0.0125)	(0.0148)
N	1,185,261	1,185,261	1,185,261	1,185,261
Pre-Treatment Mean of Dep Variable	0.3710	0.3710	0.3710	0.3710
	Panel II: Number of Drinks | Alcohol Use = 1[a]			
ENDS Tax ($)	-0.3312***	-0.3429***	-0.3014***	-0.2888***
	(0.0630)	(0.0577)	(0.0935)	(0.1028)
N	54,386	54,386	54,386	54,386
Pre-Treatment Mean of Dep Variable	4.4729	4.4729	4.4729	4.4729
	Panel III: Binge Drinking			
ENDS Tax ($)	-0.0222***	-0.0222***	-0.0228***	-0.0220**
	(0.0075)	(0.0065)	(0.0075)	(0.0083)
N	1,153,127	1,153,127	1,153,127	1,153,127
Pre-Treatment Mean of Dep Variable	0.2076	0.2076	0.2076	0.2076
	Panel IV: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0113**	-0.0113**	-0.0138**	-0.0132*
	(0.0052)	(0.0042)	(0.0057)	(0.0068)
N	1,153,127	1,153,127	1,153,127	1,153,127
Pre-Treatment Mean of Dep Variable	0.1354	0.1354	0.1354	0.1354
State and Year FE?	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes
Socioeconomic Controls?	No	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes
Alcohol and Marijuana Policy Controls?	No	No	No	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates from Panels I, III, and IV are generated via weighted least squares using the 2003-2019 waves of the state Youth Risk Behavior Surveys. Data for outcome in Panel II are available only for 2013-2019 waves. Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.

[a] Data on largest number of drinks on usual drinking occasion only available during 2013, 2015, 2017, and 2019 waves.

Table 3. Stacked Difference-in-difference Estimates of Effects of ENDS Taxes on Heavier Alcohol Use among Youths, YRBS

	(1)	(2)	(3)	(4)
	Panel I: Number of Drinks | Alcohol Use = 1[a]			
ENDS Tax ($)	-0.3275***	-0.3568***	-0.3588***	-0.3549***
	(0.0682)	(0.0499)	(0.0636)	(0.0767)
N	408,430	408,430	408,430	408,430
Pre-Treatment Mean of Dep Variable	4.5368	4.5368	4.5368	4.5368
	Panel II: Binge Drinking			
ENDS Tax ($)	-0.0313***	-0.0306***	-0.0238***	-0.0230***
	(0.0069)	(0.0064)	(0.0059)	(0.0067)
N	4,813,447	4,813,447	4,813,447	4,813,447
Pre-Treatment Mean of Dep Variable	0.2121	0.2121	0.2121	0.2121
	Panel III: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0211***	-0.0204***	-0.0192***	-0.0175***
	(0.0050)	(0.0045)	(0.0046)	(0.0060)
N	4,813,447	4,813,447	4,813,447	4,813,447
Pre-Treatment Mean of Dep Variable	0.1365	0.1365	0.1365	0.1365
State and Year FE?	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes
Socioeconomic Controls?	No	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes
Alcohol and Marijuana Policy Controls?	No	No	No	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2003-2019 waves of the state Youth Risk Behavior Surveys. Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.

[a] Data on largest number of drinks on usual drinking occasion only available during 2013, 2015, 2017, and 2019 waves.

Table 4. Sensitivity of Estimated Effects of ENDS Taxes on Heavier Alcohol Use to Spatial Heterogeneity Controls, YRBS

	(1)	(2)	(3)
	Panel I: Number of Drinks | Alcohol Use = 1[a]		
ENDS Tax ($)	-0.2888***	-0.1446	-0.3066***
	(0.1028)	(0.1306)	(0.1075)
N	54,386	54,386	54,386
Pre-Treatment Mean of Dep Variable	4.4729	4.4729	4.4729
	Panel II: Binge Drinking		
ENDS Tax ($)	-0.0220**	-0.0189**	-0.0289***
	(0.0083)	(0.0089)	(0.0071)
N	1,153,127	1,153,127	1,153,127
Pre-Treatment Mean of Dep Variable	0.2106	0.2106	0.2106
	Panel III: Multiple Binge Drinking Episodes		
ENDS Tax ($)	-0.0132*	-0.0091	-0.0186***
	(0.0068)	(0.0077)	(0.0055)
N	1,153,127	1,153,127	1,153,127
Pre-Treatment Mean of Dep Variable	0.1354	0.1354	0.1354
State and Year FE?	Yes	Yes	Yes
Full Controls?	Yes	Yes	Yes
Region-Specific Year FE?	No	Yes	No
Treatment State-Specific Linear Time Trend	No	No	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2003-2019 waves of the State Youth Risk Behavior Surveys. Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.

[a] Data on largest number of drinks on usual drinking occasion only available during 2013, 2015, 2017, and 2019 waves.

