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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 major 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 nicotine delivery systems (ENDS) use among teenagers has been deemed "an epidemic" by the U.S. Surgeon General, with state and local policymakers turning to e-cigarette taxes as a popular policy tool to curb nicotine vaping. This study is the first to explore the spillover effects of e-cigarette taxes on teenage drinking and alcohol-related traffic fatalities. 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 binge drinking among teenagers and a 5 to 10 percent reduction in traffic fatalities involving teenagers driving under the influence of alcohol. Together, these results suggest the presence of alcohol-related health benefits from e-cigarette taxation.

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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 & 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 & Köszegi, 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 (Centers for Disease Control and Prevention, 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 (National Institute on Alcohol Abuse and Alcoholism, 2021).[3] 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 monthly (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 (Centers for Disease Control and Prevention, 2012) and teen drivers account for 15 percent of passenger deaths of all ages (Insurance

[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) (National Institute on Alcohol Abuse and Alcoholism, N/D).

Institute for Highway Safety, 2022). In total, the social costs of teenage alcohol misuse in the U.S. are estimated to be $28 billion per year (Centers for Disease Control and Prevention, 2022c).[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 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 & Moore, 1993; DeSimone, 2009; Grossman et al., 1994; 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, 2001), crime (Carpenter, 2005a, 2007; Carpenter & Dobkin, 2015), suicidal behaviors (Carpenter, 2004; Carpenter & Dobkin, 2009), risky sexual behaviors and pregnancy (Carpenter, 2005b; Dee, 2001; Markowitz et al., 2005), and the use of harder substances (Kirby & 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, 2009) 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 (National Institute on Alcohol Abuse and Alcoholism, 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 (Pfefferbaum et al., 2018; Squeglia et al., 2015).

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) (National Institute on Alcohol Abuse and Alcoholism, 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 & Yarnoff, 2011). Understanding and

[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 (Centers for Disease Control and Prevention, 2022a).

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 (Dave, Dench, et al., 2019; Saffer et al., 2020) and providing a less unhealthy alternative to combustible tobacco product use (National Academies of Sciences, 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 teen ENDS use as an "epidemic."

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[6] and the most recent (and increasingly popular) policy lever to curb teenage vaping: taxation of ENDS.[7] 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, 2023). Two large counties also adopted ENDS taxes over this time period: Cook County, Illinois in 2016 and Montgomery County, Maryland in 2015. By December 2023, 31 states and Washington DC taxed these products (Public

[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 fell to 11.3 percent in 2021, increased subsequently to 14.1 percent in 2022, before decreasing again to 10.0 percent in 2023, though methodological changes that took effect during the COVID-19 pandemic preclude comparisons of the post-pandemic data with the earlier surveys.

[6] 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.

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

Health Law Center, 2023). Among adopting states, ENDS tax rates vary substantially, with some states taxing standard ENDS pods[8] less than a nickel and others taxing ENDS more than cigarettes (Cotti et al., 2022). Several recent studies show that taxing ENDS has an intended public health effect of reducing teenage and adult ENDS use (Abouk, Courtemanche, et al., 2023; Anderson et al., 2020; Pesko et al., 2020), but also find that ENDS taxes increase cigarette use (Abouk, Courtemanche, et al., 2023; Friedman & Pesko, 2022; Pesko et al., 2020), which clearly undermines the policy's tobacco-related public health goals, casting doubt on the efficacy of 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.

The direction and degree to which ENDS taxation would generate spillover effects into youth alcohol consumption depend, in part, on whether alcohol and ENDS are gross economic substitutes or complements for youth. Substitution responses can result as a tax-avoidance strategy, particularly across products that serve a common purpose.[9] Youth and young adults have been found to be responsive to the monetary cost of ENDS (Abouk, Courtemanche, et al., 2023; Friedman & Pesko, 2022; Pesko & Warman, 2022). By raising these costs, higher ENDS taxes could lead some youth vapers to substitute away from ENDS into higher levels of alcohol consumption, potentially adding to the internal and external costs of alcohol misuse.

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

[9] Both alcohol and nicotine have addictive potential. Moreover, while alcohol is technically a central nervous system depressant and nicotine classified as a psychomotor stimulant, research has shown that each of these substances can produce both stimulant and sedating effects (Hendler et al., 2013; Henningfield & Woodson, 1989). These studies suggest that nicotine at low doses could have a depressant effect, and at higher doses a stimulant effect. With respect to alcohol, some evidence indicates that individuals at high risk for an alcohol use disorder have a greater stimulant response than a sedative response to alcohol. Hence, it is possible that for some subset of youth users, who derive similar psychoactive effects from alcohol and nicotine, higher ENDS taxes may lead them to substitute towards alcohol consumption either at the intensive margin or at the extensive margin.

On the other hand, youth tend to complement their consumption with multiple addictive substances, contemporaneously by co-using and/or dynamically by transitioning across various substance use over adolescence into young adulthood. A substantial fraction of past month ENDS users (36 percent in 2019, in the national Youth Risk Behavior Survey), for instance, also co-engage in binge drinking. Several factors – biological, social, and economic – can drive this high degree of co-use. Alcohol and nicotine can both induce dopamine efflux, and in combination can magnify the activation of the mesolimbic reward system (Thrul et al., 2019; Verplaetse & McKee, 2017). This synergistic pharmacologic effect, wherein tobacco and nicotine have been found to raise alcohol-craving, supports their consumption being complementary. Recent evidence, for instance, points to the rewarding effects ("stimulation" or "buzz") of using ENDS (a stimulant due to nicotine included in these products) being enhanced when used in conjunction with alcohol (a depressant) (Russell et al., 2022; Thrul et al., 2019), though the biological relationship between ENDS and alcohol may be weaker than the same relationship between cigarettes and drinking (Thrul et al., 2019).

Teen vaping and drinking behaviors also share strong social elements (Groom et al., 2021; Rosenquist et al., 2010), wherein the utility obtained from individual consumption also depends on the consumption of others in the individual's peer group. Significant and positive peer effects have been established for youth substance use, including combustible tobacco use and drinking (Kremer & Levy, 2008; Lundborg, 2006; Powell et al., 2005), though to date, to the best of our knowledge, there is no causal evidence on peer effects in the context of ENDS taxes. Such peer effects in ENDS and alcohol use would generate a social multiplier effect with respect to a change in ENDS taxes. If ENDS taxes increase (decrease) alcohol use, then the change in drinking at the peer group level would lead to cascading increases (or decreases) in the demand for alcohol as additional (or fewer) peers consume alcohol. These pharmacological and social network-based pathways, consistent with complementarity, could lead ENDS taxes to lower both ENDS use and alcohol use.

In addition, there would also be an income effect associated with the tax-induced higher price of ENDS products, which may reduce (increase) alcohol consumption if the income elasticity is positive (negative). The income effect may also operate in the opposite direction; if the higher cost of ENDS is reducing use at the extensive margin (Abouk, Courtemanche, et al., 2023), then this may free up resources, some of which may fund greater alcohol use. Finally, ENDS taxes may also exert secondary effects on various margins of alcohol use through their impact on cigarette use. There is robust evidence that higher ENDS taxation leads youth and young adults to substitute into smoking;

to the extent that cigarette use and alcohol use are economic complements (Dee 1999; Shang 2015) the ENDS tax-induced increase in smoking could lead to complementary increases in alcohol use.[10]

The impact of ENDS regulations on other addictive consumption among youth remains an open question with very little research informing these inter-relationships between ENDS products and other substance use. This study is the first to investigate 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 the adoption of ENDS taxation in the U.S. through 2019 (the final pre-COVID-19 year).

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 6.4 to 7.0 percentage-points (or approximately 27 to 28 percent), a substantial effect that is in line with earlier findings. 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 an approximately 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 and appear larger when examining the intensive margin of drinking behavior (i.e. number of drinks consumed and multiple binge drinking episodes). These results cannot be fully explained by the income effect associated with higher ENDS taxes and prices, nor by any secondary effects on alcohol use margins that operate through ENDS tax-induced shifts in cigarette smoking. 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 0.5 to 0.9 decline in the number of alcohol-related traffic fatalities per 100,000 16-to-20-year-olds drivers in a treated state-year. We find no evidence that ENDS taxes are related to traffic

[10] We hold cigarette taxes and other tobacco control policies constant in all models, thus "shutting down" channels that link ENDS and alcohol use through changes in smoking (e.g., if youth smoking decreases due to cigarette taxes or other tobacco control policies and, through economic substitution, increases vaping).

fatalities in which the teenage driver does not appear to have positive blood alcohol content at the time of the crash, consistent with the hypothesis that alcohol use is an important mechanism through which ENDS taxes reduce traffic fatalities.

Our results suggest that alcohol is a gross complement for ENDS among teenagers and young adults. That is, we show that an increase in the cost of ENDS (via taxes) leads to a decrease in the demand for alcohol. We note that the definition of economic complements is subtle (see Newman (2008) for a discussion). In particular, ENDS taxes may reduce teen income, leading to a reduction in the demand for both alcohol and ENDS if these goods are normal.[11] And, our effects are also net of any secondary effects on the demand for alcohol operating through changes in the demand for cigarette use. While we are able to largely rule out substantial income effects or secondary effects, such indirect pathways complicate analyses of economic complementarity. In sum, our results imply that taxing ENDS can generate important, policy relevant, and beneficial impacts on alcohol use, in particular among teens.

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 and welfare implications.

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 & 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 (Carpenter & Dobkin, 2009, 2011, 2017; Carpenter et al., 2016; Cook & Moore, 2001; Dee, 1999). For example, Dee (1999) 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.

[11] Further, with our design, we are able to test whether e-cigarettes are a complement with alcohol, but alcohol may not a complement with e-cigarettes. Note that, in particular, for outcomes at the extensive margin, symmetric cross-price effects are not a necessary property of demand functions without the imposition of requisite restrictions on parameters in the utility function. An interesting avenue for future research would be exploring whether alcohol is a complement with e-cigarettes.

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 & 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 (Yörük & Xu, 2021), zero tolerance drunk driving laws (Carpenter et al., 2007), and scanner ID laws (Nesson & Shrestha, 2021; Yörük, 2014, 2018; Zheng, 2018). 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 & 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 MLDA 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 (Nesson & Shrestha, 2021; Yörük, 2014, 2018) 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 & Rafkin, 2022; Cotti et al., 2022), survey data on adults and youth (Abouk, Courtemanche, et al., 2023; Friedman & Pesko, 2022; Pesko et al., 2020), and birth record data on pregnant women (Abouk, Adams, et al., 2023). 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 over this period) leads to a 52 percent decline in ENDS sales at retail stores in the U.S., suggesting that ENDS and cigarettes are economic substitutes.[12]

More directly related to our study, two recent studies examine the impact of ENDS taxation on teen ENDS use (Abouk, Courtemanche, et al., 2023; Pesko & 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, Adams, et al. (2023) establish that a one-dollar increase in the ENDS tax rate leads to a 12.5 percent (ε = -0.08) to 33.3 percent (ε = -0.16) reduction in current teen ENDS use.[13]

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

[12] 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).
[13] 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 & Adams, 2017; Dave, Feng, & Pesko, 2019) and increase cigarette use (Dave, Feng, & Pesko, 2019; Friedman, 2015; Pesko & Currie, 2019; Pesko et al., 2016). Laws that limit or prohibit ENDS use in public places have not been found to affect ENDS use (Cheng et al., 2023; Friedman, 2021; Nguyen & Bornstein, 2020).

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 Relationship 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 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 (Burton, 2020; Goel & Morey, 1995; Koksal & Wohlgenant, 2016), others economic complements (Adams & Cotti, 2008; Bask & Melkersson, 2004; Cameron & Williams, 2001; Pierani & Tiezzi, 2009; Tauchmann et al., 2013; Ukert, 2017), and still others no relationship (Decker & 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 youth 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.[14] Dee (1999) 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,

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

Dave, Feng and Pesko (2019) 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.[15]

2.4 Public Health Literature on E-cigarettes and Alcohol

A series of public health studies uses cross-sectional survey data and documents positive associations between teen vaping and drinking (Hughes et al., 2015; Milicic & Leatherdale, 2017; Rothrock et al., 2020; Thrul et al., 2019). For example, in a meta-analysis of 28 studies, Rothrock et al. (2020) show among teens, ENDS users have 8.17 times higher odds of binge drinking than those who do not use ENDS. Thrul et al. (2019) survey young adults and find that reported euphoria derived from ENDS use is higher when ENDS is consumed in combination with alcohol than when consumed alone (as combining a stimulant, such as ENDS, with a depressant, such as alcohol, biologically increases pleasure from stimulant use). The findings of Thrul et al. (2019) imply that using alcohol with ENDS may increase the marginal utility of ENDS use.

In sum, these studies offer suggestive evidence of economic complementarity between alcohol and ENDS among teens and young adults, but due to the employed study design (in particular, comparing individuals who consume and do not consume e-cigarettes and alcohol, and relying on adjustment for observable differences), these studies are not likely able to recover estimates on whether alcohol and ENDS are causally related; more specifically there are likely omitted variables (e.g. risk preferences) that may drive the observed correlations. Our study extends this literature by using powerful quasi-experimental methods, in particular by leveraging variation driven by ENDS taxes, to assess whether there is a casual relationship between alcohol and ENDS use. Moreover, our study provides direct estimates of the effect of an important policy instrument – ENDS taxes, which may be of greater interest than the structural effect of ENDS use on alcohol consumption, given that policymakers, at most, influence ENDS use (and related outcomes) through changes in policies such as taxation. Collectively, the previous studies and our work can shed light on relationships between alcohol and ENDS.

[15] Dave, Feng and Pesko (2019) 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, Courtemanche, et al. (2023)]), 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 binge drinking and traffic fatalities.[16] 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.[17] 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 they 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 supplement our self-reported alcohol measures with more objective measures of drinking behaviors, including alcohol-involved traffic fatalities (discussed below). The state YRBS surveys are largely

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

[17] 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 state-by-year population data on 14-to-18-year-olds from the National Cancer Institute's (NCI) Surveillance, Epidemiology, and End Results Program. We note that some states, in some years, include private high schools in the sample frame.

distributed in January through June of the school year, and we therefore match policy measures based on the average values over the first two quarters. Thus, the timing and representation of our state YRBS data allow us to identify the effects of ENDS taxes for eight of 17 treatment states as well as three large local jurisdictions in two additional states (see Appendix Table 1).[18]

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 during January through June of the school year), 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.[19]

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 (23.6) percent of U.S. high school students as surveyed in the state (national) YRBS report ENDS consumption (see Appendix Table 2).

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

[19] In addition, following previous studies (see, for example, Abouk, Courtemanche, et al. (2023) 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. We also generate a similar unconditional measure that codes all respondents that do not report drinking in the past 30 days as zero; this measure, *Number of Drinks*, captures the largest number of alcoholic drinks among those teens that do and do not drink in the 30 days prior to the interview. Using the state YRBS data, we find that 4.5 (0.9) drinks is the largest number of drinks consumed in a row by the average teenage drinker (teenager).

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.[20] 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 drinking two or more times in the prior month and zero otherwise. The state YRBS data show that 19.9 percent and 13.0 percent of the respondents report any binge drinking and multiple binge drinking episodes, respectively.[21]

Appendix Figure 1 shows trends in ENDS use, and Appendix Figure 2A 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 several 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 2A reflects that both 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. In Appendix Figure 2B, we report trends in our YRBS alcohol use measures separately by groups of states based on the year in which they adopt ENDS taxes.

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.[22] Our analysis focuses on adults ages 18-to-20 (adults under the MLDA), all adults over the MLDA (21+), younger adults ages 21-to-39 (at or over the MLDA), and older adults ages 40-and-

[20] In 2017, this question was updated to account for differences in the definition of binge drinking by gender.
[21] The rates are similar in the national YRBS, where 22.3 percent and 14.7 percent of the respondents report any binge drinking and multiple binge drinking episodes, respectively.
[22] We note that this sample restriction only results in one state policy change out of 18 (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.

older.[23] In our main analyses, we do not weight the data as we focus on sub-sets of the sample (some of which, e.g. ages 18-20, reflect very small shares of the full sample), wherein the application of weights will not lead to nationally representative estimates; however in robustness checks we show results based on weighted analyses.

First, like the YRBS, the BRFSS includes measures of ENDS consumption over a short window; in this case, the years 2016-2018 (i.e. three years).[24] BRFSS respondents are asked whether they currently "use e-cigarettes or other electronic vaping products" on "some days," "every day," or "not 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 (results are unweighted) 13.5 percent of adults ages 18-to-20, 3.2 percent of adults 21-years-and-older, 6.8 percent of adults ages 21-to-39, and 2.3 percent of adults ages 40-and-older report current consumption of ENDS or other vaping products (see Appendix Table 3). We note that a limitation of using the BRFSS is that we have a relatively small sample size when focusing on specific age groups (i.e., those aged 18-20) and this sample is not representative of individuals of such sub-groups at the state level. As such, we are cautious in the conclusions we draw from the BRFSS for such groups.

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 (unweighted) mean rate of prior 30-day alcohol consumption for 18-to-20-year-olds over this sample period is 33.3 percent, 51.1 percent for adults 21-years-and-older, 61.9 percent for 21-to-39-year-olds, and 48.6 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?"

[23] The BRFSS data are available at: https://www.cdc.gov/brfss/ (last accessed 3/18/2024).
[24] The 2019 BRFSS does not include ENDS questions.

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 17.1 percent of 18-to-20-year-olds report binge drinking in the last month, and 8.2 percent report multiple binge drinking episodes in the past month.

In addition, we create measures of alcoholic drinks consumed in the prior month, including (1) the total number of drinks consumed in the last month (*Number of Drinks*), and (2) the total number of drinks consumed in the last month by drinkers (*Number of Drinks |Any Alcohol Use=1*). With respect to the latter, the average number of drinks consumed by an 18-to-20-year-old drinker is 27.2; for 21-years+, the number is 22.6.

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 alcohol use disorder 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, and shelters).[25] 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).[26] Thus, our analysis makes use of publicly available two-year overlapping state-by-year averages of binge drinking and alcohol use disorder. We conservatively match policy data on the first year of the two-year averages. 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-and older, 18-to-25 years, and 26-and-older.

For the purposes of this study, a disadvantage of the NSDUH dataset is that it does not include information about ENDS use. However, we can measure indicators of problem drinking

[25] The NSDUH sample does not include residents of hospitals or homeless individuals not residing in shelters.
[26] At the time of writing, accessing the restricted use NSDUH data is difficult and cost-prohibitive (see Balestra et al. (2021) for a discussion).

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 25.0 percent of 18-years-and-older, 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 (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).[27] We find that under these criteria, 7.0 percent of respondents 18-years-and-older, 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.

