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THE EFFECT OF E-CIGARETTE TAXES ON SUBSTANCE USE

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ABSTRACT

Public health advocates warn that the rapid growth of legal markets for electronic nicotine delivery systems (ENDS) may generate a "gateway" to marijuana and harder drug consumption, particularly among teenagers. This study explores the effects of ENDS taxes on substance use. We find that a one-dollar increase in ENDS taxes (2023$) is associated with a 1.0 to 1.5 percentage point decline in teen marijuana use and in co-use of ENDS and marijuana. This result is consistent with e-cigarettes and marijuana being economic complements. We also find that youth responses to ENDS taxes, in terms of their ENDS use and spillovers into marijuana use, appear to moderate over the longer term. We find no evidence that ENDS taxes affect drug treatment admissions or consumption of illicit drugs other than marijuana such as cocaine, methamphetamine, or opioids.

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1. Introduction

The opening of legal markets for electronic cigarettes (e-cigarettes or electronic nicotine delivery systems, "ENDS") and marijuana has dramatically increased access to these substances in the United States. Along with the immediate pleasure-related utility generated from recreational consumption (i.e., a "buzz" or "high"), their use may also generate potentially important health benefits. Increased access to ENDS has been found to curb combustible tobacco product use (Abouk & Adams, 2017; Abouk, Courtemanche, et al., 2023; Anderson et al., 2020; Pesko & Warman, 2022), which may be an effective tobacco harm-reducing strategy (Dave et al., 2019; National Academies of Sciences, 2017; Saffer et al., 2020).[1] Marijuana use may allow medical consumers to treat a variety of painful symptoms associated with chronic and acute health ailments (National Academies of Sciences 2017)[2] and marijuana use has been documented to induce substitution away from other potentially more harmful health behaviors such as problem drinking (Anderson et al., 2013) and opioid misuse (Bachhuber et al., 2014; Bradford & Bradford, 2018; Bradford et al., 2018; McMichael et al., 2020; Raman et al., 2023; Sabia et al., 2021; Vigil et al., 2017; Wen & Hockenberry, 2018).[3]

Despite these potential benefits, public health advocates caution that increased access to ENDS — particularly in a policy environment characterized by liberalized access to marijuana — may renormalize smoking and have unintended "gateway" effects on marijuana and other substance use that adversely affect health (Gorman, 2016; U.S. Department of Health Human Services, 2016). Notably, consumers who use marijuana for recreational, rather than medicinal purposes, would be less likely to receive any therapeutic benefits from the substance. Recreational consumers may be more vulnerable to addiction and other adverse health consequences as they are more likely to consume marijuana for its euphoric benefits. Frequent and heavier marijuana use has also been found to increase the risk of respiratory disease (National Academies of Sciences, 2017; Tashkin et al., 2012). Moreover, joint consumption of ENDS and marijuana products during the 2019-2020 "e-

[1] Combustible tobacco product use is the leading cause of preventable death in the U.S. and is associated with 480,000 deaths each year (Centers for Disease Control and Prevention, 2020), and causes 40 percent of all cancer diagnoses (Centers for Disease Control and Prevention, 2016), suggesting that increased smoking would worsen public health.
[2] These may include anxiety, pain, fibromyalgia, nausea, and side effects of cancer and HIV treatments (Blake et al., 2006; Chaves et al., 2020; Chu, 2015; National Academies of Sciences, 2017; Nicholas & Maclean, 2019; Nurmikko et al., 2007; Powell et al., 2018; Rog et al., 2005; Ullman, 2017).
[3] These benefits may be substantial, as excessive alcohol use has been shown to cause 90,000 deaths each year (Stahre et al., 2014) and the U.S. is in the midst of an opioid epidemic that has killed well over 500,000 Americans since 1999 (Maclean et al., 2022).

cigarette, or vaping, product use associated lung injury" (EVALI) outbreak was responsible for 68 deaths and nearly 3,000 hospitalizations for severe respiratory problems (Centers for Disease Control and Prevention, 2021). Many of these injuries occurred to youths, who often jointly consume marijuana and ENDS, sometimes with the same vaping device (U.S. Department of Health and Human Services, 2019; Zhong et al., 2016).