Table 5. Estimates of the Effects of ENDS Taxes on Dual Consumption of ENDS and Binging Alcohol, YRBS

	(1)	(2)	(3)	(4)
	Panel I: ENDS Use *and* Binge Drinking			
ENDS Tax ($)	-0.0276***	-0.0279***	-0.0282***	-0.0279***
	(0.0024)	(0.0030)	(0.0025)	(0.0027)
N	425,101	425,101	425,101	425,101
Pre-Treatment Mean of Dep Variable	0.0959	0.0959	0.0959	0.0959
	Panel II: ENDS use *and* Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0178***	-0.0183***	-0.0202***	-0.0199***
	(0.0018)	(0.0021)	(0.0020)	(0.0021)
N	425,101	425,101	425,101	425,101
Pre-Treatment Mean of Dep Variable	0.0618	0.0618	0.0618	0.0618
State and Year FE?	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes
Socioeconomic Controls?	No	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes
Alcohol & Marijuana Policy Controls?	No	No	No	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2015-2019 waves of the state Youth Risk Behavior Surveys. Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws

Table 6. Heterogeneity in Effects of ENDS Taxes on Alcohol Consumption and Marijuana Use among Youths, by Gender, Age, and Race/Ethnicity, YRBS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Males	Females	Age <17	Age 17-18	NH White	Black	Hispanic	Other
				Panel I: Number of Drinks | Alcohol Use = 1[a]				
ENDS Tax ($)	-0.3863***	-0.2080*	-0.4098***	-0.1674	-0.5098***	0.2357	0.0056	-0.1076
	(0.1219)	(0.1160)	(0.1075)	(0.1419)	(0.1689)	(0.1866)	(0.1434)	(0.3541)
N	24,457	29,929	31,183	23,203	32,002	5,000	10,803	6,581
Pre-Treatment Mean of Dep Variable	5.0104	4.0339	4.2358	4.7711	4.8878	3.4073	4.3613	3.4394
				Panel II: Binge Drinking				
ENDS Tax ($)	-0.0182**	-0.0260***	-0.0223**	-0.0261***	-0.0390**	-0.0077	-0.0263***	-0.0195***
	(0.0087)	(0.0084)	(0.0104)	(0.0082)	(0.0181)	(0.0071)	(0.0053)	(0.0038)
N	558,648	594,479	779,698	373,429	661,428	157,719	198,943	135,037
Pre-Treatment Mean of Dep Variable	0.2238	0.1973	0.1686	0.2813	0.2606	0.1104	0.2133	0.1295
				Panel III: Multiple Binge Drinking Episodes				
ENDS Tax ($)	-0.0118	-0.0149**	-0.0134*	-0.0178**	-0.0192	-0.0167***	-0.0168***	-0.0159***
	(0.0073)	(0.0064)	(0.0079)	(0.0075)	(0.0138)	(0.0046)	(0.0042)	(0.0041)
N	558,648	594,479	779,698	373,429	661,428	157,719	198,943	135,037
Pre-Treatment Mean of Dep Variable	0.1514	0.1195	0.1021	0.1916	0.1728	0.0641	0.1386	0.0788
State and Year FE?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2003-2019 waves of the state Youth Risk Behavior Surveys (YRBS). Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.

[a] Data on largest number of drinks on usual drinking occasion only available during 2013, 2015, 2017, and 2019 waves.

Table 7. TWFE Estimates of the Effects of ENDS Taxes on ENDS Use and Drinking among Adults, BRFSS

	(1)	(2)	(3)	(4)	(5)	(6)
	ENDS Use	Any Alcohol Use	Binge Drinking	Multiple Binge Episodes	20-or-more Drinks per Month	Number Drinks per Month | Alcohol Use=1
				Panel I: Ages 18-to-20		
ENDS Tax ($)	-0.0222***	-0.0236**	-0.0190***	-0.0145**	-0.0161**	-3.500**
	(0.00427)	(0.0102)	(0.00693)	(0.00710)	(0.00683)	(1.699)
N	25727	82433	82013	82013	81496	26764
Pre-Treat Mean of Dep Variable	0.134	0.328	0.171	0.117	0.116	27.32
				Panel II: Ages 21-to-39		
ENDS Tax ($)	-0.00315**	-0.00583	-0.000774	-0.00160	-0.00464	-0.140
	(0.00113)	(0.00494)	(0.00285)	(0.00229)	(0.00282)	(0.293)
N	218782	727928	722373	722373	721216	445352
Pre-Treat Mean of Dep Variable	0.068	0.618	0.262	0.163	0.217	24.02
				Panel III: Ages 40-and-older		
ENDS Tax ($)	0.00131	0.00132	0.00156	-0.0000658	-0.000692	-0.0638
	(0.00133)	(-0.00385)	(0.00124)	(0.00131)	(0.00279)	(0.181)
N	897656	3046902	3029320	3029320	3029180	1471520
Pre-Treat Mean of Dep Variable	0.028	0.486	0.095	0.061	0.169	22.19

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates on ENDS use are based on the 2016-2018 waves of the Behavioral Risk Factor Surveillance Survey (BRFSS). Alcohol measures are obtained using the 2011 to 2019 waves of the BRFSS. Standard errors are clustered at the state level. All models include state and year fixed effects and the full set of observable controls. Demographic controls include age, gender, education, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws. In addition, drinking regressions (using the longer panel) include state-specific linear time trends for treated states.

Table 8. TWFE Estimates of the Effects of ENDS Taxes on Binge Drinking and Alcohol Use Disorder among Adults, NSDUH

	(1)	(2)	(3)	(4)
	Ages 18-to-25		**Ages: 26-and-older**	
	Binge Drinking	Alcohol Use Disorder	Binge Drinking	Alcohol Use Disorder
ENDS Tax ($)	-0.0103*	-0.00601	-0.00802**	-0.00448***
	(0.00557)	(0.00427)	(0.00373)	(0.00159)
N	816	867	816	867
Pre-Treatment Mean of Dep Variable	0.397	0.143	0.225	0.058

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2003-2019 waves of the National Survey on Drug Use and Health (NSDUH). Standard errors are clustered at the state level. All observable controls include three categories of covariates: Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws. Regressions are weighted using state populations. All regressions include state fixed effects, year fixed effects, and treatment state-specific linear trends.