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 which we define as fatalities in which a driver appears to have a positive BAC at the time of the crash. 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.[28]

We focus on the period from 2003 to 2019 and generate a state-by-year panel of traffic fatalities for those drivers ages 16-to-20 and ages 21 and older. Given our interest in traffic fatalities involving alcohol, we make use of information collected on the BAC of the driver.[29] When the BAC of the driver is missing, we utilize the imputed BAC measure that is provided by the NHTSA and predicted using observed characteristics of the crash and the driver, such as prior convictions, license validity, time/day and severity the crash, vehicle type, opinion of law enforcement officials

[27] 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).

[28] The FARS data are available here: https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars (last accessed 3/20/2024).

[29] Information on BAC of the driver is available for approximately 63 percent of all traffic fatalities over the 2003-2019 period.

on the site regarding alcohol involvement, and others. Starting in 2001, the NHTSA transitioned to a multiple imputation approach to account for the range of plausible potential BAC values (when alcohol test results are not reported), and the FARS data include ten imputed values of the BAC for each missing value. In our main analyses, we assign a BAC>0 only if all ten imputation variables indicate positive BAC, and we then use the lowest of the ten imputed values to replace the missing BAC variable. We view this approach as conservative, but in robustness checks discussed below, we report results based on alternative imputation procedures.

Because our primary outcomes of interest involve drinking behaviors among teens, our main FARS variables measure traffic fatalities (of particular ages) involving teen (ages 16-20) drivers. To comprehensively study fatal crashes where teen alcohol use is potentially the contributing factor, we consider three fatal crash measures: i) fatalities of teen drivers, ii) fatalities (regardless of the decedent's age) where the driver is a teen, and iii) teen fatalities where the driver is a teen.

Appendix Table 5 reports descriptive statistics for the rate of traffic fatalities per 100,000 population (each conditional on the age and BAC of the driver). Over the 2003 to 2019 period, for example, the rates per 100,000 (teen population) of total, BAC>0, BAC>0.10, and BAC=0 teen fatalities with a teen driver are 15.2, 3.6, 2.4, and 11.6, respectively. Other fatality measures for teen drivers have different means, but the pattern across BAC level is similar to deaths of teen fatalities involving a teen driver.

Appendix Figure 3 shows trends in motor vehicle fatality rates for all ages in which a teen (ages 16-20) driver was involved (panel a), and alternately where an adult (ages 21+) driver was involved, over the period 2003-2019. We find that overall motor vehicle fatality decreases rapidly for teen drivers from 41.0 to 20.4 per 100,000 population during 2003-2019; for crashes involving alcohol (BAC>0), the rate declined from 9.6 to 3.7. For traffic fatalities involving adult drivers, the decline is less steep, from 18.3 per 100,000 population in 2003 to 13.8 in 2019; over the same period, fatalities involving an adult driver with BAC>0 declined from 5.1 to 3.4.

In Appendix Figure 4, we show trends in the all-age fatality rate involving teen drivers with a BAC>0, across treated and non-treated states by region and ENDS tax adoption cohorts. Panel (f), for instance, show trends separately for the states that adopted an ENDS tax in 2019 vs. the not-yet-adopting states by region. While the disaggregated trends are noisy, they help visualize spatial heterogeneity in the trends and the validity of non-treated states in different regions as counterfactuals for the treated states, an issue we address and discuss further below.

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. (2023) produce a standardized tax per fluid mL measure, which we use.

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.[30] By December 2023, 31 states and Washington DC taxed these products (Public Health Law Center, 2023). As can be seen in Figure 1, there is some geographic clustering of ENDS taxes, in particular, there are few Southern states that adopted ENDS taxes by 2019. Ex ante, and given the geographic clustering of taxes, due to religiosity, political preferences, vaping and alcohol prevalence rates, and other factors, we might expect that Southern states may offer a poor counterfactual for the (mainly) Western and Northeastern states that adopted ENDS taxes during our study period. In robustness checking, we include region-by-year fixed effects, which force the counterfactual comparisons we make in our difference-in-differences regressions to be within region, and alternately we drop the Southern region from the analysis sample; and our results are not overly sensitive to these changes.[31] However, to shed further light on why we might observe differences in ENDS tax adoption by state, in Appendix Table 6, we regress ENDS taxes on state-level controls included in our regressions (see Section 4), state fixed effects, and year fixed effects. Interestingly, we do not find evidence that these state-level variables systematically predict ENDS taxes, a pattern of null findings in line with earlier studies of state-level ENDS taxation predictors (Maclean et al., 2018).

4. Methods

4.1 Primary Difference-in-Differences Regressions

[30] We incorporate local taxes at the state-level based on the share of the population residing in the localities.
[31] This ex post robustness is consistent with the largely similar trends across regions for the pre-adoption periods across treatment-year cohorts (Appendix Figure 4).

We begin by drawing individual-level 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). The primary independent variable of interest, $ENDS\ Tax_{st}$, measures the standardized ENDS tax per mL of fluid (adjusted to 2019 dollars using the Consumer Price Index). 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 (or "T-21"), and alcohol and marijuana control policies (beer tax per gallon, medical marijuana laws, and recreational marijuana laws);[32] $\mathbf{Z}_{it}$, 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:

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

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

[32] The source for ENDS taxes is Cotti et al. (2023). State cigarette taxes are obtained from the CDC STATE system (Centers for Disease Control and Prevention, 2024), state beer taxes are obtained from the National Institute on Alcohol Abuse and Alcoholism (2024), demographic shares of state populations are obtained from the Surveillance, Epidemiology, and End Results Program, 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 (2023), the Prescription Drug Abuse Policy System (PDAPS), and ProCon.org. State T-21 laws are obtained from Hansen et al. (2023). State clean indoor air laws are obtained from the CDC STATE system (Centers for Disease Control and Prevention, 2024). The minimum legal sales ages for ENDS and cigarette MLSAs are identical; therefore, we control for just the presence of an ENDS MLSA since we separately control for the cigarette MLSA age. We match control variables to the data (where possible) at the quarter-year level and at the year-level otherwise.

where $\pi_{se} * t$ is a treatment-state-specific linear time trend.[33] 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 (linear) trends that may differ across the treated states. 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), and Meer and West (2016)) or isolating identifying variation that is correlated by other spurious factors (Neumark et al., 2014).

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:

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

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 covariates is matched based on the first period of the year pair in order to avoid conflation with lead effects. In addition, the vector 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 ($\pi_{se} * t$).

[33] The treatment state-specific linear time trend is calculated as the interaction between a linear time trend and an indicator for each ever-adopting state relative to the group of non-adopting states. Subscript *e* here is an indicator coded as one for states that adopt an ENDS tax by 2019; otherwise, it is zero. We do not include a separate indicator for ever-adopting an ENDS tax by 2019 as this indicator is collinear with state fixed effects.

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

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

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 (Anderson et al., 2022), 0.08 BAC laws (Insurance Information Institute, 2024), and speed limits (Insurance Institute for Highway Safety, 2024).[34] 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; fixed effects Poisson) and the treatment of zero fatality counts, which account for 2.3 percent of all observations (i.e. dropping observations with zero fatalities versus recoding them as one or 0.1).

The key policy parameter of interest in equations (1) through (4), γ_1, captures the partial effect of a one-dollar (in 2019 terms) 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, two large and one city 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 Siegloch (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):

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

[34] 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).

where *t* represents survey years, *j* represents event-time, π_j 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*. We include -6/-5 or more years pre-tax, -4/-3 years pre-tax, -2/-1 years pre-tax (our reference period), 0/1 years post-tax, and 2+ years post-tax. 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. We utilize two-year bins to maintain consistency, since our main data sets - the state and national YRBS - are fielded every two years.

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 & 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.[35] To expunge these potential biases, we turn to a stacked 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, Courtemanche, et al., 2023).

To implement this approach, we select a common event window around the adoption of an ENDS tax.[36] 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):

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

[36] In the YRBS, recall that these data are only collected every two years, this event window is three waves prior to the tax and one wave following the tax. For state-level datasets (i.e. FARS), where we have data collected in each year (though the NSDUH are two year averages), the event window is six years prior to the tax and two years following the tax.

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

where *c* denotes the cohort (each treatment state and its controls), 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 9 and Figures 2 through 5. Supplemental analyses are presented in the appendix tables and figures. All regressions are weighted,[37] though we also assess sensitivity in unweighted models (particularly for the state-aggregated analyses), and standard errors are clustered at the state level (Bertrand et al., 2004).

5.1 Adolescent ENDS and Alcohol Use

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 pooled state YRBS data. The outcome variable in all regressions in Table 1 is equal to one if the respondent reports using an ENDS product at least once in the past 30 days; it is set equal to zero otherwise (see Section 3.1 for more details). 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 (T-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 6.7 percentage-points. In our preferred specification (column 4), which also includes controls for alcohol and

[37] In analyses of national YRBS, we use weights provided by the CDC; for the pooled state YRBS, we normalize and adjust the provided weights to also make all estimates nationally representative. Population weights are used in analyses of the aggregated data from the FARS and NSDUH, where indicated. As described in Section 3, BRFSS analyses are unweighted.

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 6.4 percentage-point decline in ENDS use. This estimate corresponds to a 28 percent decline in ENDS use relative to the pre-treatment mean of youth ENDS use in the treatment states.[38]

While data on ENDS use is only available in three waves of the YRBS (2015, 2017, and 2019) thereby precluding a formal event-study analysis, in column (1) of Appendix Table 7, we descriptively explore whether the decline in youth ENDS use precedes rather than follows the adoption 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 of Table 1, 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 6.8-to-8.4 percentage-point decline in prior-month ENDS use among U.S. high school students.[39] Results from both state and national YRBS are largely consistent with those reported by Abouk, Courtemanche, et al. (2023).

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 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 observe a decline in the extensive margin of drinking (i.e. any drinking), but the coefficient estimates are imprecise. In column 4, which includes a full set of controls, our results suggest that a one-dollar increase in the ENDS tax leads to an approximately 3.5 percent decline in the probability of any

[38] The implied ENDS participation tax elasticity, based on the mean participation and tax rate for the treated units, is -0.20; this finding is consistent with YRBS estimates reported by Abouk, Courtemanche, et al. (2023).

[39] 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, Courtemanche, et al. (2023) 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 youth, roughly 6.0 percentage-points.

alcohol use among teens, with the 95 percent confidence interval ranging from zero to seven percent. We interpret these findings to imply that ENDS taxes potentially reduce drinking along the extensive margin to a small degree, but we lack the power to detect this effect with our design.

Next, in panel II, we find that a one-dollar increase in ENDS taxes leads to a 0.33 to 0.37 fewer average drinks per sitting among those youth who consume alcohol. This finding corresponds to a 7.4 to 8.2 percent reduction in the average number of drinks consumed, suggesting a potentially important effect on the intensive margin of youth alcohol use. In panel III, we examine the unconditional number of drinks (i.e. we include those teens with no drinking, assigning them a value of zero). Results are similar, in column (4), we find that a one-dollar increase in the ENDS tax leads to a reduction of 0.19 drinks, which implies a 15.4 percent reduction.

Moreover, in panels IV and V 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 10.6 to 11.1 percent and 8.2 to 10.3 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).[40] 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 8, 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

[40] To frame the spillover effects on binge drinking in context, we can use the first stage analyses (Table 1, column [4]) to calculate a back-of-the-envelope version of the treatment-on-the-treated (TOT) effect for a continuous treatment. The first-order effects of ENDS taxes on ENDS use (Table 1, column [4]) indicate approximately a six to seven percentage-point decline; using these magnitudes to rescale the reduced-form effects on binge drinking (Table 2 and Appendix Table 8 column [4], approximately two percentage-point decline) implies a TOT of about 0.27 to 0.36. In other words, about one out of every three teens, who on the margin reduces their ENDS use in response to higher taxes, also reduces their binge drinking behavior. These estimates should be interpreted with caution and are meant to be suggestive since TOT estimates rescaled in this manner 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.

negatively related to binge drinking, consistent with a complementary relationship.[41] Moreover, in Appendix Table 9, 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. As discussed above, in columns (2) through (6) of Appendix Table 7, we find no evidence that youth alcohol use declined more in treatment versus control states in the year prior to ENDS tax adoption. However, one exemption to this pattern of null results there is some evidence of leading effects for our measure of conditional number of drinks. Reassuringly, the coefficient estimate on the main tax variable is not appreciably different when we control for the tax lead.

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.[42] We find that divergence in binge drinking between treatment and control states occurs after the adoption of an ENDS tax increase.

As noted above, a 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 a stacked difference-in-differences estimator where we select an approximately balanced event-time window (three waves prior to tax adoption and at most one wave 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 0.40 fewer drinks among youth drinkers, a 2.8 percentage-point decline in binge drinking, and a 1.9 percentage-point decline in multiple episodes of binge

[41] A qualitatively similar pattern of findings on binge drinking and multiple binge drinking episodes is found in the national YRBS when we explore unweighted OLS regressions.

[42] In the case of a continuous treatment as we have, the identification of the average causal response parameter (counterpart of the average treatment effect for a dichotomous treatment variable) requires a much stronger parallel trends assumption across all treated units with different treatment intensity as well as the non-treated units, which is difficult to test.

drinking. We also find evidence in the stacked difference-in-differences specification, that the probability of any drinking declines, recall that when using TWFE the coefficient estimate was negative but not precise. In the stacked difference-in-differences estimator, we observe that following a one-dollar increase in the ENDS tax the probability of any drinking declines by 1.8 to 2.4 percentage-points. The coefficient estimates for unconditional number of drinks carry a negative sign, but are not statistically different from zero at conventional levels. An examination of the 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 generally 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 somewhat increases standard errors but also generally shows a consistent pattern of results (column 3 vs column 1). Finally, in column 4, we exclude the Southern region[43] as there are few states in this region that adopt an ENDS tax during our study period. Based on the findings reported in Table 1, we conclude that unmeasured spatial heterogeneity is not an important source of bias in the estimated effects of ENDS taxes.

In our analysis thus far, we show that ENDS taxes reduce vaping and drinking measured separately. The literature documents that ENDS and cigarettes are economic substitutes, with increases in ENDS taxes leading to increases in smoking. In prior work using data from the YRBS and the Monitoring the Future (MTF), we find robust evidence that a one-dollar increase in ENDS taxes reduces youth smoking by about 1.3 percentage-points (Abouk, Courtemanche, et al., 2023). As described in Section 2.3, whether cigarettes and alcohol use are economic complements or substitutes, or perhaps unrelated goods, is not clear at this point in time. Therefore, with this background, based on the analysis presented thus far, our results suggest that the decline in drinking

[43] The following states are in the U.S. Census Bureau's definition of the South region: Alabama, Arkansas, Delaware, the District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia.

attributable to reduced vaping more than off-sets any (potential) positive effect of an increase in drinking associated with increased smoking. This pattern of results is not implausible as the net effect will be determined by these two channels. Ex ante the dominant channel is likely to operate through the link from shifts in vaping through its relationship with alcohol use given that these first-order effects of ENDS taxes on ENDS use are an order of magnitude larger (three to eight percentage-points; see Table 1) than the second-order effects of ENDS taxes on smoking (about one percentage-point).[44] Here we test this relationship more directly, by assessing how ENDS taxation is impacting co-use of tobacco and alcohol.

Table 5 provides consistent evidence that ENDS taxes are associated with a decline in dual use of ENDS products and alcohol (any drinking, any binge drinking, and multiple binge drinking episodes). In our preferred specification (column 4), we find that a one-dollar increase in ENDS taxes is associated with a 3.7 percentage-point reduction in ENDS use and drinking at the extensive margin, a 2.9 percentage-point reduction in ENDS use *and* binge drinking, and a 2.2 percentage-point reduction in ENDS use *and* multiple binge drinking episodes. These coefficient estimates are consistent with ENDS and binge drinking being gross economic complements. In order to assess if the complementarity channel is driven by secondary shifts in tobacco use (notably smoking) due to the primary reduction in ENDS use, we also examine whether ENDS taxes impact co-participation in smoking and drinking behaviors. Despite a high degree of co-use of cigarettes and alcohol, and a high prevalence of binge drinking among current smokers (approximately 60 percent in the 2019 YRBS), we do not find any statistically or economically significant changes in co-use behaviors between smoking and drinking. These results suggest that any spillover effects on alcohol consumption through ENDS tax-induced secondary effects on smoking behaviors are negligible.[45]

[44] Assuming a structural causal effect of smoking on drinking of about 0.4 to 0.5 (Dee, 1999), consistent with economic complementarity, this would imply that the secondary channel (ENDS taxes increase smoking by one percentage-point) would lead to approximately a 0.4 to 0.5 percentage-point increase in youth drinking, in which case our estimated effects are net of this pathway. If on the other hand, smoking and drinking are substitutes among youth (causal effect of smoking on drinking probability of -0.5 to -0.4), this would mean that less than a quarter of the effect we find is driven by this secondary spillover on drinking behaviors through ENDS tax-induced increase in smoking.

[45] Clinical studies document that high-intensity ENDS users are more likely to substitute between cigarettes and ENDS (Snider et al., 2017). In supplementary analyses (Appendix Table 10), we examine which ENDS users (light, moderate, or high intensity) consume less alcohol following ENDS tax increases. To this end, in the state YBRS, we examine co-consumption intensity measures of frequent/daily ENDS use vs. non-frequent/non-daily ENDS use with binge drinking. These analyses indicate that the declines in binge drinking are associated with shifts in both lighter and heavy vaping margins; the coefficient magnitudes imply somewhat larger declines in co-use of daily vaping and binge drinking (than for non-daily vaping and binge drinking), though we are not able to reject the null of similar absolute declines in co-consumption margins groups of vapers.

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 Income Effects

The spillover effects on binge drinking that we observe may reflect an indirect effect through the negative income shock generated as higher ENDS taxes reduce the purchasing power of teens' nominal income levels. In order to assess the extent to which our estimates can be explained by this pathway, we gauge the strength of this income effect in two ways. First, we assess how ENDS taxes are impacting the demand for other products (i.e. consumption of soda, milk, vegetables, ever cocaine use for harder drug consumption,[46] and use of condoms during sexual intercourse), which comprise relatively large spending shares for teens and would also presumably be impacted if higher ENDS taxes are producing a substantially large income effect. From the estimates for state YBRS 2003-2019 in Appendix Table 11, we find little evidence that higher ENDS taxation impacts teens' engagement in these other behaviors: coefficient estimates are relatively small and none rise to the level of statistical significance.