Marijuana use and ENDS use among youths and young adults are of particular concern to leading public health and medical organizations (American Medical Association, 2021; American Public Health Association, 2020) for broader reasons than the risk of severe lung injury. After alcohol, nicotine vaping and marijuana remain the two most commonly used substances by adolescents and young adults. Beyond age-based legality of access to tobacco and marijuana products, studying ENDS and marijuana effects separately for youth and adults is important for several reasons. Because the brain continues to develop through one's early 20s (Giedd et al., 1999; Sowell et al., 2001) — most notably in regions linked to executive function, reward, and impulse control — marijuana use and nicotine exposure during this developmental stage may persistently damage longer-run cognition and adversely affect outcomes that rely on these regions of the brain for functioning (Scheier & Griffin, 2021).[4] Adults, whose brain has reached neurological maturity, do not face this cost associated with substance use. Further, and likely related to continued brain development, many substance use disorders emerge during adolescence, and early adolescent substance use heightens the risk of dependence and lifelong substance use disorder (Kessler et al., 2005). For instance, early initiation into marijuana use more than triples the risk for cannabis use disorder (CUD),[5] a chronic and costly condition affecting over 16 million Americans (Fergusson et al., 2003; Substance Abuse and Mental Health Services Administration, 2023), and could increase the

[4] Early initiation of marijuana use, for instance, has been linked to diminished neuro-psychological and neuro-developmental function, increased risk of psychotic disorders, and increased risk of suicide behaviors (U.S. Department of Health and Human Services, 2019). Similarly, adolescent nicotine exposure can have lasting adverse neuro-developmental consequences, including deficits in cognitive function and emotional dysregulation U.S. Department of Health and Human Services, 2016; Leslie, 2020; López-Ojeda and Hurley, 2024).

[5] According to the American Psychiatric Association (2013) Diagnostic and Statistical Manual of Mental Disorders (DSM-5), CUD is defined as meeting at least two of the following behaviors in the past 12 months: 1) using more cannabis than intended, 2) trying but failing to quit using cannabis; 3) spending a lot of time using cannabis; 4) craving cannabis; 5) using cannabis even though it causes problems at home, school, or work; 6) continuing to use cannabis despite social or relationship problems; 7) giving up important activities with friends and family in favor of using cannabis; 8) using cannabis in high-risk situations, such as while driving a car; 9) continuing to use cannabis despite physical or psychological problems; and 10) needing to use more cannabis to get the same high. The consequences of CUD can include: reduced brain function (e.g., memory, decision-making, and coordination); heart disease, stroke, and other vascular diseases; lung disease; impaired driving; poor mental health (e.g., anxiety and depression); and unintentional poisoning (Centers for Disease Control and Prevention, 2024a).

risk of harder drug use if younger users are seeking a more intense recreational "high" (National Institute on Drug Abuse, 2021).

This study contributes to an emerging literature that explores the spillover effects of e-cigarette policies on the consumption of substances that carry substantial private and external health costs (Abouk, Adams, et al., 2023; Abouk, Courtemanche, et al., 2023; Dave et al., 2023; Hansen et al., 2023; Pesko & Warman, 2022). We focus on ENDS taxes, an increasingly popular policy strategy to curb nicotine vaping among youth and young adults, as well as a tool that can, when optimally set, potentially correct for market externalities and internalities (DeCicca et al., 2022) associated with e-cigarette use. However, evaluating the efficacy of a Pigouvian tax requires assessing general equilibrium effects, particularly those with potentially large social benefits or costs.

As of December 2023, 31 states and the District of Columbia had an e-cigarette tax in place (Public Health Law Center, 2023).[6] Minnesota was the first state to adopt a statewide ENDS tax in August 2010, starting with a $2.48 tax per ml of e-liquid (in 2023$). Given the scope (i.e., more than half of states have adopted ENDS taxes) and size (i.e., taxes range from $0.01 to almost $3.80 per ml of fluid) of ENDS taxes, and the potentially important general equilibrium effects of these policies, understanding the effect of ENDS taxation on marijuana and harder drug use is crucial.

Conceptually, ENDS taxes may affect marijuana use through a number of channels. ENDS and marijuana may be economic complements, perhaps because (1) the utility-enhancing "buzz" of one product's consumption is enhanced by consumption of the other,[7] (2) vaping nicotine serves as a gateway to marijuana use, (3) joint consumption enhances social capital acquisition (e.g., demonstrating one's "coolness" to peers), and/or (4) since nicotine and marijuana can both be vaped, investing in the fixed cost of a nicotine vaping device reduces the cost of vaping marijuana.[8] These biological, social and economic channels may also explain the high degree of co-engagement, particularly among youth, in both activities.[9] In this case, an increase in ENDS taxes would decrease demand for marijuana.