Table 9. Difference-in-Differences Estimates of the Effect of ENDS Taxes on Log (Traffic Fatalities per 100,000 Population) Among 16-to-20-year-olds, FARS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Total Traffic Fatalities	Total Traffic Fatalities | BAC Test Administered	Traffic Fatalities with Drivers BAC > 0	Traffic Fatalities with Drivers BAC > 0.1	Traffic Fatalities with Drivers BAC = 0	Weekend Traffic Fatalities	Weekday Traffic Fatalities
				Panel I: Baseline TWFE Estimates			
ENDS Tax ($)	-0.0255	-0.0482	-0.110**	-0.103*	-0.0547	-0.0905**	0.00781
	(0.0369)	(0.0574)	(0.0425)	(0.0518)	(0.0658)	(0.0399)	(0.0436)
N	867	867	867	867	867	867	867
Pre-Treatment Mean DV	18.86	15.76	4.56	3.02	11.21	7.25	11.61
				Panel II: Extended Controls TWFE Estimates			
ENDS Tax ($)	-0.0204	-0.0611	-0.102**	-0.101*	-0.0388	-0.0856**	0.0134
	(0.0368)	(0.0469)	(0.0430)	(0.0508)	(0.0697)	(0.0352)	(0.0436)
N	867	867	867	867	867	867	867
Pre-Treatment Mean of DV	18.86	15.76	4.56	3.02	11.21	7.25	11.61
				Panel III: Alternate Coding of 0s in Dependent Variable, TWFE Estimates			
ENDS Tax ($)	0.00193	-0.0347	-0.128*	-0.147	-0.0157	-0.0922*	0.0550
	(0.0509)	(0.0596)	(0.0640)	(0.0911)	(0.0922)	(0.0548)	(0.0634)
N	867	867	867	867	867	867	867
Pre-Treatment Mean DV	18.86	15.76	4.55	3.02	11.21	7.25	11.61
				Panel IV: Stacked DD Estimates			
ENDS Tax ($)	-0.0403	-0.0962***	-0.153***	-0.161***	-0.0490	-0.0731***	-0.0154
	(0.0290)	(0.0342)	(0.0487)	(0.0589)	(0.0506)	(0.0275)	(0.0371)
N	3,587	3,587	3,587	3,587	3,587	3,587	3,587
Pre-Treatment Mean DV	16.78	13.97	3.84	2.54	10.13	6.41	10.37

***Significant at 1% level **at 5% level *at 10% level

Note: OLS estimates are generated from the Fatality Analysis Reporting System (FARS) from years 2003 to 2019. Standard errors are clustered at the state level. Regressions are weighted using state populations. Full controls include three categories of covariates: Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws. All regressions include state fixed effects, year fixed effects, and treatment-state specific linear trends. The dependent variable is equal to the natural log of the traffic fatalities per 100,000 people. In panels I II, and IV, 0 fatality counts are replaced with 1 before taking the natural log. In panel III, the zero fatality count is assigned a value of 0.01 to examine the robustness of alternative zero treatments.