Second, we perform a back-of-the-envelope calculation on how much of our estimated effect can be attributed to the negative income shock, calibrating this imputation based on observed average spending on ENDS products and income levels among youth, and estimates of the income elasticity of alcohol, and the price pass-through of ENDS taxes from the literature (Cotti et al., 2022; Gallet, 2007).[47] Under the assumption that alcohol is a normal good, these calculations indicate that the negative income effect generated by higher ENDS taxes is negligible and could at most explain eight to nine percent (0.2 percentage-point) of the estimated decline in binge drinking (2.2 to 2.3 percentage-points; Table 2). If alcohol, and in particular heavy alcohol use, is an inferior good

[46] For our difference-in-differences analysis, the treatment effect will, therefore, be identified off of the *initiation* margin of harder drug use (see Dave et al. (2023) for a discussion of ever use measures in policy analyses).
[47] Specifically, we assume the following: average annual income among teens (ages 12-19) is $4,423 (2019 CPS Annual Social and Economic Supplement); annual spending on ENDS among regular users is about $1,000 (Sears et al., 2016); and income elasticity for alcohol of one (Gallet (2007) ; we use the larger estimate from the range provided to derive the maximal contribution of an income effect to our estimates); ENDS tax pass-through rate to prices of 0.90 ~ 1.0 and a mean price of ENDS of $4.82 (Cotti et al., 2022).

among teens and young adults, or if ENDS taxes in reducing ENDS use at the extensive margin are freeing up resources for teens, then our estimates of the ENDS tax-induced decline in binge drinking would be moderately understated (again by about eight to nine percent). In either case, we conclude that the income effect generated by a one-dollar increase in the ENDS tax is not nearly large enough to explain the estimated reduction in intensive alcohol use.

5.3 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). A limitation of the BRFSS is that ENDS information is only available from 2016-2018. We find that a one-dollar increase in the ENDS tax is associated with a 3.1 percentage-point decline in prior-month ENDS use for those ages 18-to-20 (column 1, panel I); this translates to a 22.3 percent decline relative to the pre-treatment mean. Controlling for the one-year lead tax effects decreases the magnitude of the decline to 2.8 percentage-points (Appendix Table 12). For adults ages 21-years-and-older (Table 7, panel II), we do not any meaningful or statistically distinguishable reduction in ENDS use. Thus, the first stage effects appear concentrated largely among younger adults in particular those 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 declines in alcohol consumption and binge drinking, but only among those age groups whose ENDS use is responsive to taxation.[48] Notably, a one-dollar increase in ENDS taxes is associated with a 1.6 percentage-point decline in the probability of binge drinking (panel I, column 3) among those 18-to-20-years of age and 2.2 fewer drinks among drinkers in this age group, coefficient estimates for other drinking outcomes carry a negative sign but are imprecise.[49]

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 estimator both without (panel a) and with (panel b) the inclusion of linear time trends. 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

[48] In Appendix Table 13, we disaggregate adults above the MLDA (ages 21+) into ages 21-39 and ages 40+, and continue to find little evidence of meaningful spillovers into alcohol consumption for any of these age groups.
[49] Appendix Table 14A shows estimated ENDS tax effects in the BRFSS using specifications that include treatment state-specific linear time trends. The results are qualitatively similar to those shown in Table 7. Appendix Table 14B reports BRFSS analysis on 18-20-year-olds using survey weights provided by the CDC.

effects in the pre-treatment period and declines materializing only following tax enactment, particularly in the shorter-run (i.e. in the year of the tax change and following year).[50]

In Table 8, we bring a different surveillance dataset, the NSDUH, into our analyses, which allows us to assess effects on a DSM-based measure of problem drinking (alcohol use disorder). 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 in adults 18-years-and-older, and separately among 18-to-25-year-olds and those ages 26-years-and-older. Given that the analyses are based on state-aggregates, we weight by the state population to derive the treatment effects for the average individual in a treated state, noting that these effects will be more reflective of individuals in more populated states. We report results without and with treatment-state specific linear time trends. While there are suggestive declines in binge drinking overall and alcohol use disorders, effect magnitudes are small, often highly imprecisely estimated, and do not show any clear patterns across younger vs. older adults, with or without controls for treatment state-specific linear trends.

5.4 Traffic Fatalities Results

Together, our findings above offer 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, generated using equation (4). We report results without and with treatment state-specific linear time trends included in the regression specification.

Overall, as reported in panels I to V in Table 9, our results suggest that ENDS taxes reduce fatalities in which the driver is a teen. While the coefficient estimates generally do not rise to the level of statistical significance, results in Table 9 (column 1, panels I-V) offer suggestive evidence that, following a one-dollar increase in the ENDS tax, total traffic fatalities involving a teen driver decline by as much as 4.4 percent. When we separate fatalities by driver BAC, a consistent pattern emerges pointing to an ENDS tax-induced decline in alcohol-involved traffic fatalities. Examining fatalities in which the driver has BAC > 0 and BAC > 0.10 allows us to stratify by any and higher levels of alcohol (driving with a BAC > 0.10 is illegal in all states), while fatalities associated with

[50] In Appendix Table 12, we take the alternate approach of including a dummy for the year prior to the enactment of an ENDS tax.

drivers with BAC = 0 can serve as an "anti-test" in that, if ENDS taxes reduce alcohol-involved fatalities, then we should not observe declines in fatalities not related to alcohol.

Specifically, for crashes involving drivers ages 16-to-20 years with a BAC>0 (column 2), the age demographic for whom we find the largest declines in binge drinking in the YRBS and BRFSS, we find that a one-dollar increase in ENDS taxes is associated with an 7.7 percent decline in the number of driver fatalities, 11.2 percent decline in all motor vehicle-related fatalities of all ages (drivers, passengers, others), and 9.5 percent decline in all motor-vehicle related fatalities of teens.[51] In contrast, and as expected, the coefficient 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 indistinguishable from zero at conventional levels (column 4). This pattern of results 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.[52] Conservatively, if we take the difference between the estimate in columns (2) and (4), "difference-in-difference-in-differences (DDD)" results imply an approximately six to 11 percent decline in alcohol-involved traffic fatalities involving 16-20-year-old drivers.[53] This number translates to approximately three fewer traffic fatalities (of any age) per treated state-year associated with alcohol-involved 16-20-year-old drivers.[54] Event study analyses (Figure 5) support a causal interpretation for these effects.

When we turn to alcohol-related fatalities involving adult (above the legal purchase age; ages 21+) drivers (panels VI and VII), we find close-to-zero and insignificant effects whether we consider the DD or the DDD (estimates in columns 2 or 3 minus those in column 4). This finding is reassuring given that there was little to no behavioral response for these individuals in terms of their problem drinking behaviors.

Appendix Figures 5 and 6 report stacked DD event-studies, and Appendix Figures 7 and 8 report effects using alternative, less restrictive, definitions of positive BAC values (i.e., we require

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

[52] 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.

[53] Estimated effects are robust to alternate sample restrictions and functional forms, including dropping zero fatality counts, using the non-logged rate as the outcome, and estimating models using fixed effects Poisson regression (Appendix Table 15). Estimates are also largely similar in unweighted models, though there is some loss in precision (Appendix Table 16).

[54] We use the coefficient estimates 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(-0.120)-(1-exp(0.006))), and then multiply it by the pre-treatment mean of total number of alcohol-involved traffic fatalities (BAC > 0).

fewer of the multiple imputed measures indicating positive BAC to construct the BAC>0 variable). In Appendix Table 15, we use a Poisson regression and add a value of 0.01 prior to taking the logarithm, in Appendix Table 16 we estimate unweighted regressions; and in Appendix Table 17, continuing to focus on adult-aged drivers, we disaggregate all-age fatalities into different age groups, in order to assess if the overall null effects are masking any age-based distributional effects; these findings continue to validate that there are little to no effects of ENDS taxation on alcohol-related motor vehicle crashes involving drivers ages 21 and older.

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

6. Conclusion

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, Courtemanche, et al., 2023; Cotti et al., 2022).

Teen alcohol misuse remains high and imposes substantial costs on society — with estimated annual social costs of $28 billion dollars (Centers for Disease Control and Prevention, 2022c) — and policy action by state and federal government 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 are only raised through legislative action infrequently. There appears to be little appetite for raising alcohol taxes at the state or federal levels with a regulatory stance that may favor alcohol producers over consumers.[55] 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

[55] 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).

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 some weak impact at the extensive margin of teen drinking (any alcohol consumption), but its main impact operates by curtailing 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 about five to ten percent following a one-dollar hike in the ENDS tax.

Interestingly, our findings suggest that experimental teen drinking (proxied by any alcohol use) and ENDS are largely 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 suggests that alcohol and tobacco products may be economic complements among teens (Dee, 1999), and this research shows that this relationship extends to ENDS for the first time. Moreover, our findings cannot fully be attributed to the negative income shock associated with higher ENDS taxes. While we show that alcohol appears to be a gross complement for ENDS among teens and young adults, our design (which exploits plausibly exogenous variation in ENDS taxes) does not allow us to explore the extent to which the relationship is symmetric, i.e., the extent to which ENDS is a gross complement for alcohol. Future work could investigate this question using different sources of identifying variation.

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 (Groom et al., 2021;

Rosenquist et al., 2010) and are often consumed together; for example, a substantial fraction of teen ENDS users (40 percent 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, Courtemanche, et al. (2023) and Pesko and Warman (2022)). Given the prior work suggesting that smoking and alcohol use are complements among teens (e.g. Dee (1999)), 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. 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. In particular, since ENDS taxes have been shown to impact both vaping and smoking, an ENDS-tax attributable rise in smoking could increase or decrease alcohol use, which acts in conjunction with the economic complementarity between ENDS and alcohol use. However, our indirect checks to assess the strength of this secondary pathway suggested that spillovers on the alcohol market from changes in cigarette consumption cannot fully explain our results, and at most may reflect less than a quarter of the estimated effects of ENDS on alcohol use.

While a full welfare analysis is beyond the scope of this study, we can assess how changes in vaping, smoking, and drinking may impact public health. First, we show that a one-dollar increase in the ENDS tax rates leads to a 28.2 percent (6.4 percentage-point) decrease in vaping, a 10.9 percent (2.3 percentage-point) decrease in binge drinking, and a 10.6 percent decrease in alcohol-related traffic fatalities associated with teen drivers, while in our earlier work we show that this tax increase leads to a 19.7 percent (1.3 percentage-points) (Abouk, Courtemanche, et al., 2023).

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 social cost perspective. Based on our preferred estimates, we document that a one-dollar increase in the ENDS tax rate leads to about two to three fewer all-age alcohol-related traffic fatalities per state-year associated with teen (16-to-20-year-old) drivers (Table 9). If all states raised their ENDS tax by one-dollar, this policy change would imply 125 teen lives saved annually. Using the Federal Emergency Management Agency's value of a statistical life ($14.35 million)[56] (Federal Emergency Management Agency, 2020), the value of these saved lives is nearly $1.79 billion 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 value of a statistical life estimate) is $13.1 million,[57] using this estimate suggests that a one-dollar increase in the ENDS tax rate would lead to nearly $1.64 billion in savings 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).[58]

While understanding the implications of the initial ENDS emergence in the U.S. into the U.S. market in 2006 is beyond the scope of our study, if ENDS and alcohol are economic complements, then the introduction of ENDS could have spurred additional alcohol use among teens. Taken in this light, one possible interpretation of our findings is that ENDS taxes are suppressing some of the additional alcohol use spurred by ENDS introduction into the U.S. market in 2006. That is, absent ENDS entering the U.S. and becoming so popular, some of today's ongoing alcohol use among teens may not have occurred, and ENDS taxes partially offset such use.

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 teens following ENDS taxation are concerning. Our prior finding, that a one-dollar increase in ENDS

[56] Inflated by the authors from $7.5 million in 2020 terms to 2022 dollars using the Consumer Price Index.
[57] Inflated by the authors from $11.2 million in 2020 terms to 2022 dollars using the Consumer Price Index.
[58] If we consider outcomes beyond mortality, the cost-benefit analysis becomes more complex. Kasunic and Lee (2014) estimate that the economic burden of alcohol use and smoking to the U.S. to be $354 billion and $319 billion respectively (we inflate the original estimates, $255 billion and $230 billion, from 2011 dollars to 2023 dollars using the Consumer Price Index). Taking this broader perspective of economic costs would add to the societal cost savings from reduced teen alcohol use.

taxation results in 1.3 percentage points increase in cigarette use among teens (Abouk, Courtemanche, et al., 2023), would add $83.9 billion in total lifetime societal costs.[59]

Finally, all of this needs to be balanced against societal benefits that accrue from fewer teens taking up ENDS use. Our estimates – in line with prior work (Abouk, Courtemanche, et al., 2023) – indicate about 1.28 million fewer teens using ENDS as a result of the higher tax. Smoking is believed to be much more harmful to health than vaping, though there is some debate on the relative risk of these two behaviors. The U.K. Office of Health Improvement and Disparities (McNeill et al., 2022) notes that vaping poses only a small fraction of the risk of smoking (about five percent) and a recent survey of 137 tobacco control experts finds that the expected reductions in life-expectancy associated with vaping are just 37 percent of the reduction in this outcome associated with tobacco product (including cigarettes) use (Allcott & Rafkin, 2022). Weighing the societal cost estimates of smoking (from Sloan et al. (2006)) by this range in the relative risk (0.05 ~ 0.37) suggests that the shrinking the pool of teen vapers results in societal cost savings of between $18.7 billion and $138.6 billion.[60]

While the cost savings resulting from the declines in alcohol-related traffic fatalities are meaningful, they are outweighed by the added societal burden from the ENDS tax-induced substitution to smoking and the potential cost savings that may result from fewer teens taking up ENDS. Moreover, even if the net welfare implications from ENDS taxation – based on shifts in smoking and problem alcohol use and the lower range of the estimate for ENDS users – are negative, there are important distributional implications to consider. Our results indicate that the declines in problem alcohol use are not driven by tax induced-increases in smoking; thus, the sub-population of youth who impose higher societal costs from higher smoking are not necessarily the same group who generates societal benefits in terms of reduced alcohol use.

Our work explicitly excludes the COVID-19 period, that is we close our panel in 2019. The COVID-19 pandemic upended many aspects of American lives, including substance use and health behaviors. An interesting avenue for future research is to explore how public policy impacts may change during crisis times, such as the COVID-19 pandemic. Such periods of time may increase or decrease the effectiveness of various public policies, including ENDS policies. However,

[59] We utilize estimates for the total social cost of smoking over one's lifetime from Sloan et al. (2006). The study reports that total social costs amount to $106,000 for a woman and $220,000 for a man. We take the average (given that gender effects on smoking reported in Abouk, Courtemanche, et al. (2023) are largely similar), and deflate to 2022 dollars, resulting in a lifetime cost estimate of $292,700 per average smoker.

[60] This large range reflects the uncertainty in the relative risk of vaping compared to smoking.

understanding and shedding light on this important question is beyond the scope of our work and a fruitful avenue for further research.

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.

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Figure 1. Geographic and Temporal Variation in ENDS Taxes

Panel (a): 2010

Panel (b): 2015

Panel (c): 2016

Panel (d): 2017

Panel (e): 2018

Panel (f): 2019

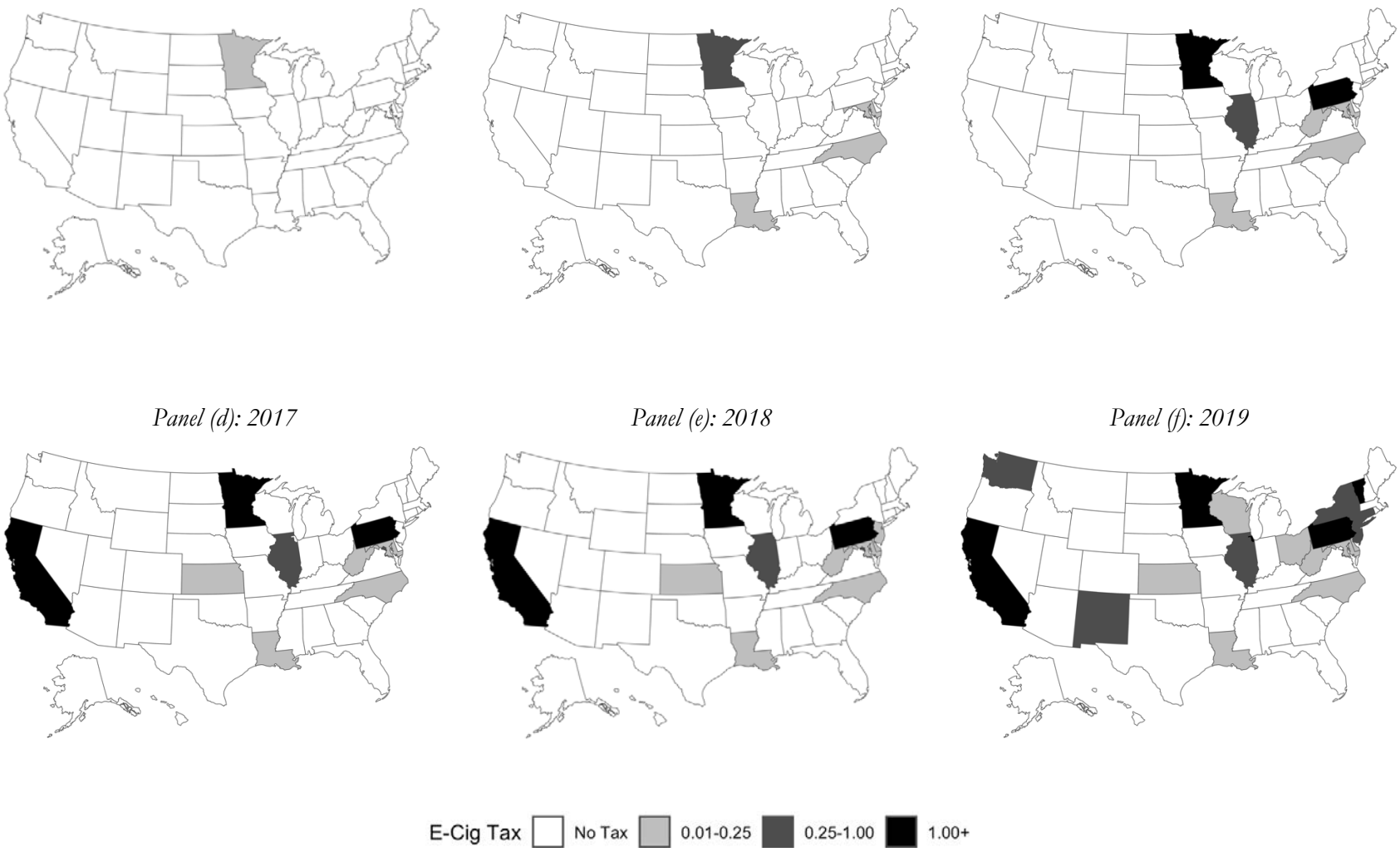
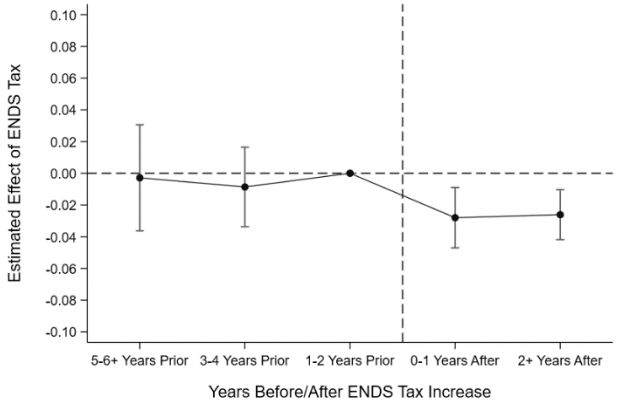
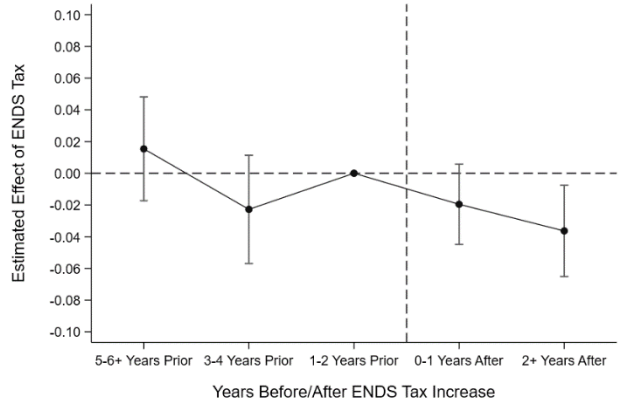