[6] Some states have adopted an ad valorem tax, which is a percentage of the retail price, while others have adopted a tax per milliliter (ml) of the nicotine-containing fluid ("e-liquid") inside the e-cigarettes that is heated into the vaped aerosol.
[7] Such reinforcing cross marginal utility effects have been indicated for the consumption of ENDS and alcohol (see: Thrul et al. (2019) and Dave et al. (2024)).
[8] Over 87 percent of middle- and high-school students who consumed e-cigarettes over the past 30 days reported doing so using devices (tank systems, mod systems, pods) which could also be readily used for vaping marijuana, based on the 2019 National Youth Tobacco Survey.
[9] Over 60 percent of teens who used electronic vaping products in the past 30 days, also consumed marijuana (2023 National Youth Risk Behavior Survey - YRBS; 61.3 percent in the 2023 State YRBS). This share increased from approximately 48 percent in 2019.

On the other hand, if the two goods are substitutes, perhaps serving as competing ways to attain utility from a buzz or even the act of vaping, then ENDS taxes will increase demand for marijuana. Substitution responses could also result as a tax-avoidance strategy, particularly across products that serve a common purpose or have similar psychoactive effects.[10] ENDS taxes could also affect marijuana use via an income effect, whereby consumers of ENDS will simply have less income to purchase marijuana. Or it may be that ENDS taxes serve as an information shock about the dangers of smoking or vaping a menu of products that include ENDS and marijuana. Finally, ENDS taxes could affect marijuana use through "second order" spillover effects: that is, through the effects of ENDS taxes on alcohol (Dave et al., 2024) or combustible tobacco product use (Abouk & Adams, 2017; Abouk, Courtemanche, et al., 2023; Anderson et al., 2020; Pesko & Warman, 2022), which could also be related to marijuana consumption decisions. Several other studies show that addictive substances are related goods among youth (Crost & Guerrero, 2012; DiNardo & Lemieux, 2001; Pacula, 1998b), offering further premise for exploring the extent to which ENDS taxation impacts marijuana use.

With respect to recreational consumption of harder drugs such as opioids (i.e., fentanyl, heroin, or nonmedical use of prescription painkillers), cocaine, or methamphetamine, the pathways through which ENDS taxes may affect such outcomes are conceptually similar to those noted above for marijuana. However, the effects are likely to be smaller given that harder drugs are much less likely to be economic complements or substitutes for e-cigarettes among youth.[11] Rather, we might expect that a relationship between ENDS access and harder drugs, if present, is likely to be explained by income effects or, perhaps, longer-run gateway effects through marijuana use.

This study provides a comprehensive exploration of the spillover effects of ENDS taxes on marijuana and harder drug use. "We build on "preliminary" prior work (Anderson et al., 2020) in several key respects including: (1) capitalizing on a recent ENDS tax standardization approach that allows us to leverage variation in not just the adoption of an ENDS tax but also its intensity; (2) exploiting substantially more policy variation and post-treatment data than were available to prior researchers, (3) widening the focus of the analysis to study various measures and margins of marijuana use, co-use of marijuana and ENDS, as well as other non-marijuana substance use; (4)

[10] Marijuana and nicotine have addictive potential. Research has shown that each of these can produce both stimulant and sedating effects depending on dose and the user (Henningfield & Woodson, 1989; Murray, 1986). Hence, for some subset of youth users, who derive similar psychoactive effects from marijuana and nicotine, higher ENDS taxes may lead them to substitute towards marijuana use either at the intensive margin or at the extensive margin.

[11] After alcohol use, nicotine vaping and cannabis use constitute the most reported substance use and early onset use among teens in the 2019 Monitoring and Future Survey and 2019 State YRBS.

extending the analyses period to include a window that enveloped a fast-changing ENDS market (including the rise and fall in popularity of JUUL and adoption of a federal minimum legal purchasing age for all tobacco products), the evolving marijuana policy landscape, and the COVID-19 pandemic; (5) implementing difference-in-differences methods designed to curb potential biases in two-way fixed effects methods that arise from dynamic and spatial heterogeneity in treatment effects within a staggered adoption setting; and (6) assessing and ruling out hypothesized pathways through which ENDS taxes affect substance use, including economic complementarities, income effects, and indirect effects through spillovers to combustible cigarettes or alcohol.