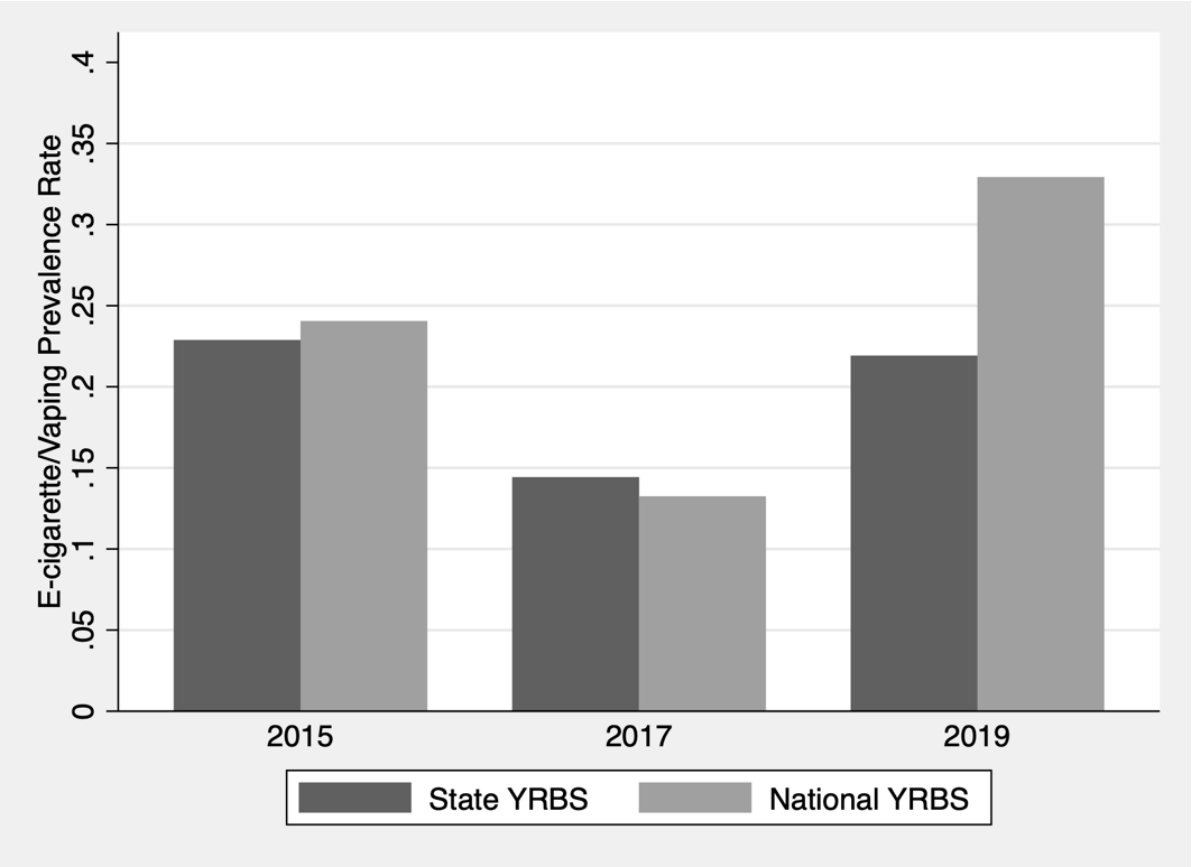
Table 10. Difference-in-Difference Estimates of the Effect of ENDS Taxes on Log (Traffic Fatalities Per 100,000 Population) Among those Ages 21-and-older, FARS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Total Traffic Fatalities	Total Traffic Fatalities | BAC Test Administered	Traffic Fatalities with Drivers BAC > 0	Traffic Fatalities with Drivers BAC > 0.1	Traffic Fatalities with Drivers BAC = 0	Weekend Traffic Fatalities	Weekday Traffic Fatalities
				Panel I: Ages 21-to-39			
ENDS Tax ($)	0.00287	-0.0446	-0.0457	-0.0276	-0.0430	-0.00855	0.00940
	(0.0260)	(0.0314)	(0.0439)	(0.0431)	(0.0334)	(0.0302)	(0.0289)
N	867	867	867	867	867	867	867
Pre-Treatment Mean of DV	15.99	13.52	5.96	4.66	7.56	6.27	9.71
				Panel II: Ages 40-and-older			
ENDS Tax ($)	-0.00893	-0.0332	-0.0228	-0.0353	-0.0219	0.00773	-0.0191
	(0.0208)	(0.0489)	(0.0329)	(0.0306)	(0.0439)	(0.0288)	(0.0205)
N	867	867	867	867	867	867	867
Pre-Treatment Mean of DV	13.07	10.91	2.54	1.89	8.38	3.96	9.11

***Significant at 1% level **at 5% level *at 10% level

Note: OLS estimates are generated from the Fatality Analysis Reporting System (FARS) from years 2003 to 2019. Standard errors are clustered at the state level. Regressions are weighted using state populations. Full controls include three categories of covariates: Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, the presence of an indoor smoking restriction, and the presence of an indoor ENDS use restriction. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws. All regressions include state fixed effects, year fixed effects, and treatment-state specific linear trends. The dependent variable is equal to the natural log of the traffic fatalities per 100,000 people (assigning 1 to 0 fatal crashes).

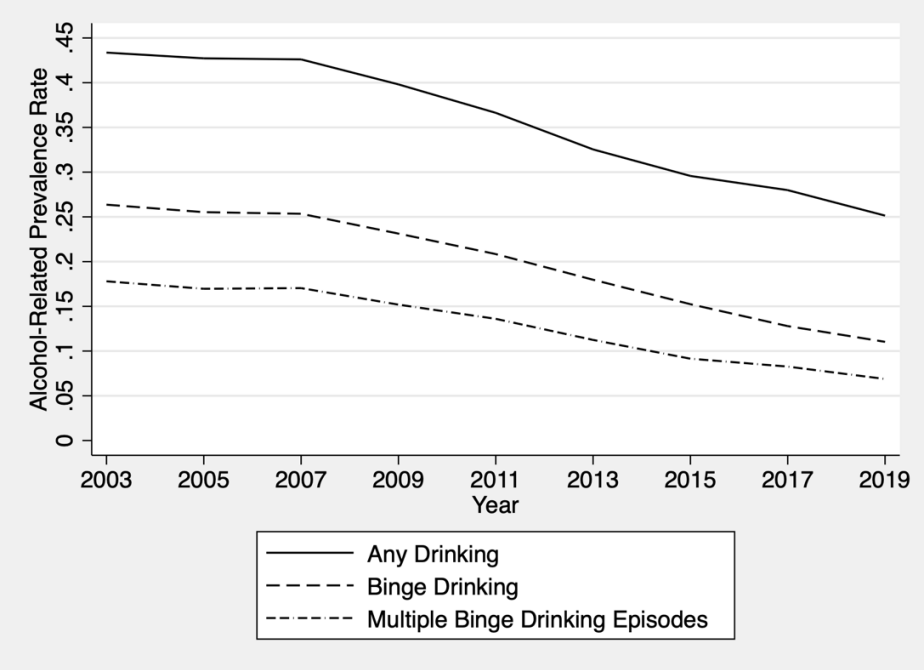
Appendix Figure 1. Trends in ENDS Use, YRBS Surveys, 2015-2019