Figure 2. Event-Study Analysis of ENDS Taxes and Binge Drinking, Using TWFE Estimates, State YRBS

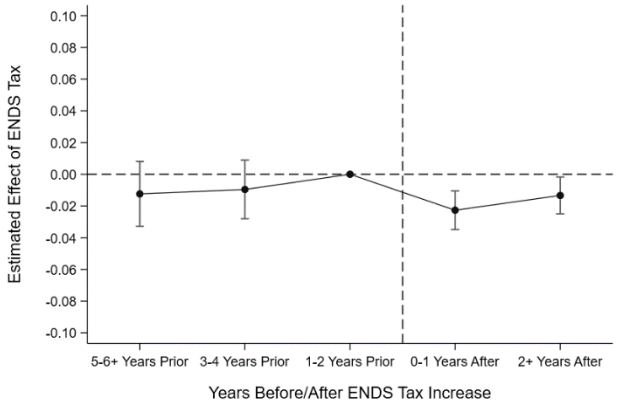
Panel (a): Binge Drinking, No Trends



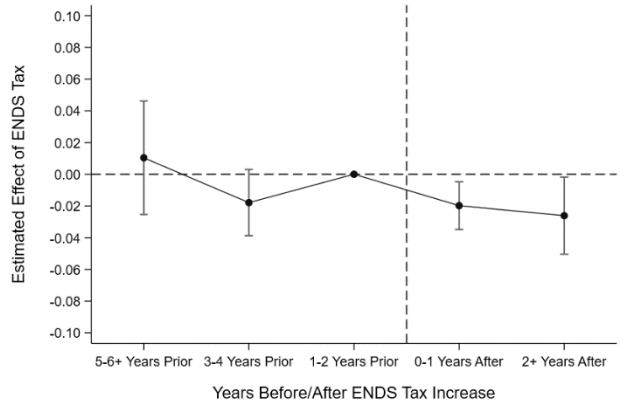
Panel (b): Binge Drinking, with Trends



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



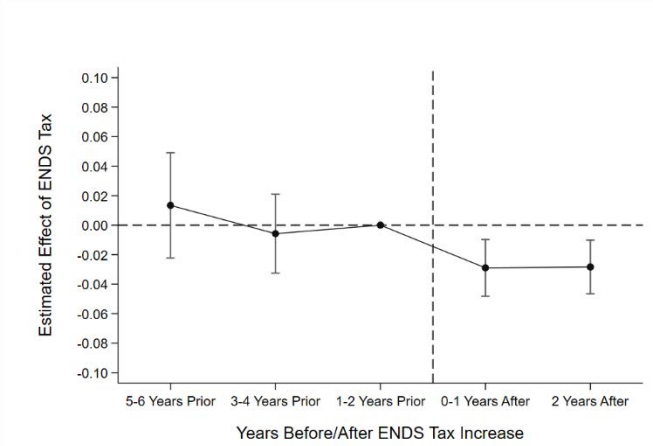
Panel (d): Multiple Binge Drinking Episodes, with Trends



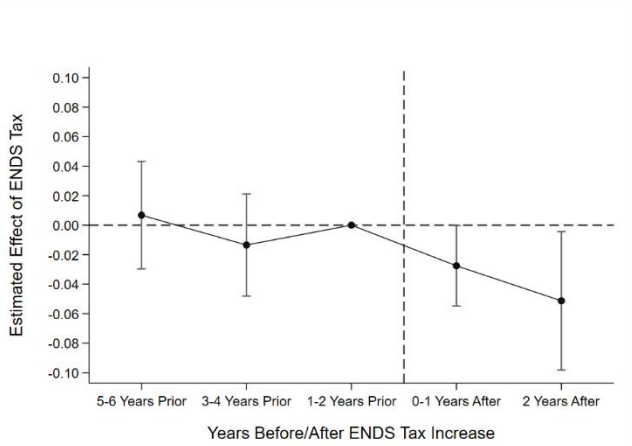
Note: Population weighted OLS estimates (with 90% CIs) from the event-study regression model described in equation (4) are shown. Regressions include state and year fixed effects and a full set of controls listed in Table 1. Panels (b) and (d) further include treatment state-specific linear time trends.

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

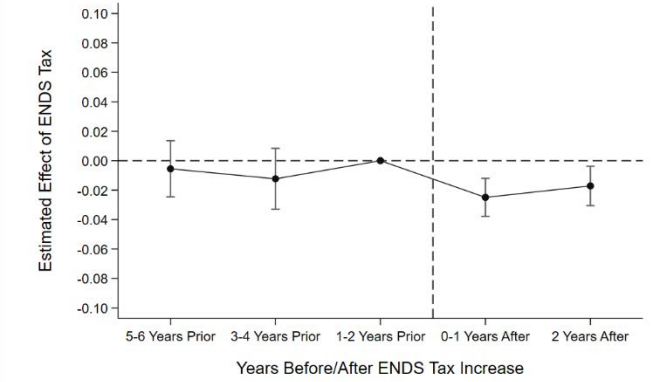
Panel (a): Binge Drinking, No Trends



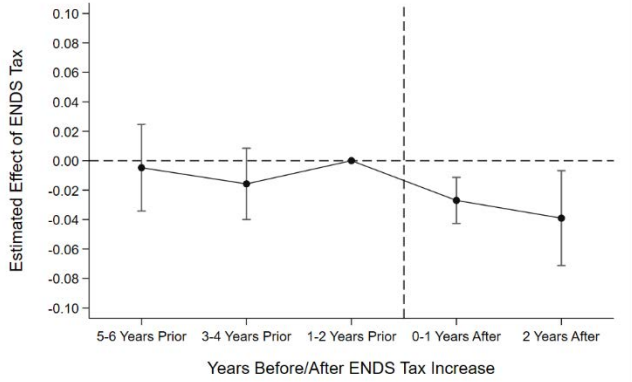
Panel (b): Binge Drinking, with Trends



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



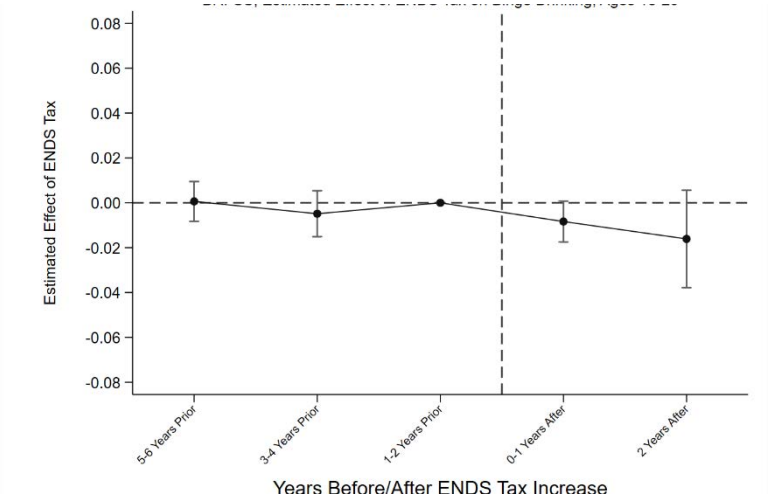
Panel (d): Multiple Binge Drinking Episodes, with Trends



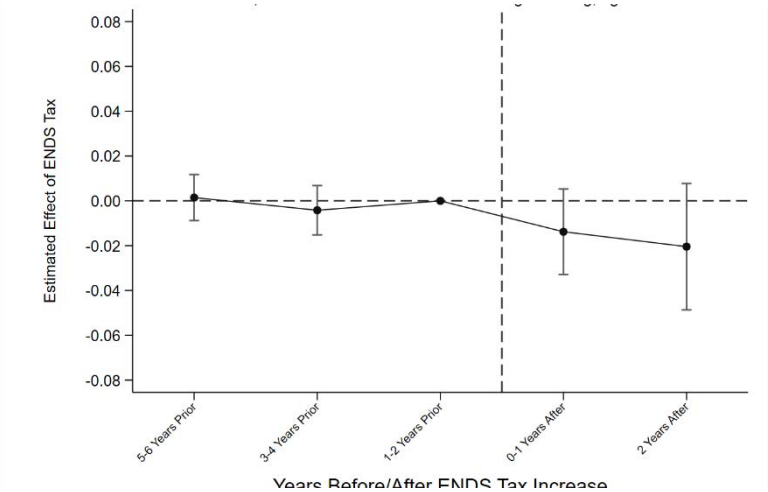
Note: Population weighted OLS estimates (with 90% CIs) from a stacked difference-in-differences regression over time are reported. Regressions include cohort, cohort-state, and cohort-year fixed effects and a full set of controls listed in Table 1. Panels (b) and (d) further include treatment state-specific linear time trends.

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

Panel (a): Binge Drinking, No Trends

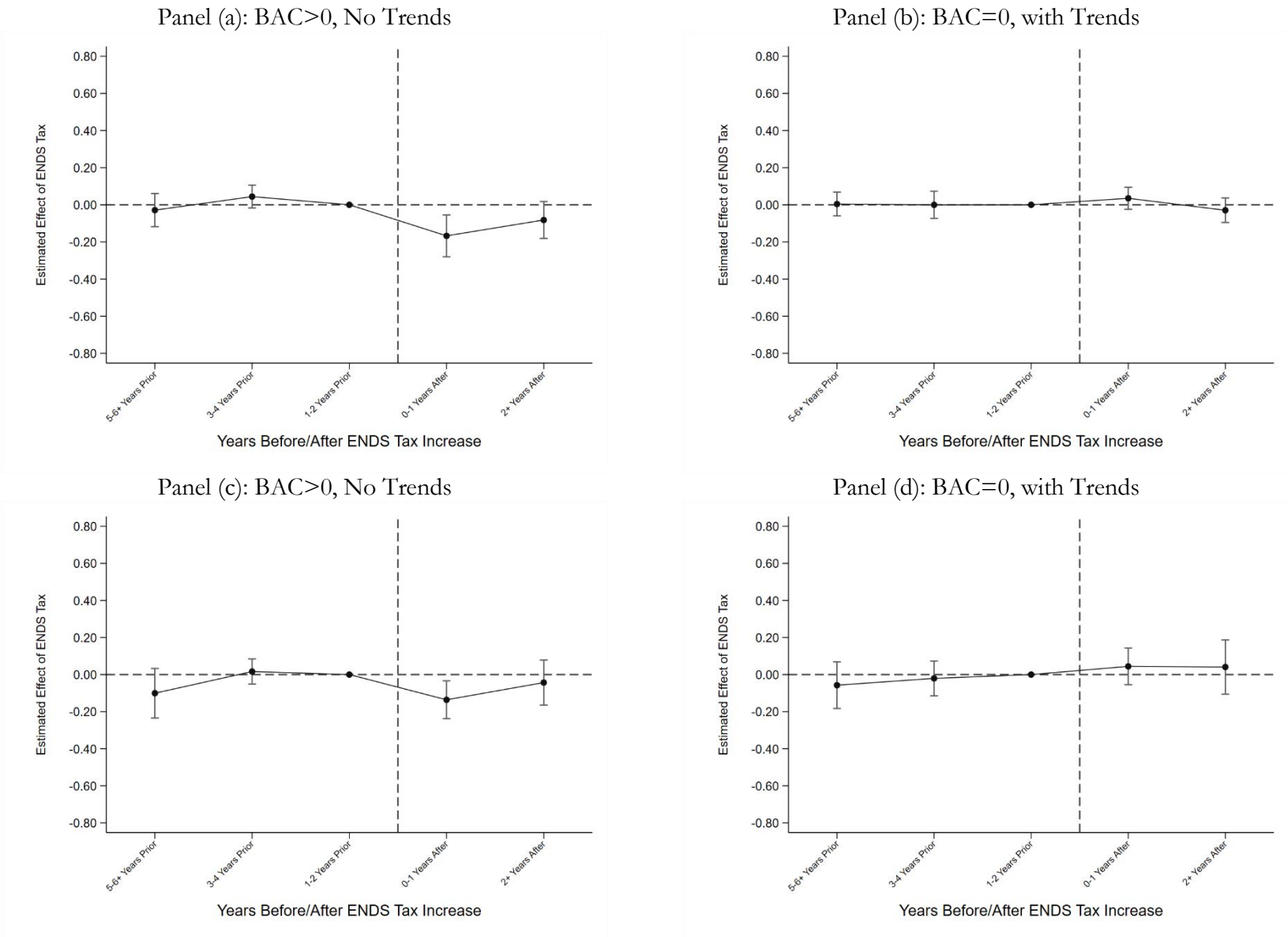


Panel (b): Binge Drinking, with Trends



Note: OLS estimates (with 90% CIs) are reported. Estimates include state and year fixed effects and a full set of controls listed in Table 7. Panels (b) further includes treatment state-specific linear time trends.

Figure 5. Event-Study Analysis of ENDS Taxes and Traffic Fatalities of Teens Involving Teen Driver, FARS



Note: Population weighted OLS estimates (and their 90% CIs) from a regression model are shown. The included control variables are specified in the notes to Table 9. Panels (b) and (d) further includes treatment state-specific linear time trends.

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

	(1)	(2)	(3)	(4)
		Panel I: State YRBS		
ENDS Tax ($)	-0.0342***	-0.0360***	-0.0670***	-0.0639***
	(0.0055)	(0.0073)	(0.0140)	(0.0162)
N	499,839	499,839	499,839	499,839
Pre-Treatment Mean of Dep Variable	0.2269	0.2269	0.2269	0.2269
		Panel II: National YRBS		
ENDS Tax ($)	-0.0693***	-0.0680***	-0.0836***	-0.0699***
	(0.0160)	(0.0174)	(0.0210)	(0.0256)
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: The outcome is any ENDS use in the past 30 days. 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 state T-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, State YRBS

	(1)	(2)	(3)	(4)
		Panel I: Any Alcohol Use		
ENDS Tax ($)	-0.0129	-0.0127	-0.0142	-0.0128
	(0.0104)	(0.0092)	(0.0124)	(0.0150)
N	1,185,261	1,185,261	1,185,261	1,185,261
Pre-Treatment Mean of Dep Variable	0.3710	0.3710	0.3710	0.3710
	Panel II: Number of Drinks | Alcohol Use = 1[a]			
ENDS Tax ($)	-0.3312***	-0.3455***	-0.3673***	-0.3540***
	(0.0629)	(0.0633)	(0.1118)	(0.1137)
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: Number of Drinks (Include Zeroes)[a]			
ENDS Tax ($)	-0.1408	-0.1303	-0.2009*	-0.1928*
	(0.0949)	(0.0911)	(0.1185)	(0.1141)
N	493,542	493,542	493,542	493,542
Pre-Treatment Mean of Dep Variable	1.2519	1.2519	1.2519	1.2519
	Panel IV: Binge Drinking			
ENDS Tax ($)	-0.0221***	-0.0220***	-0.0231***	-0.0227**
	(0.0075)	(0.0065)	(0.0078)	(0.0087)
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 V: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0113**	-0.0111**	-0.0140**	-0.0138*
	(0.0052)	(0.0043)	(0.0059)	(0.0070)
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, IV, and V are generated via weighted least squares using the 2003-2019 waves of the state Youth Risk Behavior Surveys. Data for the outcomes in Panels II and III 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 state T-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 Alcohol Use among Youths, State YRBS

	(1)	(2)	(3)	(4)
		Panel I: Any Alcohol Use		
ENDS Tax ($)	-0.0199***	-0.0184***	-0.0235**	-0.0210*
	(0.0067)	(0.0060)	(0.0099)	(0.0124)
N	5,179,044	5,179,044	5,179,044	5,179,044
Pre-Treatment Mean of Dep Variable	0.3668	0.3668	0.3668	0.3668
	Panel II: Number of Drinks | Alcohol Use = 1[a]			
ENDS Tax ($)	-0.3277***	-0.3626***	-0.4233***	-0.4028***
	(0.0682)	(0.0569)	(0.0968)	(0.1008)
N	408,430	408,430	408,430	408,430
Pre-Treatment Mean of Dep Variable	4.5615	4.5615	4.5615	4.5615
	Panel III: Number of Drinks (Include Zeros)[a]			
ENDS Tax ($)	-0.1206	-0.1137	-0.1448	-0.1342
	(0.0989)	(0.0946)	(0.1466)	(0.1438)
N	3,123,476	3,123,476	3,123,476	3,123,476
Pre-Treatment Mean of Dep Variable	1.2654	1.2654	1.2654	1.2654
	Panel IV: Binge Drinking			
ENDS Tax ($)	-0.0252***	-0.0247***	-0.0270***	-0.0277***
	(0.0048)	(0.0047)	(0.0059)	(0.0065)
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 V: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0141***	-0.0134***	-0.0193***	-0.0187***
	(0.0029)	(0.0026)	(0.0041)	(0.0049)
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 from Panels I, IV, and V are generated via weighted least squares using the 2003-2019 waves of the state Youth Risk Behavior Surveys. Data for the outcomes in Panels II and III 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 state T-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 and Exclude the Southern Region, State YRBS