Using data spanning the period 2000 to 2023, and a generalized difference-in-differences approach, we document three key findings. First, we show that a one-dollar increase in ENDS taxes (in 2023$) leads to a 2.8 to 2.9 percentage-point (14 percent) reduction in teenage ENDS use and approximately a one percentage-point (six percent) reduction in younger (18-to-30 years) adult vaping. This pattern of significantly negative "first stage" effects, that are stronger for youth than for adults, is in line with findings from earlier studies (Abouk, Courtemanche, et al., 2023; Pesko et al., 2020). However, the magnitude of the own-tax response that we estimate is smaller than previously reported, a finding that we attribute to ENDS use becoming more inelastic in recent years and in particular since the pandemic.[12] Second, we find consistent evidence of spillover effects of ENDS taxes on marijuana use. A one-dollar increase in ENDS taxes leads to about a 1.1 to 1.4 percentage-point (six to eight percent) reduction in marijuana use among high school students. Our "reduced form" effects are about 50 to 60 percent smaller in absolute magnitude relative to the first stage effects on e-cigarette use, suggesting that reduced-form spillover effects are plausible. We also find significant ENDS tax-induced decreases in the co-use of ENDS and marijuana among youth, a behavior that was alarmingly brought to light during the EVALI outbreak.

Finally, we find no consistent evidence that ENDS taxes affect more frequent marijuana use, marijuana-related drug treatment admissions, or use of "harder" (non-marijuana) drugs. To the contrary, the results indicate that ENDS taxes affect marijuana use largely on the margin of lighter or infrequent consumption. Broadly, our findings underscore the importance of examining spillover effects of ENDS taxes and access generally on related outcomes in order to fully assess their efficacy. With respect to public health concerns surrounding youth substance use, our findings

[12] Abouk, Courtemanche, et al. (2023) utilize data from the MTF and YRBS through 2019, and Pesko et al. (2020) utilize data from the BRFSS and National Health Interview Survey (NHIS) through 2018.

suggest that ENDS taxation can generate important and beneficial spillover effects in terms of reducing marijuana use as well as joint use of e-cigarettes and marijuana among teens.

2. Background

2.1 Literature on Tobacco and Marijuana Use

Much of the prior work that has considered the inter-relationship between tobacco control policies and marijuana use has expectedly focused on combustible cigarette smoking. In an early study, Pacula (1998a) uses data from the 1983 and 1984 National Longitudinal Survey of Youth and documents that as cigarette prices (including taxes) increase, youth marijuana use declines.[13] Using data from the National Household Survey on Drug Abuse for the period 1990–1996, Farrelly et al. (2001) similarly find that higher cigarette taxes are associated with decreases in the intensity of marijuana use among 12-to-20-year-olds. Applying a similar empirical approach with data from Monitoring the Future (MTF) over the period 1992 to 1994, Chaloupka et al. (1999) also find that cigarette taxes are negatively related to intensity of marijuana use among users. These studies suggest that marijuana and combustible cigarettes are complements for youths, though findings are based on the U.S. tobacco market from the 1980s and 1990s, which predated the entry of ENDS products and is quite different from the current landscape.

When using data for a more recent time period (1991–2017) from the Youth Risk Behavior Survey (which we also use in our analysis), Anderson et al. (2020) find little evidence supporting the hypothesis of teen marijuana consumption being sensitive to cigarette taxes. The authors conclude that one possible reason for the null finding is that combustible cigarette taxes have become less effective at deterring youth combustible tobacco product use because the marginal smoker in more recent years has a relatively inelastic demand for cigarettes. Overall, studies exploiting variation in cigarette taxes suggest that combustible cigarettes and marijuana are economic complements, or are unrelated goods.

In addition to taxes, researchers have leveraged other policy shocks to explore whether marijuana and tobacco are related goods. Hansen et al. (2023) exploits data from the 2009-2019 State YRBS to study the effect of Tobacco-21 (T-21) laws on youth tobacco, alcohol, and marijuana

[13] A concern with using prices is that they are determined by market forces that are difficult to fully account using regression methods. Thus, results based on prices could be vulnerable to omitted variables and simultaneity bias.

consumption. The authors find evidence that marijuana use declines following the adoption of state T-21 laws, consistent with the hypothesis that tobacco and marijuana are complements for teens.