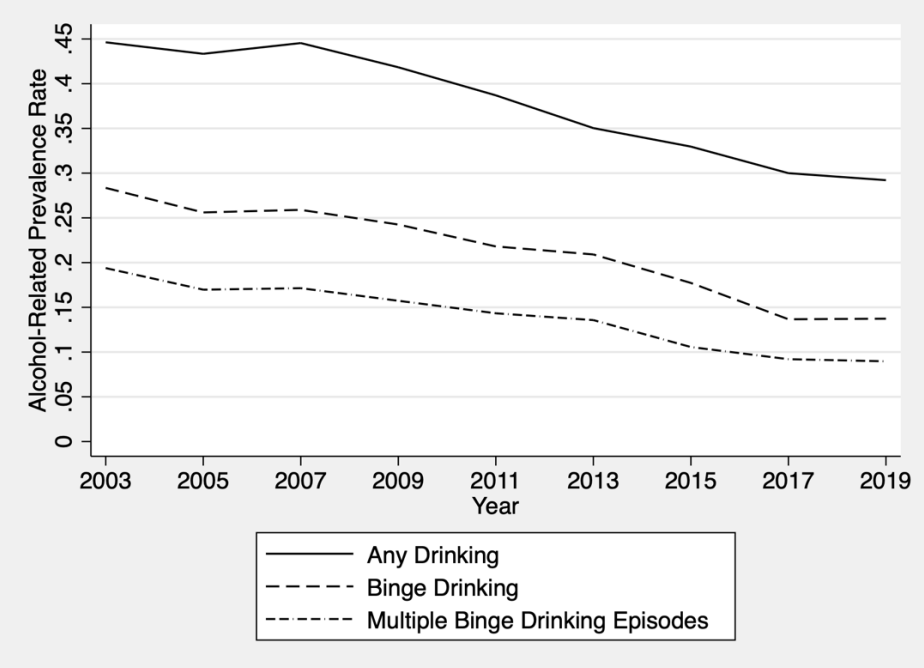
Note: Weighted estimates are from the 2015-2017 state and national Youth Risk Behavior Surveys.

Appendix Figure 2. Drinking-Related Outcomes among Youths, YRBS 2003-2019

Panel (a): State YRBS



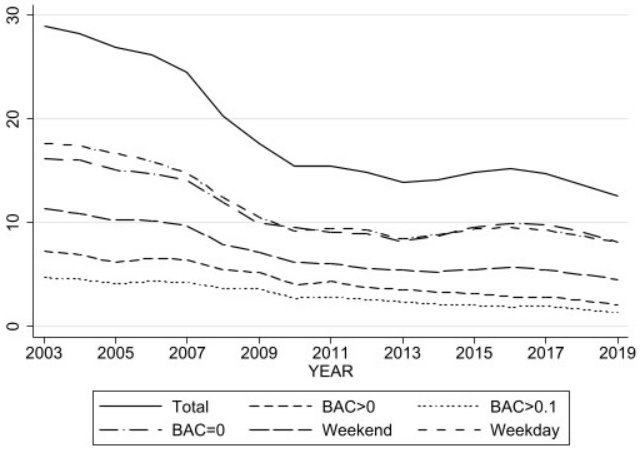
Panel (b): National YRBS



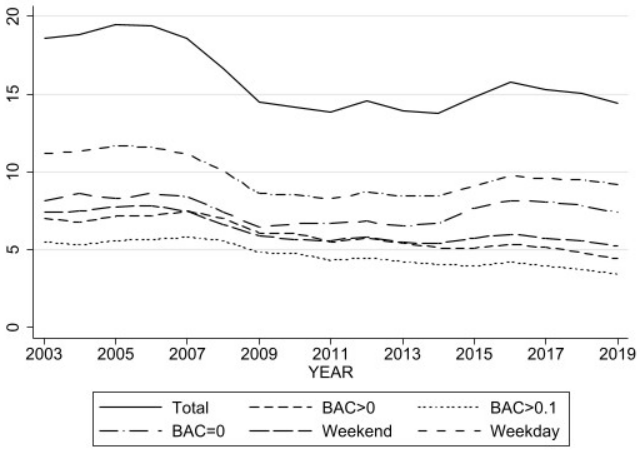
Note: Weighted estimates are from the 2015-2017 state and national Youth Risk Behavior Surveys.

Appendix Figure 3. Traffic Fatalities among Adults, FARS 2003-2019

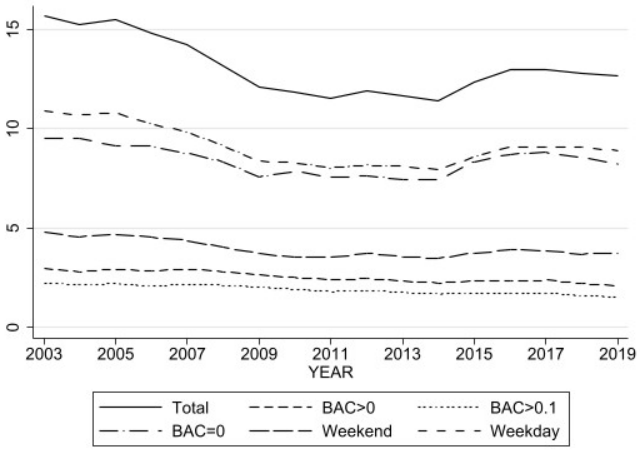
Panel (a): Ages 16-to-20



Panel (b): Ages 21-to-39



Panel (c): Ages 40-and-older



Note: Weighted estimates are from the 2033-2019 Fatality Analysis Reporting System.