	(1)	(2)	(3)	(4)
		Panel I: Any Alcohol Use		
ENDS Tax ($)	-0.0128	-0.0153	-0.0192	-0.0124
	(0.0150)	(0.0145)	(0.0149)	(0.0131)
N	1,185,261	1,185,261	1,185,261	729,599
Pre-Treatment Mean of Dep Variable	0.3762	0.3762	0.3762	0.3762
	Panel II: Number of Drinks | Alcohol Use = 1[a]			
ENDS Tax ($)	-0.3540***	0.0759	-0.4030**	-0.1800
	(0.1137)	(0.1305)	(0.1650)	(0.4671)
N	54,386	54,386	54,386	37,307
Pre-Treatment Mean of Dep Variable	4.4729	4.4729	4.4729	4.4729
	Panel III: Number of Drinks (Include Zeros)[a]			
ENDS Tax ($)	-0.1928*	-0.1790	-0.2037	-0.2864***
	(0.1141)	(0.1462)	(0.1269)	(0.1013)
N	493,542	493,542	493,542	273,344
Pre-Treatment Mean of Dep Variable	1.2519	1.2519	1.2519	1.2519
	Panel IV: Binge Drinking Episodes			
ENDS Tax ($)	-0.0227**	-0.0194**	-0.0300***	-0.0264***
	(0.0087)	(0.0092)	(0.0076)	(0.0086)
N	1,153,127	1,153,127	1,153,127	679,429
Pre-Treatment Mean of Dep Variable	0.1354	0.1354	0.1354	0.1354
	Panel V: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0138*	-0.0093	-0.0195***	-0.0161**
	(0.0070)	(0.0079)	(0.0061)	(0.0069)
N	1,153,127	1,153,127	1,153,127	679,429
Pre-Treatment Mean of Dep Variable	0.1354	0.1354	0.1354	0.1354
State and Year FE?	Yes	Yes	Yes	Yes
Full Controls?	Yes	Yes	Yes	Yes
Region-Specific Year FE?	No	Yes	No	No
Treatment State-Specific Linear Time Trend	No	No	Yes	No
Exclude Southern Region	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 the outcomes in Panel II is 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 state T-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 Smoking, and Binging Alcohol, State YRBS

	(1)	(2)	(3)	(4)
	Panel I: ENDS Use *and* Any Drinking			
ENDS Tax ($)	-0.0313***	-0.0323***	-0.0366***	-0.0367***
	(0.0034)	(0.0050)	(0.0079)	(0.0097)
N	462,243	462,243	462,243	462,243
Pre-Treatment Mean of Dep Variable	0.1469	0.1469	0.1469	0.1469
	Panel II: ENDS Use *and* Binge Drinking			
ENDS Tax ($)	-0.0276***	-0.0287***	-0.0303***	-0.0289***
	(0.0024)	(0.0031)	(0.0059)	(0.0076)
N	425,101	425,101	425,101	425,101
Pre-Treatment Mean of Dep Variable	0.0959	0.0959	0.0959	0.0959
	Panel III: ENDS Use *and* Multiple Binging Episodes			
ENDS Tax ($)	-0.0178***	-0.0189***	-0.0230***	-0.0216***
	(0.0018)	(0.0021)	(0.0038)	(0.0047)
N	425,101	425,101	425,101	425,101
Pre-Treatment Mean of Dep Variable	0.0618	0.0618	0.0618	0.0618
	Panel IV: Smoking *and* Any Drinking			
ENDS Tax ($)	-0.0075	-0.0096	-0.0064	-0.0046
	(0.0107)	(0.0095)	(0.0076)	(0.0068)
N	1,139,383	1,139,383	1,139,383	1,139,383
Pre-Treatment Mean of Dep Variable	0.1321	0.1321	0.1321	0.1321
	Panel V: Smoking *and* Binge Drinking			
ENDS Tax ($)	-0.0073	-0.0094	-0.0082	-0.0065
	(0.0085)	(0.0072)	(0.0057)	(0.0049)
N	1,103,155	1,103,155	1,103,155	1,103,155
Pre-Treatment Mean of Dep Variable	0.0972	0.0972	0.0972	0.0972
	Panel VI: Smoking *and* Multiple Binging Episodes			
ENDS Tax ($)	-0.0045	-0.0067	-0.0063	-0.0047
	(0.0070)	(0.0057)	(0.0044)	(0.0037)
N	1,103,155	1,103,155	1,103,155	1,103,155
Pre-Treatment Mean of Dep Variable	0.0728	0.0728	0.0728	0.0728
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 in Panels I, II, and III are generated via weighted least squares using the 2015-2019 waves of the state Youth Risk Behavior Surveys. Estimates in Panels IV, V, and VI 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 state T-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 among Youths, by Gender, Age, and Race/Ethnicity, State YRBS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Males	Females	Age <17	Age 17-18	NH White	Black	Hispanic	Other
				Panel I: Any Drinking				
ENDS Tax ($)	-0.0022	-0.0230*	-0.0096	-0.0195	-0.0247	-0.0224	-0.0221	-0.0128*
	(0.0178)	(0.0130)	(0.0142)	(0.0184)	(0.0226)	(0.0196)	(0.0132)	(0.0065)
N	573,218	612,043	800,266	384,995	691,580	150,001	195,609	148,071
Pre-Treatment Mean of Dep Variable	0.3670	0.3854	0.3258	0.4610	0.4208	0.3029	0.3572	0.2612
				Panel II: Number of Drinks | Alcohol Use = 1[a]				
ENDS Tax ($)	-0.5425***	-0.1865	-0.5575***	-0.1457	-0.5461***	0.0769	-0.0098	-0.1008
	(0.1783)	(0.1115)	(0.1002)	(0.1638)	(0.1910)	(0.1622)	(0.1623)	(0.3327)
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 III: Number of Drinks (Include Zeros)				
ENDS Tax ($)	-0.2156	-0.1680	-0.1187	-0.3327**	-0.2106	-0.0557	-0.1836*	-0.1050
	(0.1398)	(0.1027)	(0.1067)	(0.1381)	(0.1989)	(0.1193)	(0.0963)	(0.0687)
N	242,046	251,496	340,280	153,262	271,819	66,997	83,526	71,200
Pre-Treatment Mean of Dep Variable	1.3367	1.1681	0.9743	1.7424	1.4628	0.7424	1.216	0.7090
				Panel IV: Binge Drinking				
ENDS Tax ($)	-0.0176**	-0.0280***	-0.0222**	-0.0274***	-0.0383**	-0.0089	-0.0305***	-0.0276***
	(0.0085)	(0.0094)	(0.0107)	(0.0081)	(0.0182)	(0.0071)	(0.0060)	(0.0057)
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 V: Multiple Binge Drinking Episodes				
ENDS Tax ($)	-0.0117	-0.0162**	-0.0135	-0.0183**	-0.0187	-0.0168***	-0.0207***	-0.0213***
	(0.0073)	(0.0070)	(0.0081)	(0.0076)	(0.0137)	(0.0046)	(0.0055)	(0.0057)
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 from Panels I, IV, and V are generated via weighted least squares using the 2003-2019 waves of the state Youth Risk Behavior Surveys. Data for the outcomes in Panels II and III 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 state T-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)
	Current ENDS Use	Any Alcohol Use	Binge Drinking	Multiple Binge Episodes	Number Drinks per Month | Alcohol Use=1	Number Drinks per Month
				Panel I: Aged 18-to-20		
ENDS Tax ($)	-0.0306**	-0.0183	-0.0162*	-0.0062	-4.7341	-2.2029*
	(0.0133)	(0.0125)	(0.0097)	(0.0052)	(3.0551)	(1.1658)
N	25,653	81,729	81,313	81,313	26,566	81,112
Pre-Treat Mean of Dep Variable	0.137	0.329	0.169	0.082	27.486	8.912
				Panel II: Aged 21-and-older		
ENDS Tax ($)	-0.0013	-0.0024	0.0001	0.0010	-0.2169	-0.1671
	(0.0023)	(0.0050)	(0.0020)	(0.0009)	(0.2764)	(0.2095)
N	1,116,585	3,755,646	3,732,735	3,732,735	1,908,903	3,745,814
Pre-Treat Mean of Dep Variable	0.032	0.505	0.125	0.054	22.673	11.411
Survey years:	2016-18	2011-19	2011-19	2011-19	2011-19	2011-19

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

Note: Ordinary least squares (OLS) estimates on ENDS use are obtained using the 2016-2018 waves of the Behavioral Risk Factor Surveillance Survey (BRFSS). OLS estimates on alcohol use are obtained using the 2011 to 2019 waves of the BRFSS. Standard errors are clustered at the state level and estimates are unweighted. All models include state, year and month fixed effects and the full set of observable controls. Demographic controls include age, gender, education (no high school, high school, some college), race (white, black, and Hispanic), and marital status. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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 8. TWFE Estimates of the Effects of ENDS Taxes on Binge Drinking and Alcohol Use Disorder among Adults, NSDUH

	(1)	(2)	(3)	(4)	(5)	(6)
	Aged 18-and-older		**Aged 18-to-25**		**Ages: 26-and-older**	
	Binge Drinking	Alcohol Use Disorder	Binge Drinking	Alcohol Use Disorder	Binge Drinking	Alcohol Use Disorder
			Panel I: Unweighted TWFE Estimates			
ENDS Tax ($)	-0.0027	-0.0044***	0.0042	-0.0051**	-0.0025	-0.0037***
	(0.0023)	(0.0011)	(0.0032)	(0.0020)	(0.0024)	(0.0011)
Pre-Treatment Mean of Dep Variable	0.253	0.074	0.412	0.154	0.225	0.060
N	816	867	816	867	816	867
	Panel II: Unweighted TWFE + Treatment State-Specific Linear Time Trends					
ENDS Tax ($)	-0.0061	-0.0037**	-0.0051	-0.0055**	-0.0043	-0.0027
	(0.0037)	(0.0015)	(0.0046)	(0.0024)	(0.0036)	(0.0017)
Pre-Treatment Mean of Dep Variable	0.253	0.074	0.412	0.154	0.225	0.060
N	816	867	816	867	816	867
	Panel II: Weighted TWFE + Treatment State-Specific Linear Time Trends					
ENDS Tax ($)	-0.0074*	-0.0012	-0.0048	0.0019	-0.0072*	-0.0014
	(0.0038)	(0.0027)	(0.0073)	(0.0050)	(0.0039)	(0.0024)
Pre-Treatment Mean of Dep Variable	0.253	0.074	0.412	0.154	0.225	0.060
N	816	867	816	867	816	867

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

Note: Estimates from Panels I, II, and II are generated via ordinary least squares using the 2002-2019 waves of the National Survey on Drug Use and Health (NSDUH). Panels I and II are unweighted, and Panel III is weighted using the state population. 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 the share of the state population that is female, college-educated, African American, and Hispanic. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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 the right-hand side variables merged with the NSDUH data (which are based on two-year averages) are merged according to the initial year of the two-wave average.

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

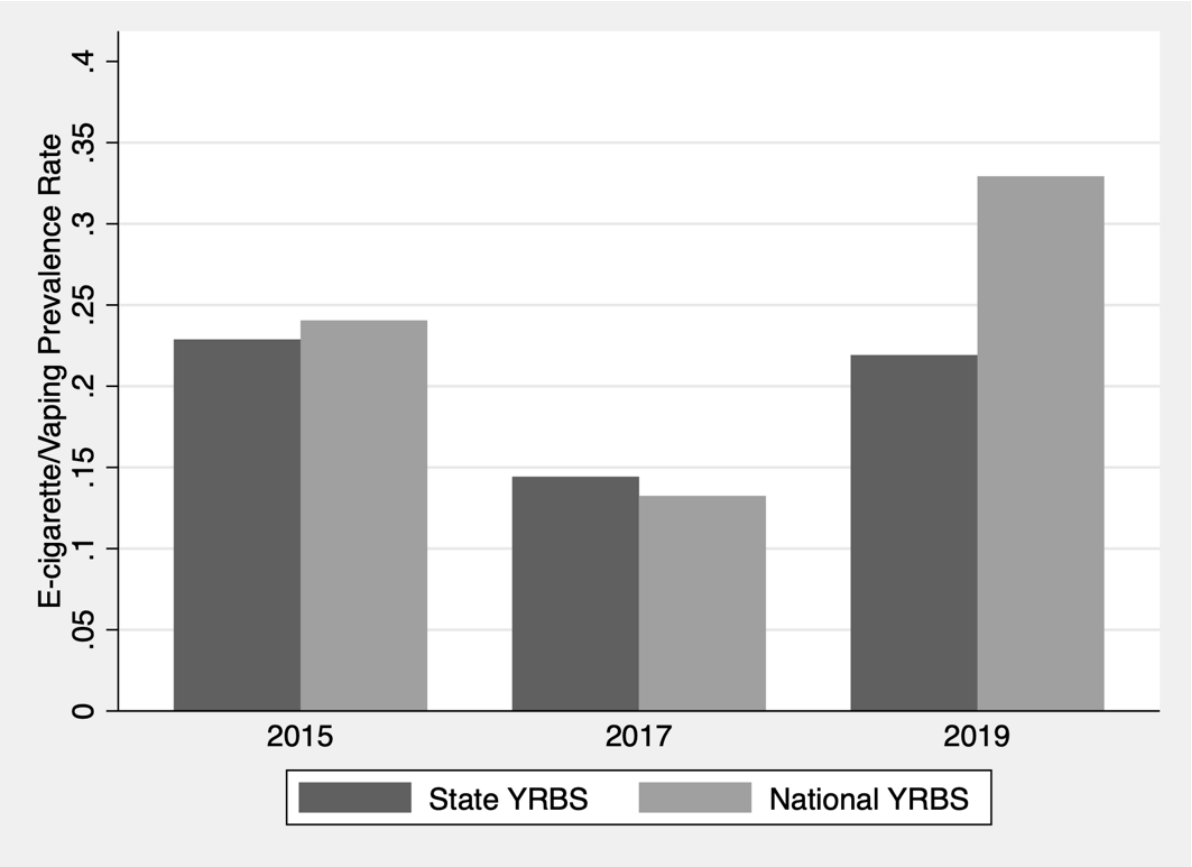
	(1)	(2)	(3)	(4)
	Total Traffic Fatalities	Traffic Fatalities Drivers BAC > 0	Traffic Fatalities Drivers BAC > 0.1	Traffic Fatalities Drivers BAC = 0
	Panel I: Fatalities of Teen (Aged 16-20) Drivers			
ENDS Tax ($)	-0.045*	-0.080***	-0.069***	-0.020
	(0.024)	(0.027)	(0.024)	(0.032)
Pre-Treatment Mean DV	11.407	2.812	2.012	8.595
	Panel II: Fatalities (of Any Age) Involving Teen Driver			
ENDS Tax ($)	-0.024	-0.119***	-0.110***	-0.006
	(0.031)	(0.042)	(0.038)	(0.035)
Pre-Treatment Mean DV	27.897	4.864	3.144	23.034
	Panel III: Panel II + Treatment State-Specific Linear Time Trend[a]			
ENDS Tax ($)	0.016	-0.149*	-0.116*	0.043
	(0.065)	(0.076)	(0.065)	(0.070)
Pre-Treatment Mean DV	27.897	4.864	3.144	23.034
	Panel IV: Fatalities of Teens Involving Teen Driver			
ENDS Tax ($)	-0.033	-0.100***	-0.095***	-0.007
	(0.028)	(0.036)	(0.032)	(0.032)
Pre-Treatment Mean DV	15.769	3.779	2.516	11.990
	Panel V: Panel IV + Treatment State-Specific Linear Time Trend[a]			
ENDS Tax ($)	0.005	-0.131*	-0.073	0.042
	(0.055)	(0.076)	(0.067)	(0.063)
Pre-Treatment Mean DV	15.769	3.779	2.516	11.990
	Panel VI: Fatalities (of Any Age) Involving Adult Driver (21-and-older)[a]			
ENDS Tax ($)	-0.031	-0.030	-0.040	-0.035
	(0.029)	(0.036)	(0.039)	(0.030)
Pre-Treatment Mean DV	15.209	4.232	3.214	10.977
	Panel VII: Fatalities of Adults Involving Adult Driver (21-and-older)[a]			
ENDS Tax ($)	-0.028	-0.033	-0.040	-0.030
	(0.028)	(0.037)	(0.040)	(0.030)
Pre-Treatment Mean DV	13.379	3.999	3.063	9.379
N	867	867	867	867

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

Note: Estimates are generated from the Fatality Analysis Reporting System (FARS) from the years 2003 to 2019. Standard errors are clustered at the state level. Regressions are weighted using state populations unless otherwise indicated. All models include state and year fixed effects and the full set of observable controls. Demographic controls include gender, race, ethnicity, and education. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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 and year fixed effects. The dependent variable is equal to the natural log of 1 plus traffic fatalities per 100,000 people. Trends refer to treated state-specific linear time trends. Additionally, we account for policies related to traffic laws, including the seat belt laws, the 0.08 BAC laws, MLDA, and the 65-mph speed limit. We classify the BAC of the driver using observable BAC information when the text is provided; if missing, we use an imputed measure based on the minimum BAC generated from all imputed values provided in the data.

[a]These regression estimates include controls for treatment state-specific linear time trends.