Appendix Table 1. Effective Dates of ENDS Taxes

Jurisdiction	Effective Date	Contributes to Identifying Variation?			Tax per mL Fluid, Q1-4 Average (2019 $)					
		State YRBS	*National YRBS*	*BRFSS, NSDUH, FARS*	*2010*	*2015*	*2016*	*2017*	*2018*	*2019*
California	4/2017, 7/2017, 7/2018, 7/2019	Yes	Yes	Yes	$0	$0	$0	$1.13	$1.74	$1.61
Connecticut	10/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.10
Delaware	1/2018	Yes	Yes	Yes	$0	$0	$0	$0	$0.05	$0.05
Illinois	7/2019 (state-wide) 1/2016, 1/2019 (Chicago) 5/2016 (Cook County)	Yes	Yes	Yes	$0	$0	$0.38	$0.40	$0.38	$0.78
Kansas	1/2017, 7/2017	Yes	No	Yes	$0	$0	$0	$0.14	$0.05	$0.05
Louisiana	7/2015	Yes	Yes	Yes	$0	$0.03	$0.05	$0.05	$0.05	$0.05
Maryland	8/2015 (Montgomery County)	Yes	Yes	Yes	$0	$0.07	$0.16	$0.15	$0.14	$0.14
Minnesota	8/2010, 7/2013	No	Yes	Yes	$0.42	$2.90	$2.84	$2.72	$2.59	$2.50
North Carolina	6/2015	Yes	Yes	Yes	$0	$0.03	$0.05	$0.05	$0.05	$0.05
New Jersey	10/2018, 11/2019	Yes	Yes	Yes	$0	$0	$0	$0	$0.03	$0.15
New Mexico	7/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.25
New York	12/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.07
Ohio	10/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.03
Pennsylvania	7/2016	Yes	Yes	Yes	$0	$0	$0.60	$1.14	$1.09	$1.05
Vermont	7/2019	No	No	Yes	$0	$0	$0	$0	$0	$1.21
District of Columbia	10/2015, 10/2016, 10/2017, 10/2018	No	No	Yes	$0	$0.51	$1.97	$1.82	$1.88	$2.53
Washington	10/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.07
West Virginia	7/2016	Yes	Yes	Yes	$0	$0	$0.04	$0.08	$0.08	$0.08
Wisconsin	10/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.01

Note: Standardized ENDS taxes are from Cotti et al. Analysis using the YRBS utilizes a q1-q2 average to better match the timing of the survey.

Appendix Table 2. Descriptive Statistics, State and National YRBS

	State	*National*
Dependent Variables		
ENDS Use [a]	0.197	0.236
	(0.398)	(0.425)
	[N=499,839]	[N=39,153]
Any Alcohol Consumption	0.357	0.389
	(0.479)	(0.487)
	[N=1,185,261]	[N=129,830]
Any Binge Drinking [b]	0.199	0.223
	(0.399)	(0.417)
	[N=1,153,127]	[N=135,696]
Multiple Binge Drinking Episodes [b]	0.130	0.147
	(0.336)	(0.354)
	[N=1,153,127]	[N=135,696]
Number of Drinks | Alcohol Use = 1	4.467	4.635
	(3.057)	(3.091)
	[N= 69,165]	[N=12,649]
Individual Controls		
Female	0.494	0.494
	(0.500)	(0.500)
Age	16.027	16.032
	(1.236)	(1.231)
Non-Hispanic White	0.570	0.582
	(0.495)	(0.493)
Non-Hispanic Black	0.170	0.139
	(0.376)	(0.346)
Latino/Hispanic	0.187	0.135
	(0.390)	(0.342)
Non-Hispanic Other Race	0.073	0.144
	(0.259)	(0.351)

Appendix Table 2. Continued

Grade	10.405	10.404
	(1.119)	(1.118)
Independent Variables		
ENDS Tax (2019 $)	0.056	0.082
	(0.253)	(0.370)
Cigarette Tax (2019 $)	1.354	1.241
	(1.042)	(0.946)
Beer Tax (2019 $)	0.291	0.266
	(0.258)	(0.243)
Tobacco 21 Law	0.050	0.036
	(0.208)	(0.179)
ENDS MLSA	0.346	0.299
	(0.476)	(0.458)
Presence of Indoor Smoking Restriction	0.481	0.436
	(0.500)	(0.496)
Presence of Indoor ENDS Restriction	0.076	0.058
	(0.265)	(0.234)
Recreational Marijuana Law	0.054	0.047
	(0.225)	(0.212)
Medical Marijuana Law	0.276	0.348
	(0.444)	(0.472)
Unemployment Rate	5.882	6.102
	(2.104)	(2.173)
Poverty Rate	13.200	13.073
	(2.998)	(2.898)
N	1,286,324	141,510

Note: Means and standard deviations (in parenthesis) are reported.

[a] Dependent variable is based on questions asked in the 2015-2019 YRBS.

[b] Dependent variable is based on questions asked in the 2003-2019 YRBS.