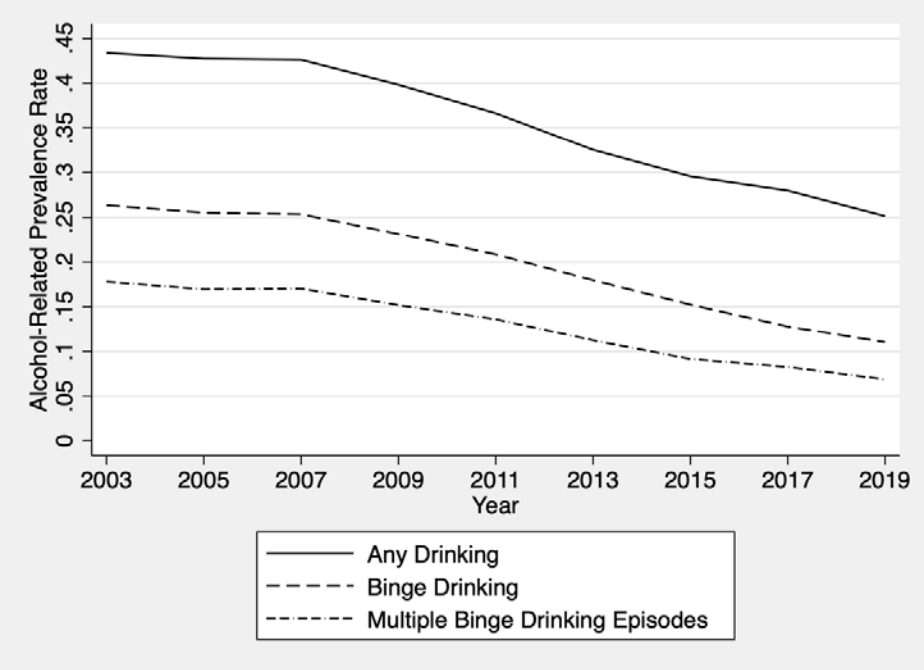
Appendix Figure 1. Trends in ENDS Use, YRBS Surveys, 2015-2019



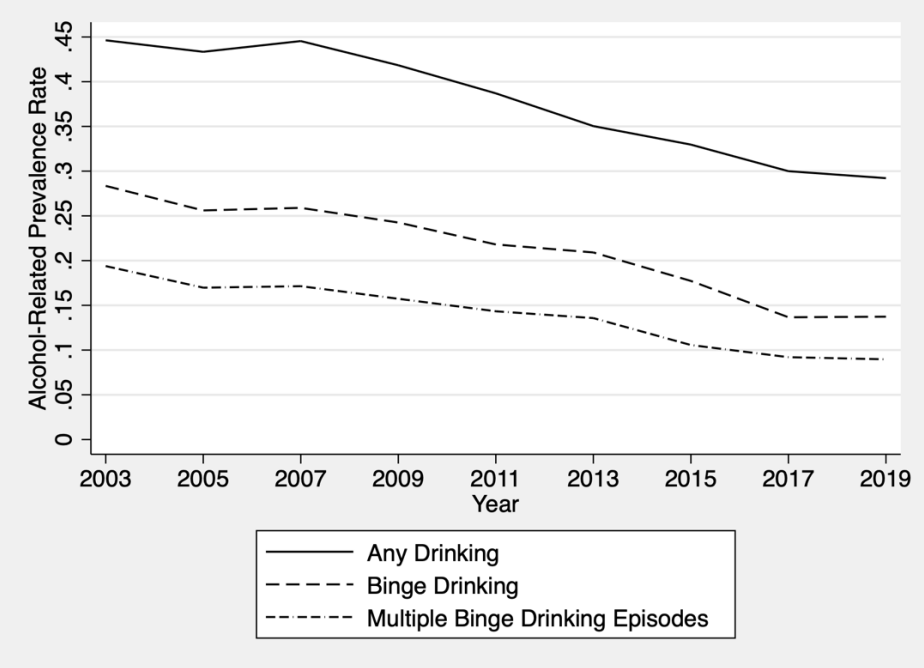
Note: Weighted estimates are from the 2015-2017 state and national Youth Risk Behavior Surveys.

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

Panel (a): State YRBS



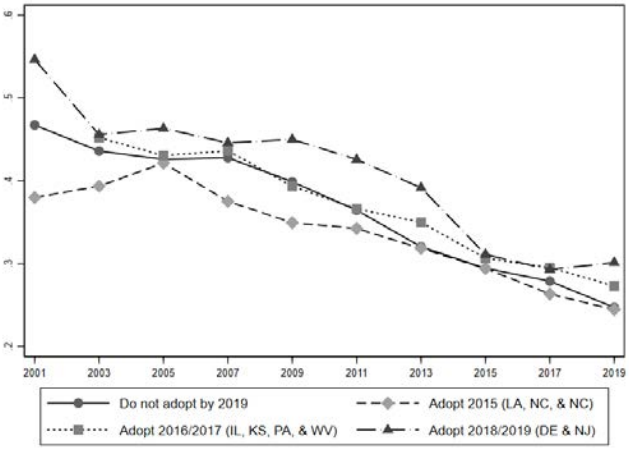
Panel (b): National YRBS



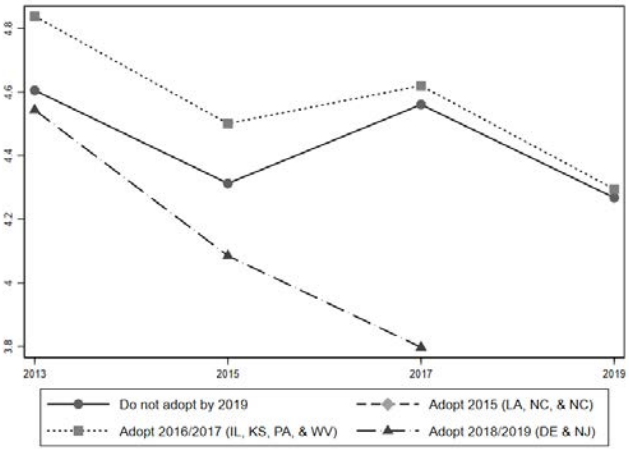
Note: Weighted estimates are from the state and national Youth Risk Behavior Surveys.

Appendix Figure 2B. Trends in Alcohol Use among Youth by Year of Adoption, State YRBS 2003-2019

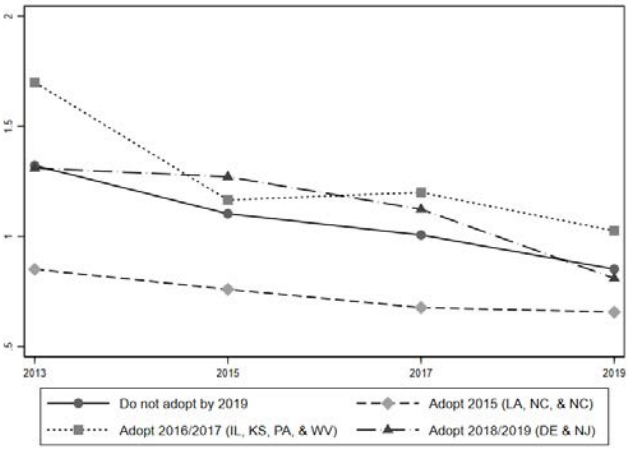
Panel A: Any Drinking



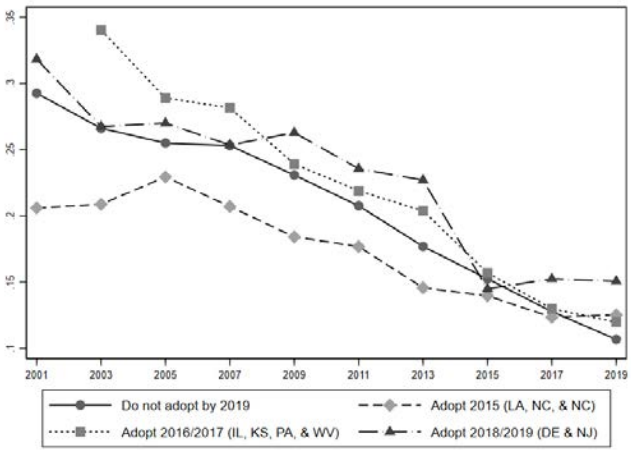
Panel B: Number of Drinks | Any Drinking



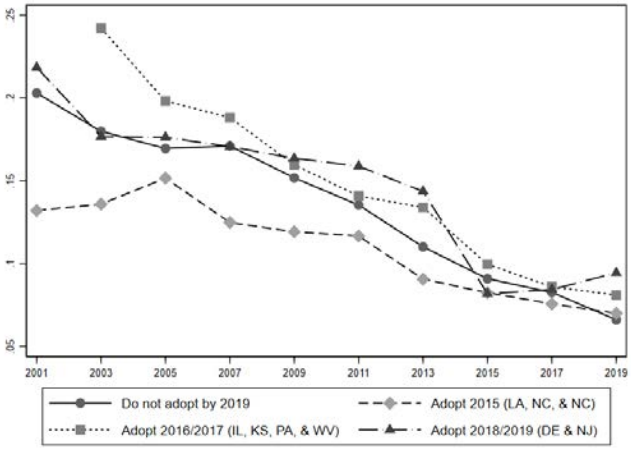
Panel C: Number of Drinks (Include Zeroes)



Panel D: Binge Drinking



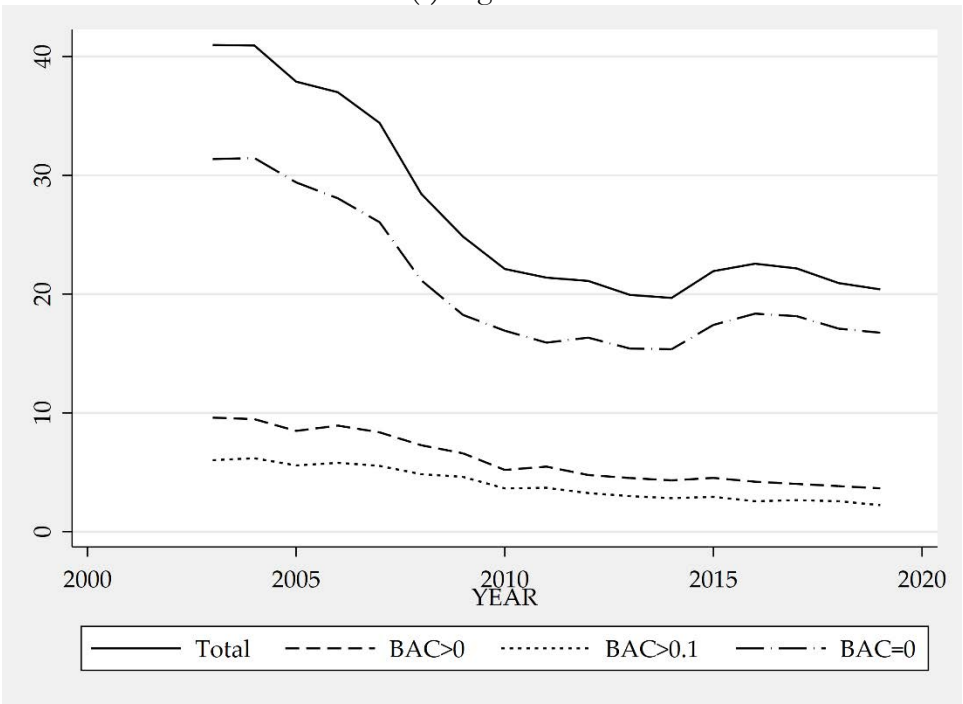
Panel E: Multiple Binge Drinking Episodes



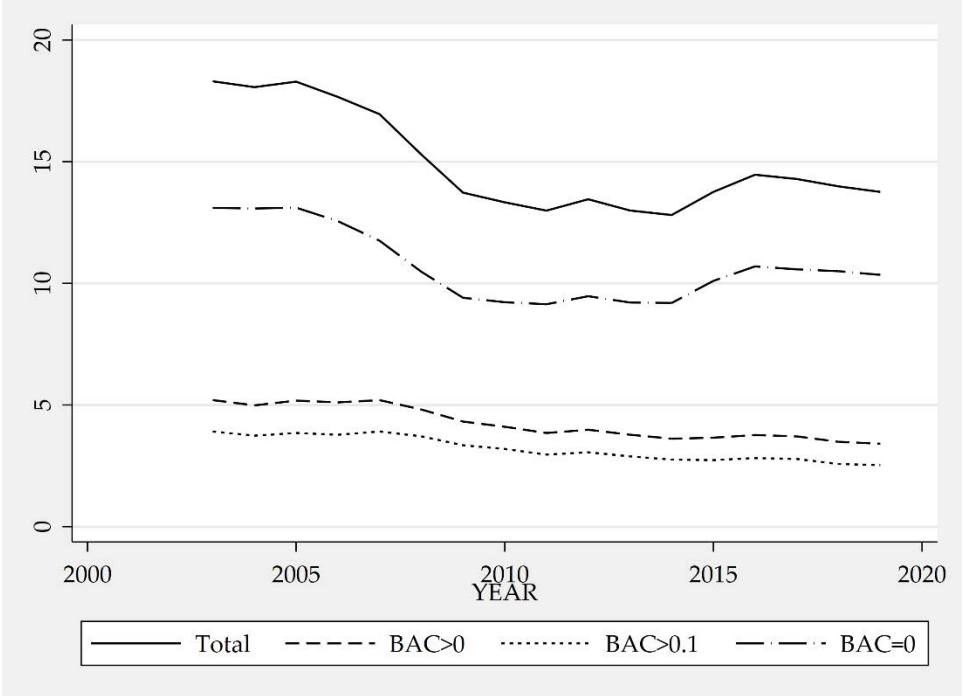
Note: Weighted estimates are from State Youth Risk Behavior Surveys. Not all states appear in all years of the data, thus some trends lines are not available in all years.

Appendix Figure 3. All-age Traffic Fatalities involving Teen and Adult Drivers, FARS 2003-2019

Panel (a): Ages 16-to-20

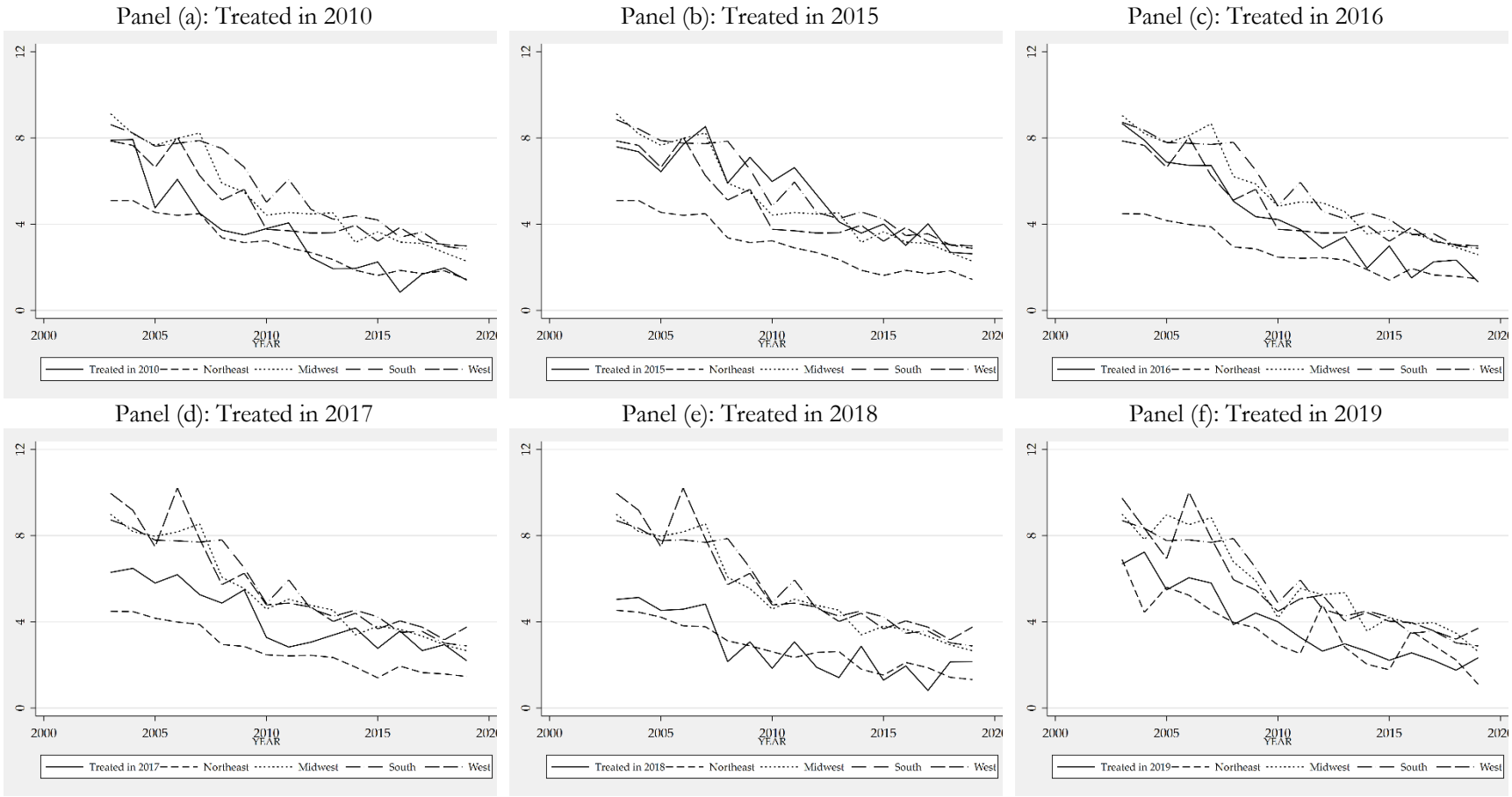


Panel (b): Ages 21-to-39



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

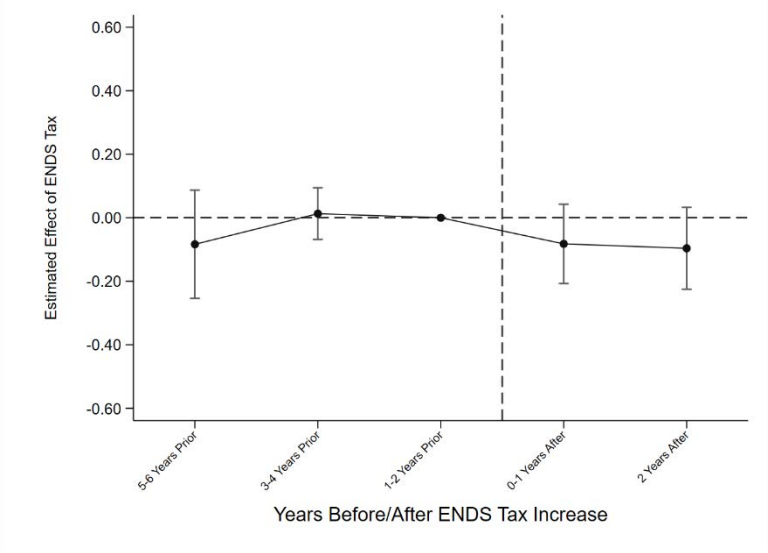
Appendix Figure 4. All-age Traffic Fatalities involving Teen Drivers with BAC>0, FARS 2003-2019



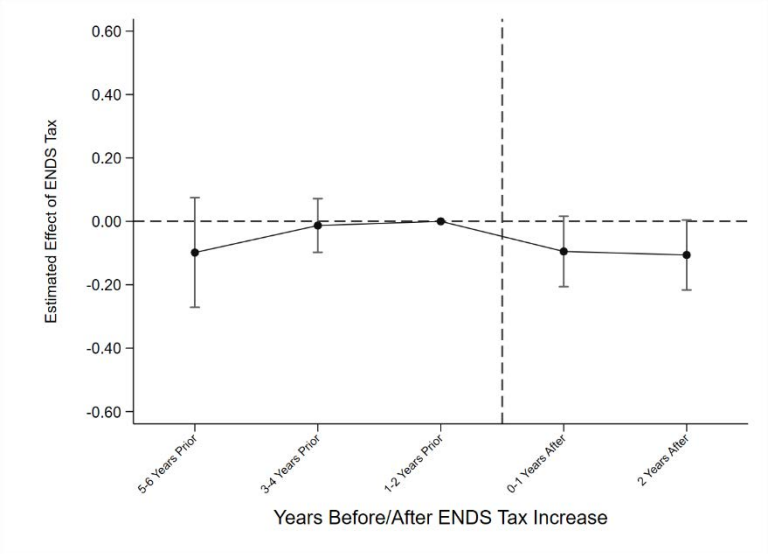
Note: Weighted estimates are from the Fatality Analysis Reporting System.

Appendix Figure 5. Event-Study Analysis of ENDS Taxes and Traffic Fatalities of Teens, Using Stacked DD Estimates and Not-Yet and Never Adopters as Counterfactuals

Panel (a): BAC>0, Fatalities of Teens Involving Teen Driver



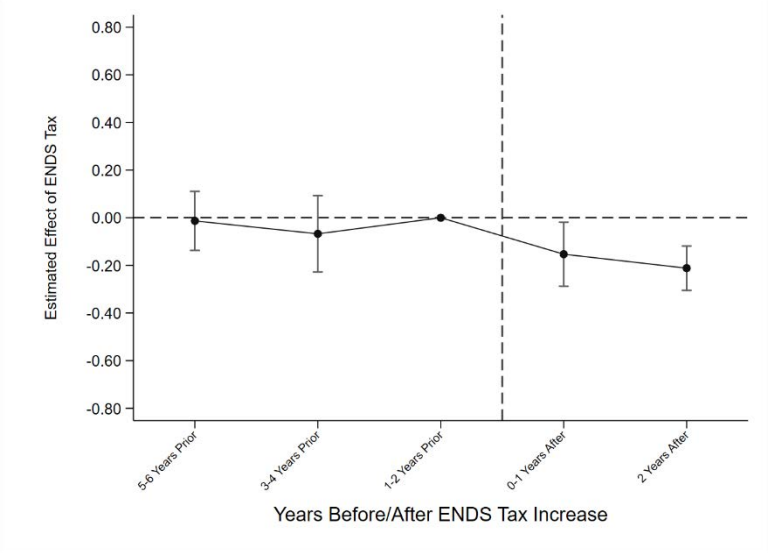
Panel (c): BAC>0, Fatalities of Teen Driver



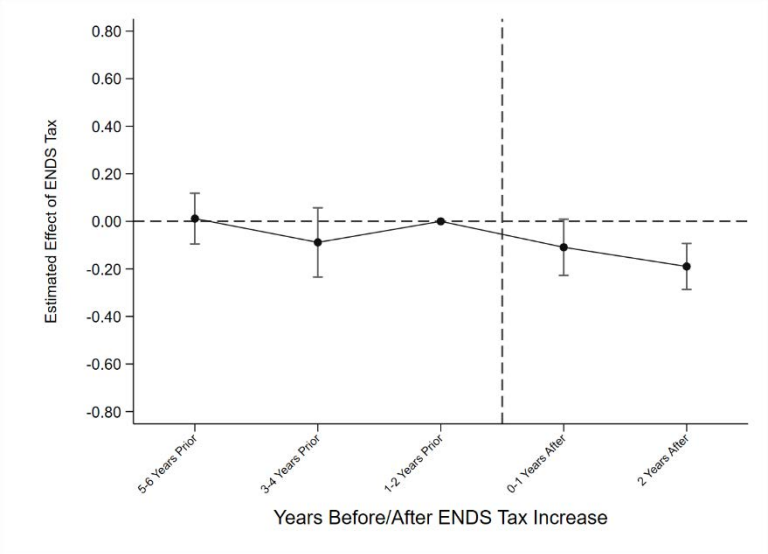
Note: Population weighted OLS estimates (and their 90% CIs) from a regression model are shown. The included control variables are specified in the notes to Table 9. Never adopters and not-yet adopters as counterfactuals.

Appendix Figure 6. Event-Study Analysis of ENDS Taxes and Traffic Fatalities of Teens, Using Stacked DD Estimates and Never Adopters as Counterfactuals

Panel (a): BAC>0, Fatalities of Teens Involving Teen Driver

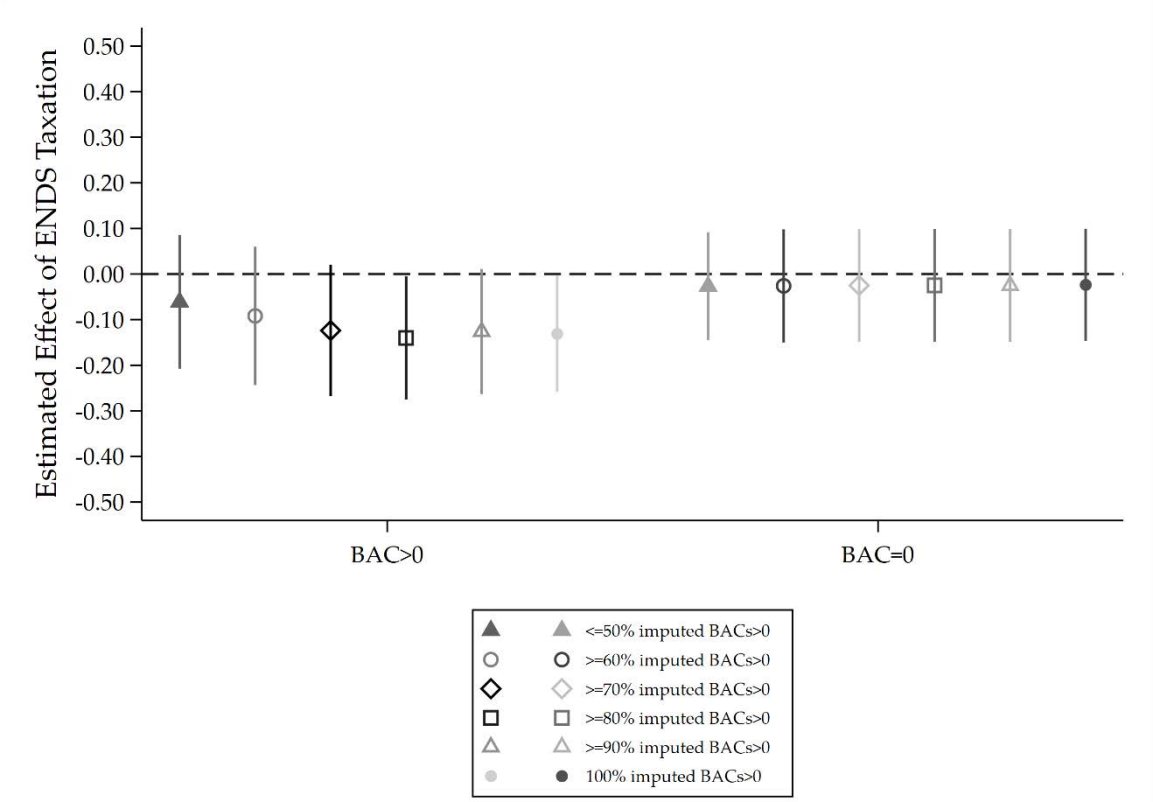


Panel (c): BAC>0, Fatalities of Teen Driver



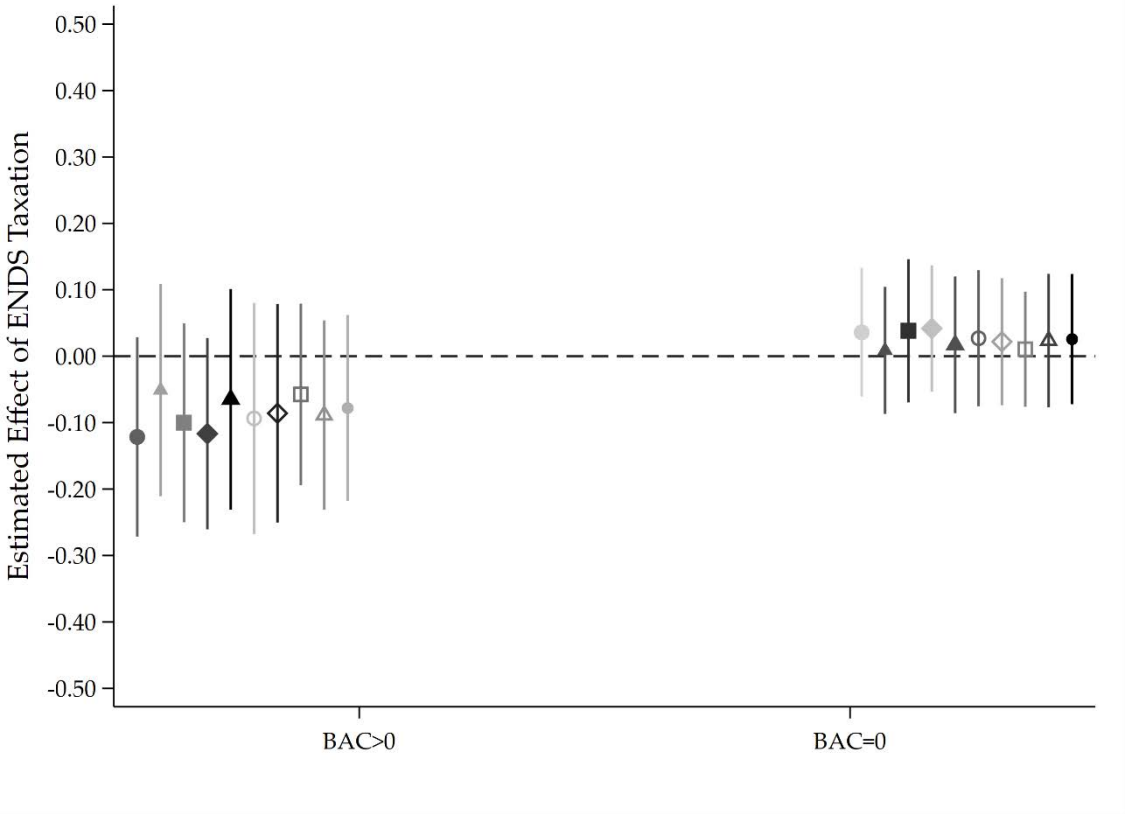
Note: Population weighted OLS estimates (and their 90% CIs) from a regression model are shown. The included control variables are specified in the notes to Table 9. Never adopters and not-yet adopters as counterfactuals.

Appendix Figure 7. Sensitivity to Imputation Choice, Using Summary of 10 Imputation Values, Teen Fatalities involving Teen Drivers (Table 9, Panel V)



Note: All estimates are generated via weighted OLS and include a full set of control variables as specified in Table 9. Each model includes treated-state specific linear time trends. The vertical bars represent 90% confidence intervals around the estimated effects of ENDS taxes from samples in which a teen traffic death involving a teen driver is classified as a drunk driving fatality (or a non-alcohol-related traffic fatality) if a given percentage (see shape enveloping estimated treatment effect for relevant percentage) of 10 imputed values provided by the FARS are greater than 0.

Appendix Figure 8. Sensitivity to Imputation Choice, Using Each of 10 Imputation Values, Teen Fatalities involving Teen Drivers (Table 9, Panel V)



Note: All estimates are generated via weighted OLS and include a full set pf control variables as specified in Table 9. Each model includes treated-state specific linear time trends. The vertical bars represent 90% confidence intervals around the estimated effects of ENDS taxes from samples in which the BAC is imputed using each of 10 values provided by the FARS data.

Appendix Table 1. Effective Dates of ENDS Taxes

Jurisdiction	Effective Date	Contributes to Identifying Variation?			Tax per mL Fluid, Q1-4 Average (2019 $)					
District/State		*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	$1.08	$1.71	$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	Yes	Yes	Yes	$0	$0	$0	$0	$0	$0.20
Kansas	1/2017, 7/2017	Yes	No	Yes	$0	$0	$0	$0.13	$0.05	$0.05
Louisiana	7/2015	Yes	Yes	Yes	$0	$0.03	$0.05	$0.05	$0.05	$0.05
Minnesota	8/2010, 7/2013	No	Yes	Yes	$0.45	$2.70	$2.66	$2.61	$2.55	$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	12/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.25
New York	7/2019	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	$0.56	$1.10	$1.07	$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	$0.47	$1.86	$1.75	$1.85	$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
County/City										
Chicago Illinois	1/2016, 1/2019	Yes	Yes	Yes						
Cook County, IL	5/2016	Yes	Yes	Yes	$0	$0	$0.89	$0.92	$0.92	$1.64
Montgomery County, MD	8/2015	Yes	Yes	Yes	$0	$0.78	$0.84	$0.80	$0.80	$0.79

Note: Standardized ENDS taxes are from Cotti et al (2022).

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]
Number of Drinks | Alcohol Use = 1	4.467	4.508
	(3.057)	(3.032)
	[N= 69,165]	[N=8,248]
Number of Drinks (Include Zeroes) [a]	0.927	1.246
	(2.296)	(2.583)
	[N=493,429]	[N= 35,000]
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]
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 $)	0.057	0.082
	(0.254)	(0.370)
Cigarette Tax (2019 $)	1.508	1.402
	(1.092)	(0.974)
Beer Tax (2019 $)	0.340	0.325
	(0.304)	(0.302)
Tobacco 21 Law	0.053	0.036
	(0.216)	(0.179)
ENDS MLSA	0.346	0.299
	(0.476)	(0.458)
Presence of Indoor Smoking Restriction	0.478	0.434
	(0.498)	(0.495)
Presence of Indoor ENDS Restriction	0.079	0.058
	(0.270)	(0.234)
Recreational Marijuana Law	0.054	0.052
	(0.225)	(0.221)
Medical Marijuana Law	0.274	0.344
	(0.444)	(0.472)
Unemployment Rate	5.989	6.211
	(2.093)	(2.166)
Poverty Rate	13.206	13.073
	(2.993)	(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	0.135	0.342	25,653
Alcohol Consumption in Last 30 Days	0.333	0.471	81,729
Binge Drinking in Last 30 Days	0.171	0.376	81,313
Multiple Binge Drinking Episodes in Last 30 Days	0.082	0.274	81,313
Number of Drinks in Last 30 Days| Alcohol Use	27.278	62.805	26,566
Number of Drinks in Last 30 Days	8.934	38.154	81,112
Individuals Ages 21-and-older			
ENDS Use	0.032	0.175	1,116,585
Alcohol Consumption in Last 30 Days	0.511	0.500	3,755,646
Binge Drinking in Last 30 Days	0.127	0.334	3,732,735
Multiple Binge Drinking Episodes in Last 30 Days	0.054	0.227	3,732,735
Number of Drinks in Last 30 Days| Alcohol Use	22.605	46.334	1,908,903
Number of Drinks in Last 30 Days	11.520	34.954	3,745,814
Individuals Ages 21-to-39			
ENDS Use	0.068	0.252	218,990
Alcohol Consumption in Last 30 Days	0.618	0.486	724,609
Binge Drinking in Last 30 Days	0.262	0.440	719,110
Multiple Binge Drinking Episodes in Last 30 Days	0.109	0.312	719,110
Number of Drinks in Last 30 Days| Alcohol Use	23.979	49.654	443,628
Number of Drinks in Last 30 Days	14.769	40.676	720,294
Individuals Ages 40-and-older			
ENDS Use	0.023	0.149	897,595

Alcohol Consumption in Last 30 Days	0.485	0.500	3,031,037
Binge Drinking in Last 30 Days	0.095	0.294	3,013,625
Multiple Binge Drinking Episodes in Last 30 Days	0.041	0.199	3,013,625
Number of Drinks in Last 30 Days| Alcohol Use	22.189	45.273	1,465,275
Number of Drinks in Last 30 Days	10.746	33.401	3,025,520

Note: Estimates are unweighted. 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-and-older			
Any Binge Drinking	0.250	0.028	816
Alcohol Use Disorder	0.070	0.011	867
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: Data are weighted using state population.

Appendix Table 5. Descriptive Statistics, FARS

Traffic Fatalities per 100,000 population	**Mean**	**Standard Deviation**	**N**
Ages 16-to-20			
Fatalities of Teen (16-20) Drivers			867
Total Fatalities	11.030	6.042	
Fatalities (BAC > 0)	2.692	1.781	
Fatalities (BAC > 0.1)	1.925	1.349	
Fatalities (BAC = 0)	8.338	4.796	
Fatalities (of Any Age) Involving Teen Driver			867
Total Fatalities	27.088	12.950	
Fatalities (BAC > 0)	6.149	3.534	
Fatalities (BAC > 0.1)	4.047	2.470	
Fatalities (BAC = 0)	20.938	10.333	
Fatalities of Teens Involving Teen Driver			867
Total Fatalities	15.231	8.012	
Fatalities (BAC > 0)	3.613	2.360	
Fatalities (BAC > 0.1)	2.408	1.685	
Fatalities (BAC = 0)	11.618	6.319	
Ages 21+			
Fatalities (of Any Age) of Involving Adult Driver			867
Total Fatalities	14.927	5.664	
Fatalities (BAC > 0)	4.236	1.763	
Fatalities (BAC > 0.1)	3.202	1.401	
Fatalities (BAC = 0)	10.690	4.232	
Fatalities of Adults Involving Adult Driver			867
Total Fatalities	13.150	4.985	
Fatalities (BAC > 0)	3.915	1.627	
Fatalities (BAC > 0.1)	2.994	1.316	
Fatalities (BAC = 0)	9.235	3.675	
Ages 21-39			
Fatalities (of Any Age) Involving Adult Driver			867
Total Fatalities	23.609	9.378	
Fatalities (BAC > 0)	7.913	3.289	
Fatalities (BAC > 0.1)	5.985	2.601	
Fatalities (BAC = 0)	15.696	6.773	
	23.609	9.378	
Fatalities of Adults Involving Adult Driver			867
Total Fatalities	14.212	5.925	
Fatalities (BAC > 0)	5.947	2.540	
Fatalities (BAC > 0.1)	4.653	2.079	
Fatalities (BAC = 0)	8.265	3.946	

Ages 40+			
Fatalities (of Any Age) Involving Adult Driver			867
Total Fatalities	14.731	5.556	
Fatalities (BAC > 0)	3.255	1.383	
Fatalities (BAC > 0.1)	2.410	1.093	
Fatalities (BAC = 0)	11.476	4.444	
Fatalities of Adults Involving Adult Driver			867
Total Fatalities	10.807	4.182	
Fatalities (BAC > 0)	2.265	1.030	
Fatalities (BAC > 0.1)	1.707	0.845	
Fatalities (BAC = 0)	8.542	3.374	

Note: Estimates are weighted using relevant age population in each state. We classify the BAC of the driver using observable BAC information when the text is provided; if missing, we use an imputed measure based on the minimum BAC generated from all imputed values provided in the data.

Appendix Table 6. Determinants of ENDS Taxes

Control Variable:	ENDS Tax ($)
Female	0.1968
	(0.7001)
Age	-0.1033
	(0.0915)
Grade	-0.1037
	(0.1631)
Black	-0.7597
	(0.7611)
Unemployment Rate	0.0011
	(0.0056)
Poverty Rate	-0.0010
	(0.0021)
T-21 Law	0.1242
	(0.1031)
MLSA for vaping	-0.0363
	(0.0334)
Cigarette Tax	0.0442
	(0.0324)
Indoor Smoking Ban	0.0251
	(0.0257)
Indoor Vaping Ban	-0.0177
	(0.0219)
Beer Tax	-0.0207
	(0.0137)
MML	0.0333
	(0.0283)
RML	0.0236
	(0.0474)
Observations	373

Note: Data are aggregated to the state-year level.