Appendix Table 3. Descriptive Statistics, BRFSS

	Mean	Standard Deviation	N
Individuals Ages 18-to-20			
ENDS Use	0.120	0.325	25,749
Alcohol Consumption in Last 30 Days	0.325	0.468	82,013
Binge Drinking in Last 30 Days	0.163	0.370	82,013
Multiple Binge Drinking Episodes in Last 30 Days	0.111	0.314	82,013
20-or-more Drinks in Last 30 Days	0.116	0.320	82,013
Number of Drinks in Last 30 Days| Alcohol Use	27.348	63.192	26,764
Individuals Ages 21-to-39			
ENDS Use	0.072	0.258	218,782
Alcohol Consumption in Last 30 Days	0.619	0.486	722,373
Binge Drinking in Last 30 Days	0.269	0.443	722,373
Multiple Binge Drinking Episodes in Last 30 Days	0.170	0.376	722,373
20-or-more Drinks in Last 30 Days	0.217	0.412	722,373
Number of Drinks in Last 30 Days| Alcohol Use	24.030	49.884	445,352
Individuals Ages 40-and-older			
ENDS Use	0.027	0.162	898,403
Alcohol Consumption in Last 30 Days	0.500	0.500	3,029,320
Binge Drinking in Last 30 Days	0.116	0.321	3,029,320
Multiple Binge Drinking Episodes in Last 30 Days	0.075	0.263	3,029,320
20-or-more Drinks in Days 30 Days	0.169	0.375	3,029,320
Number of Drinks in Last 30 Days| Alcohol Use	22.191	45.365	1,471,521

Note: Estimates from the BRFSS are weighted using relevant survey-provided sample weights. ENDS use variable is based on questions asked in the 2016-2018 BRFSS.

Appendix Table 4. Descriptive Statistics, NSDUH

	Mean	Standard Deviation	N
Ages 18-to-25			
Any Binge Drinking	0.397	0.055	816
Alcohol Use Disorder	0.143	0.035	867
Ages 26-and-older			
Any Binge Drinking	0.225	0.028	816
Alcohol Use Disorder	0.058	0.008	867

Note: Estimates are weighted using relevant age population in each state.

Appendix Table 5. Descriptive Statistics, FARS

	Traffic Fatality Rate (Per 100,000 Population)	Traffic Fatality Count	N
Ages 16-to-20			
Total Fatalities	18.66	162.02	867
	(9.12)	(137.01)	
Total Fatalities | BAC Test	15.61	129.50	867
	(8.04)	(109.85)	
Fatalities (BAC > 0)	4.49	39.70	867
	(2.76)	(38.50)	
Fatalities (BAC ≥ 0.1)	2.99	26.35	867
	(1.92)	(25.75)	
Fatalities (BAC = 0)	11.11	89.79	867
	(6.20)	(76.17)	
Fatalities (Weekend)	7.17	63.16	867
	(3.75)	(55.98)	
Fatalities (Weekday)	11.49	98.85	867
	(5.70)	(81.89)	
Ages 21-to-39			
Total Fatalities	15.93	541.33	867
	(6.44)	(448.85)	
Total Fatalities | BAC Test	13.48	438.61	867
	(5.79)	(357.80)	
Fatalities (BAC > 0)	5.93	199.10	867
	(2.57)	(168.16)	
Fatalities (BAC ≥ 0.1)	4.64	155.72	867
	(2.10)	(131.81)	
Fatalities (BAC = 0)	7.55	239.51	867
	(3.91)	(203.92)	
Fatalities (Weekend)	6.24	214.74	867
	(2.53)	(179.96)	
Fatalities (Weekday)	9.68	326.56	867
	(4.03)	(270.17)	

Ages 40-and-older			
Total Fatalities	13.03	747.18	867
	(4.59)	(572.33)	
Total Fatalities | BAC Test	10.89	596.04	867
	(4.59)	(474.20)	
Fatalities (BAC > 0)	2.52	138.84	867
	(1.11)	(107.00)	
Fatalities (BAC ≥ 0.1)	1.88	102.79	867
	(0.90)	(79.59)	
Fatalities (BAC = 0)	8.36	457.20	867
	(3.83)	(380.83)	
Fatalities (Weekend)	3.95	230.19	867
	(1.46)	(184.06)	
Fatalities (Weekday)	9.09	516.96	867
	(3.22)	(389.30)	

Note: Estimates are weighted using relevant age population in each state.

Appendix Table 6. Examining Lead Effect of ENDS Taxes, YRBS

	(1)	(2)	(3)	(4)
	ENDS Use	Number of Drinks | Any Drinking	Binge Drinking	Multiple Binge Drinking Episodes
1 Wave Prior to ENDS Adoption	0.0053	-0.2389	0.0001	-0.0066
	(0.0126)	(0.2040)	(0.0071)	(0.0036)
ENDS Tax ($)	-0.0477***	-0.5260***	-0.0249**	-0.0155**
	(0.0086)	(0.1479)	(0.0095)	(0.0063)
N	499,839	54,386	1,104,083	1,104,083
Pre-Treatment Mean of Dep Variable	0.2269	4.48	0.2076	0.1331
State and Year FE?	Yes	Yes	Yes	Yes
Full Controls?	Yes	Yes	Yes	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2003-2019 waves of the state Youth Risk Behavior Surveys. Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.