Appendix Table 7. Examining Lead Effect of ENDS Taxes, State YRBS

	(1)	(2)	(3)	(4)	(5)	(6)
	ENDS Use	Any Drinking	Binge Drinking	Multiple Binge Drinking Episodes	Number of Drinks |Any Drinking	Number of Drinks (Include Zeroes)
1 Year Prior to ENDS Adoption	0.0042	-0.0010	-0.0041	-0.0033	-0.4421**	-0.0985
	(0.0188)	(0.0064)	(0.0057)	(0.0047)	(0.1796)	(0.0651)
ENDS Tax ($)	-0.0618***	-0.0129	-0.0228**	-0.0139*	-0.4728***	-0.2149*
	(0.0157)	(0.0150)	(0.0088)	(0.0071)	(0.1075)	(0.1261)
N	499,839	1,185,261	1,153,127	1,153,127	54,386	493,542
Pre-Treatment Mean of Dep Variable	0.2269	0.3762	0.2106	0.1354	4.4729	1.2519
State and Year FE?	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls?	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. 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 state T-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 Effect of ENDS Taxes on Alcohol Use, National YRBS

	(1)	(2)	(3)	(4)
	Panel I: Any Alcohol Use			
ENDS Tax ($)	-0.0124	-0.0136	-0.0066	-0.0060
	(0.0107)	(0.0102)	(0.0142)	(0.0134)
N	129,830	129,830	129,830	129,830
Pre-Treatment Mean of Dep Variable	0.4036	0.4036	0.4036	0.4036
	Panel II: Number of Drinks |Any Drinking[a]			
ENDS Tax ($)	-0.2578*	-0.2393*	-0.4040	-0.3305
	(0.1318)	(0.1261)	(0.2880)	(0.2908)
N	12,242	12,242	12,242	12,242
Pre-Treatment Mean of Dep Variable	4.5661	4.5661	4.5661	4.5661
	Panel III: Number of Drinks (Include Zeroes)[a]			
ENDS Tax ($)	-0.0977	-0.0803	-0.3756	-0.3752
	(0.1215)	(0.1205)	(0.3309)	(0.3042)
N	46,865	46,865	46,865	46,865
Pre-Treatment Mean of Dep Variable	1.5307	1.5307	1.5307	1.5307
	Panel IV: Binge Drinking			
ENDS Tax ($)	-0.0215***	-0.0216***	-0.0192**	-0.0192**
	(0.0057)	(0.0053)	(0.0092)	(0.0087)
N	135,696	135,696	135,696	135,696
Pre-Treatment Mean of Dep Variable	0.2342	0.2342	0.2342	0.2342
	Panel V: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0149***	-0.0149***	-0.0161**	-0.0162**
	(0.0033)	(0.0031)	(0.0063)	(0.0061)
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 (Panel I, IV,V) and 2013-2019 waves (Panel II, III) of the national 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 state T-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.

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

Appendix Table 9. TWFE Estimates of the Effects of ENDS Taxes on Alcohol Consumption among Youths, State YRBS, 2015-2019

	(1)	(2)	(3)	(4)
		Panel I: Any Alcohol Use		
ENDS Tax ($)	-0.0238***	-0.0201***	-0.0254***	-0.0311***
	(0.0076)	(0.0073)	(0.0080)	(0.0102)
N	510,442	510,442	510,442	510,442
Pre-Treatment Mean of Dep Variable	0.2946	0.2946	0.2946	0.2946
	Panel II: Number of Drinks | Alcohol Use = 1[a]			
ENDS Tax ($)	-0.3069***	-0.3576***	-0.2945**	-0.1563
	(0.0743)	(0.0896)	(0.1348)	(0.1771)
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: Number of Drinks (Include Zeroes)[a]			
ENDS Tax ($)	-0.1276	-0.0936	-0.2303*	-0.1829
	(0.1014)	(0.0917)	(0.1177)	(0.1117)
N	368,906	368,906	368,906	368,906
Pre-Treatment Mean of Dep Variable	1.178	1.178	1.178	1.178
		Panel IV: Binge Drinking		
ENDS Tax ($)	-0.0296***	-0.0294***	-0.0318***	-0.0315***
	(0.0046)	(0.0050)	(0.0083)	(0.0099)
N	469,332	469,332	469,332	469,332
Pre-Treatment Mean of Dep Variable	0.1518	0.1518	0.1518	0.1518
	Panel V: Multiple Binge Drinking Episodes			
ENDS Tax ($)	-0.0171***	-0.0170***	-0.0231***	-0.0236***
	(0.0029)	(0.0033)	(0.0061)	(0.0066)
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 state T-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.

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

Appendix Table 10. Estimates of the Effects of ENDS Taxes on Dual Consumption of ENDS and Binging Alcohol, State YRBS

	(1)	(2)	(3)	(4)
	Panel I: Daily ENDS Use *and* Binge Drinking			
ENDS Tax ($)	-0.0106***	-0.0116***	-0.0219***	-0.0192***
	(0.0026)	(0.0029)	(0.0031)	(0.0033)
N	425,101	425,101	425,101	425,101
Pre-Treatment Mean of Dep Variable	0.0114	0.0114	0.0114	0.0114
	Panel II: Non-Daily ENDS Use *and* Binge Drinking			
ENDS Tax ($)	-0.0174***	-0.0170***	-0.0152	-0.0152
	(0.0034)	(0.0040)	(0.0096)	(0.0126)
N	412,043	412,043	412,043	412,043
Pre-Treatment Mean of Dep Variable	0.1434	0.1434	0.1434	0.1434
	Panel III: Frequent ENDS Use *and* Binge Drinking			
ENDS Tax ($)	-0.0157***	-0.0170***	-0.0264***	-0.0227***
	(0.0031)	(0.0036)	(0.0041)	(0.0041)
N	425,101	425,101	425,101	425,101
Pre-Treatment Mean of Dep Variable	0.0162	0.0162	0.0162	0.0162
	Panel IV: Non-Frequent ENDS *and* Binge Drinking			
ENDS Tax ($)	-0.0127***	-0.0120***	-0.0106	-0.0119
	(0.0034)	(0.0038)	(0.0097)	(0.0128)
N	406,439	406,439	406,439	406,439
Pre-Treatment Mean of Dep Variable	0.1398	0.1398	0.1398	0.1398
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 in Panels I, II, and III are generated via weighted least squares using the 2015-2019 waves of the state Youth Risk Behavior Surveys. Estimates in Panels IV, V, and VI 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 state T-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 law

Appendix Table 11. Exploring an Income Effect of ENDS Taxes on Consumption of Non-Alcoholic Drinks, Food, Condoms, and Illicit "Hard" Drugs, YRBS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Drank Soda in Last Wk	Drank Soda Everyday	Drank Milk in Last Wk	Drank Milk Everyday	Ate Veggies Last Wk	Ate Veggies Everyday	Sex without Condoms	Condom Use | Sex	Ever Cocaine Use
ENDS Tax ($)	0.00785	0.01115	0.00914	0.00880	-0.00071	0.00965	0.00720	-0.00957	-0.00493
	(0.00793)	(0.01141)	(0.00583)	(0.00931)	(0.00681)	(0.00706)	(0.00600)	(0.01901)	(0.00484)
N	930,844	930,844	701,298	701,298	968,337	968,337	1,026,131	407,469	1,033,821
Pre-Treat Mean Dep Var	0.7618	0.2439	0.7900	0.3678	0.8202	0.2130	0.1552	0.6453	0.0617

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

Notes: Estimates generated using data pooled from the State Youth Risk Behavior Surveys spanning the period 2003-2019. All regressions include controls for state and year fixed effects, individual demographic controls, socioeconomic controls, tobacco policy controls, marijuana policy controls, and alcohol policy controls. Regressions are weighted and standard errors are corrected for clustering at the state level.

Appendix Table 12. 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	-0.0213	0.0013
	(0.022)	(0.011)
	-0.0284**	-0.0154
ENDS Tax ($)	(0.014)	(0.012)
N	25,653	81,313
Pre-Treatment Mean of Dep Variable	0.137	0.169
Full Controls?	Yes	Yes

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

Note: Ordinary least squares (OLS) estimates on ENDS use are obtained using the 2016-2018 waves of the Behavioral Risk Factor Surveillance Survey (BRFSS). OLS estimates on alcohol use are obtained using the 2011 to 2019 waves of the BRFSS. Standard errors are clustered at the state level and estimates are unweighted. All models include state, year and month fixed effects and the full set of observable controls. Demographic controls include age, gender, education (no high school, high school, some college), race (white, black, and Hispanic), and marital status. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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.

Appendix Table 13. Sensitivity of BRFSS Estimates on Adults Aged 21-and-older to Disaggregation of 21-39-Year-Old and 40-and-older Adults

	(1)	(2)	(3)	(4)	(5)	(6)
	Current ENDS Use	Any Alcohol Use	Binge Drinking	Multiple Binge Episodes	Number Drinks per Month | Alcohol Use=1	Number Drinks per Month
				Panel I: Aged 21-to-39		
ENDS Tax ($)	-0.0070	-0.0094	-0.0062	0.0020	-0.3810	-0.2465
	(0.0051)	(0.0070)	(0.0042)	(0.0022)	(0.3130)	(0.3585)
N	218,990	724,609	719,110	719,110	720,294	443,628
Pre-Treat Mean of Dep Variable	0.070	0.612	0.259	0.108	14.658	24.050
				Panel II: Aged 40-and-older		
ENDS Tax ($)	-0.0010	-0.0008	0.0013	0.0007	-0.1087	-0.2022
	(0.0030)	(0.0048)	(0.0017)	(0.0009)	(0.2313)	(0.3367)
N	897,595	3,031,037	3,013,625	3,013,625	3,025,520	1,465,275
Pre-Treat Mean of Dep Variable	0.023	0.479	0.094	0.041	10.651	22.262

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

Note: Ordinary least squares (OLS) estimates on ENDS use are obtained using the 2016-2018 waves of the Behavioral Risk Factor Surveillance Survey (BRFSS). OLS estimates on alcohol use are obtained using the 2011 to 2019 waves of the BRFSS. Standard errors are clustered at the state level and estimates are unweighted. All models include state, year and month fixed effects and the full set of observable controls. Demographic controls include age, gender, education (no high school, high school, some college), race (white, black, and Hispanic), and marital status. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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.

Appendix Table 14A. Sensitivity of Estimated Effects of ENDS Taxes on Alcohol Consumption Inclusion of Treatment State-Specific Linear Time Trends, BRFSS

	(1)	(2)	(3)	(4)	(5)	(6)
	Current ENDS Use (**no trends**)	Any Alcohol Use	Binge Drinking	Multiple Binge Episodes	Number Drinks per Month | Alcohol Use=1	Number Drinks per Month
				Panel I: Aged 18-to-20		
ENDS Tax ($)	-0.0306**	-0.0183	-0.0162*	-0.0062	-4.7341	-2.2029*
	(0.0133)	(0.0125)	(0.0097)	(0.0052)	(3.0551)	(1.1658)
N	25,653	81,729	81,313	81,313	26,566	81,112
Pre-Treat Mean of Dep Variable	0.137	0.329	0.169	0.082	27.486	8.912
				Panel II: Aged 21-and-older		
ENDS Tax ($)	-0.0013	0.0037	0.0014	0.0018	0.3232	0.2118
	(0.0023)	(0.0033)	(0.0011)	(0.0012)	(0.3309)	(0.1940)
N	1,116,585	3,755,646	3,732,735	3,732,735	1,908,903	3,745,814
Pre-Treat Mean of Dep Variable	0.032	0.505	0.125	0.054	22.673	11.411

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

Note: Ordinary least squares (OLS) estimates on ENDS use are obtained using the 2016-2018 waves of the Behavioral Risk Factor Surveillance Survey (BRFSS). OLS estimates on alcohol use are obtained using the 2011 to 2019 waves of the BRFSS. Standard errors are clustered at the state level and estimates are unweighted. All models include state, year and month fixed effects, state-specific linear time trends, and the full set of observable controls. Demographic controls include age, gender, education (no high school, high school, some college), race (white, black, and Hispanic), and marital status. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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.

Appendix Table 14B. Sensitivity of BRFSS Estimates for 18-20 Year-Olds to Weighting Regressions

	(1)	(2)	(3)	(4)	(5)	(6)
	Current ENDS Use	Any Alcohol Use	Binge Drinking	Multiple Binge Episodes	Number Drinks per Month | Alcohol Use=1	Number Drinks per Month
ENDS Tax ($)	-0.0118	-0.0105	-0.0061	-0.0048	-4.2675	-1.5672
	(0.0078)	(0.0150)	(0.0150)	(0.0081)	(4.0774)	(1.6590)
N	25,653	81,685	81,270	81,270	26,552	81,069
Pre-Treat Mean of Dep Variable	0.124	0.328	0.164	0.078	26.727	8.633

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

Note: Ordinary least squares (OLS) estimates on ENDS use are obtained using the 2016-2018 waves of the Behavioral Risk Factor Surveillance Survey (BRFSS). OLS estimates on alcohol use are obtained using the 2011 to 2019 waves of the BRFSS. Standard errors are clustered at the state level and estimates are weighted. All models include state, year and month fixed effects and the full set of observable controls. Demographic controls include age, gender, education (no high school, high school, some college), race (white, black, and Hispanic), and marital status. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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.

Appendix Table 15. Sensitivity of Estimated Alcohol and Non-Alcohol Traffic Fatality Effects for 16-20-Year-Olds to Use of Poisson Model and Alternative Coding of 0

	(1)	(2)	(3)	(4)
	Poisson (*Dep.Var.*= Fatality Count)		OLS, (*Dep.Var.*=log(0.01+fatality rate))	
	Teen Traffic Fatalities Involving Teen Drivers BAC > 0	Teen Traffic Fatalities Involving Teen Drivers BAC = 0	Teen Traffic Fatalities Involving Teen Drivers BAC > 0	Teen Traffic Fatalities Involving Teen Drivers BAC = 0
ENDS Tax ($)	-0.195***	-0.051	-0.126**	0.005
	(0.054)	(0.041)	(0.059)	(0.048)
N	867	867	867	867
Pre-Treatment Mean Dep Variable (level)	32.097	100.072	3.779	11.990

***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 state T-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 16. Sensitivity of FARS Estimates on Teenage Fatalities to Use of Unweighted OLS Estimation

	(1)	(2)	(3)	(4)
	Total Traffic Fatalities	Traffic Fatalities Drivers BAC > 0	Traffic Fatalities Drivers BAC > 0.1	Traffic Fatalities Drivers BAC = 0
	Panel I: Fatalities of Teen (Aged 16-20) Drivers			
ENDS Tax ($)	-0.010	-0.092	-0.110*	0.036
	(0.025)	(0.065)	(0.056)	(0.037)
Pre-Treatment Mean DV	11.407	2.812	2.012	8.595
	Panel II: Fatalities (of Any Age) Involving Teen Driver			
ENDS Tax ($)	0.072	-0.099	-0.123**	0.096
	(0.106)	(0.067)	(0.060)	(0.117)
Pre-Treatment Mean DV	27.897	4.864	3.144	23.034
	Panel III: Fatalities of Teens Involving Teen Driver			
ENDS Tax ($)	0.002	-0.106	-0.127*	0.046
	(0.041)	(0.073)	(0.066)	(0.059)
Pre-Treatment Mean DV	15.769	3.779	2.516	11.990
N	867	867	867	867

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

Note: Estimates are generated from the Fatality Analysis Reporting System (FARS) from the years 2003 to 2019. Standard errors are clustered at the state level. Regressions are unweighted. All models include state and year fixed effects and the full set of observable controls. Demographic controls include gender, race, ethnicity, and education. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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 and year fixed effects. The dependent variable is equal to the natural log of 1 plus traffic fatalities per 100,000 people. Trends refer to treated state-specific linear time trends. Additionally, we account for policies related to traffic laws, including the seat belt laws, the 0.08 BAC laws, and the 65-mph speed limit. The measure of BAC is generated using observable BAC when BAC is provided and "imputed" when such information is missing.

Appendix Table 17. Sensitivity of FARS Estimates on Adults Aged 21-and-older to Disaggregation of 21-39-Year-Old Drives and 40-and-older Drivers

	(1)	(2)	(3)	(4)
	Total Traffic Fatalities	**Traffic Fatalities Drivers BAC > 0**	**Traffic Fatalities Drivers BAC > 0.1**	**Traffic Fatalities Drivers BAC = 0**
	Panel I: Fatalities (of Any Age) Involving Driver Aged 21-39			
ENDS Tax ($)	-0.015	-0.014	-0.006	-0.022
	(0.030)	(0.037)	(0.047)	(0.032)
Pre-Treatment Mean DV	24.050	8.094	6.126	15.956
	Panel II: Fatalities of Adults Aged 21-39 Involving Adult Driver (21-39)			
ENDS Tax ($)	0.009	-0.011	0.012	0.008
	(0.037)	(0.041)	(0.048)	(0.043)
Pre-Treatment Mean DV	14.496	6.086	4.765	8.410
	Panel III: Fatalities (of Any Age) Involving Driver Aged 40-and-older			
ENDS Tax ($)	-0.042	-0.040	-0.076	-0.041
	(0.031)	(0.042)	(0.046)	(0.031)
Pre-Treatment Mean DV	14.988	3.314	2.457	11.674
	Panel IV: Fatalities of Adults 40-and-older Involving Adult Driver (40-and-older)			
ENDS Tax ($)	-0.041	-0.047	-0.077*	-0.037
	(0.030)	(0.037)	(0.039)	(0.030)
Pre-Treatment Mean DV	11.002	2.308	1.743	8.693
N	867	867	867	867

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

Note: Estimates are generated from the Fatality Analysis Reporting System (FARS) from the years 2003 to 2019. Standard errors are clustered at the state level. Regressions are weighted using state populations. All models include state and year fixed effects and the full set of observable controls. Demographic controls include gender, race, ethnicity, and education. Socioeconomic controls include state unemployment rate and state poverty rate. Tobacco policy controls include state T-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 and year fixed effects. The dependent variable is equal to the natural log of 1 plus traffic fatalities per 100,000 people. All models include treated state-specific linear time trends. Additionally, we account for policies related to traffic laws, including the seat belt laws, the 0.08 BAC laws, and the 65-mph speed limit. The measure of BAC is generated using observable BAC when BAC is provided and "imputed" when such information is missing. All models include a treatment state-specific linear time trend for each treated state.