Appendix Table 7. TWFE Estimates of Effect of ENDS Taxes on Alcohol Use, National YRBS

	(1)	(2)	(3)	(4)
	Panel I: Any Alcohol Use			
ENDS Tax ($)	-0.0143	-0.0132	-0.0200	-0.0172
	(0.0114)	(0.0109)	(0.0146)	(0.0138)
N	129,830	129,830	129,830	129,830
Pre-Treatment Mean of Dep Variable	0.4036	0.4036	0.4036	0.4036
	Panel II: Binge Drinking			
ENDS Tax ($)	-0.0206***	-0.0195***	-0.0228**	-0.0193**
	(0.0053)	(0.0056)	(0.0088)	(0.0077)
N	135,696	135,696	135,696	135,696
Pre-Treatment Mean of Dep Variable	0.2342	0.2342	0.2342	0.2342
	Panel III: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0145***	-0.0135***	-0.0183***	-0.0157***
	(0.0022)	(0.0023)	(0.0052)	(0.0041)
N	135,696	135,696	135,696	135,696
Pre-Treatment Mean of Dep Variable	0.1509	0.1509	0.1509	0.1509
State and Year FE?	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes
Socioeconomic Controls?	No	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes
Alcohol and Marijuana Policy Controls?	No	No	No	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2003-2019 waves of the state (Panel I) and national (Panel II) Youth Risk Behavior Surveys; estimates in Panel III are based on the 2011-2019 waves of the Behavioral Risk Factor Surveillance Survey (BRFSS) Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.

Appendix Table 8. TWFE Estimates of the Effects of ENDS Taxes on Alcohol Consumption among Youths, YRBS, 2015-2019

	(1)	(2)	(3)	(4)
	Panel I: Any Alcohol Use			
ENDS Tax ($)	-0.0238***	-0.0211***	-0.0321***	-0.0324***
	(0.0076)	(0.0068)	(0.0081)	(0.0087)
N	510,442	510,442	510,442	510,442
Pre-Treatment Mean of Dep Variable	.2946	.2946	.2946	.2946
	Panel II: Number of Drinks | Alcohol Use = 1[a]			
ENDS Tax ($)	-0.3070***	-0.3517***	-0.3071**	-0.2802**
	(0.0744)	(0.0729)	(0.1132)	(0.1279)
N	38,668	38,668	38,668	38,668
Pre-Treatment Mean of Dep Variable	4.3453	4.3453	4.3453	4.3453
	Panel III: Binge Drinking			
ENDS Tax ($)	-0.0296***	-0.0295***	-0.0318***	-0.0316***
	(0.0046)	(0.0048)	(0.0050)	(0.0052)
N	469,332	469,332	469,332	469,332
Pre-Treatment Mean of Dep Variable	0.1518	0.1518	0.1518	0.1518
	Panel IV: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0171***	-0.0168***	-0.0226***	-0.0228***
	(0.00290)	(0.00310)	(0.00340)	(0.00340)
N	469,332	469,332	469,332	469,332
Pre-Treatment Mean of Dep Variable	0.0895	0.0895	0.0895	0.0895
State and Year FE?	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes
Socioeconomic Controls?	No	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes
Alcohol and Marijuana Policy Controls?	No	No	No	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates are generated via weighted least squares using the 2015-2019 waves of the state Youth Risk Behavior Surveys. Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.

Appendix Table 9: Sensitivity of Effects of ENDS Taxes on ENDS Use and Binge Drinking to Addition of Control for One Period Lead, BRFSS

	(1)	(2)
	ENDS Use	**Binge Drinking**
1 Wave Prior to ENDS Adoption	-0.0124	-0.00808
	(0.0133)	(0.00513)
ENDS Tax ($)	-0.0246***	-0.0134**
	(0.00665)	(0.00584)
Pre-Treatment Mean of Dep Variable	0.119	0.163
N	25,890	82,013
State and Year FE?	Yes	Yes
Full Controls?	Yes	Yes

***Significant at 1% level **at 5% level *at 10% level

Note: Estimates on ENDS use are based on the 2016-2018 waves of the Behavioral Risk Factor Surveillance Survey (BRFSS). Alcohol measures are obtained using the 2011 to 2019 waves of the BRFSS. Standard errors are clustered at the state level. Demographic controls include age, gender, education, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws. Columns (2) to (6) include state fixed effects, year fixed effects, and treatment state-specific linear trends.

Appendix Table 10. Sensitivity of Estimated Alcohol and Non-Alcohol Traffic Fatality Effects for 16-to-20-Year-Olds to Use of Poisson Model

	(1)	(2)
	Traffic Fatalities with Drivers BAC > 0	Traffic Fatalities with Drivers BAC = 0
ENDS Tax ($)	-0.130**	-0.0576
	(0.0605)	(0.0593)
N	867	867
Pre-Treatment Mean Dep Variable	39.70	89.79

***Significant at 1% level **at 5% level *at 10% level

Note: Poisson estimates are generated from the Fatality Analysis Reporting System (FARS) from years 2003 to 2019. Standard errors are clustered at the state level. Regressions are weighted using state populations. Full controls include three categories of covariates: Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws. All regressions include state fixed effects, year fixed effects, and treatment-state specific linear trend.

Appendix Table 11. TWFE Estimates of Effect of ENDS Taxes on Drinking and Driving

	State YRBS Ages 16-18	BRFSS Ages 18-20
ENDS Tax ($)	-0.0001	-0.0116
	(0.0022)	(0.0104)
N	1,033,321	37,319
Pre-Treatment Mean Dep Variable	0.0713	0.0144

Significant at 1% level **at 5% level *at 10% level
Note: Column (1) is based on the 2003-2019 waves of the State Youth Risk Behavior Surveys and column (2) is based on the 2012-2018 waves of BRFSS. Standard errors are clustered at the state level. Demographic controls include age, gender, grade, and race. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include Tobacco-21 laws, ENDS minimum legal sales age laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. Alcohol and marijuana policy controls include beer taxes, medical marijuana laws, and recreational marijuana laws.