Other studies have examined the effect of changes in access to marijuana on tobacco use. Dave et al. (2023) find that the adoption of recreational marijuana laws leads to a lagged reduction in adult vaping and combustible cigarette smoking. Miller and Seo (2021) and Choi et al. (2019) also demonstrate a similar pattern of results suggesting that marijuana and tobacco may be substitutes for adults.[14] There is very little causal evidence on the impact of recreational marijuana legalization on youth tobacco consumption.

2.2 Health and Cognitive Effects of Marijuana Use

In 2021, marijuana was the most commonly used recreational drug in the U.S. with 13.7 percent of adults (18 years and older) and 5.8 percent of youth (ages 12-to-17 years) reporting past-30-day use of this product (Substance Abuse and Mental Health Services Administration, 2023). In light of evidence linking marijuana consumption - particularly when initiated at earlier ages and consumed more frequently at heavier doses – with increased risk of addiction, marijuana-related psychosis, respiratory problems, motor vehicle crashes, adverse birth outcomes, and exposure to toxic ingredients such as arsenic (National Academies of Sciences, 2017), important public health concerns surround marijuana use amidst a fast-evolving marijuana landscape. Much of these concerns have centered around youth.

Marijuana use among youths and young adults is also associated with cognitive impairment such as memory loss (Levine et al., 2017); psychological conditions including mood disorders, hallucinations, delusions, and psychosis (Levine et al., 2017; Scheier & Griffin, 2021; Van Ours & Williams, 2015; Wang et al. 2022); increased risk for motor vehicle accidents (Hingson et al., 1982);[15] and cannabis use disorder or CUD (Hasin et al., 2015), with 30 percent of current marijuana consumers having a CUD. Frequent or heavy marijuana smoking can cause important respiratory and lung related injuries such as chronic cough, bronchial episodes, increased phlegm productivity, chronic bronchitis symptoms, airway inflammation, and airflow obstruction (Joshi et al., 2014; National Academies of Sciences, 2017), and long-term marijuana smoking has been found to be associated with increased respiratory symptoms suggestive of obstructive lung disease (Tetrault et al.,

[14] In contrast, a handful of studies find no evidence of an association between marijuana legalization and tobacco use (Alley et al., 2020; Andreyeva & Ukert, 2019; Veligati et al., 2020).

[15] A substantial portion of high-school students, 16 years and older, who currently use marijuana, report having driven a car or vehicle in the past month when they had been using marijuana (41.2 percent based on 2017 National YRBS).

2007). Marijuana use during pregnancy has been found to raise the risk of infants born with low birthweight and raise the risk of anemia for pregnant women (Gunn et al., 2016).

The health harms of marijuana use are particularly concerning for youth due to important biological and social developmental changes that occur during this life stage. For example, the teenage period is an important time for human capital accumulation (i.e., through educational investments) and marijuana use can impede such accumulation through direct cognitive impairment, hangover effects, and adverse physical and mental health effects (Van Ours & Williams, 2009). Given the theoretical and empirical importance of human capital for earnings and labor market success (Becker, 2009), marijuana use could have long-term consequences for financial stability.[16]

Furthermore, youths may discount the longer-term costs of current consumption decisions over addictive goods (Gruber & Köszegi, 2001; Scheier & Griffin, 2021; Steinberg, 2008), which could be substantial. Early marijuana use disproportionally increases the likelihood of a CUD, as 16 percent of people who initiate marijuana use during youth develop a CUD at some point in their lifetime versus just five percent of those who initiate at later ages (Fergusson et al., 2003).

Many major mental health disorders also emerge during youth (Kessler et al., 2005), and marijuana use may exacerbate development of a mental health disorder or potentially cause youth to avoid seeking treatment for fear of disclosing marijuana use. The prefrontal cortex area of the brain, which is associated with impulse control and judgement, continues to develop through the early 20s (Giedd et al., 1999; Sowell et al., 2001) and substance use during this period can persistently damage brain development (Pfefferbaum et al., 2018; Salmanzadeh et al., 2020; Volkow et al., 2014). Youth marijuana use is linked to increased risk of mental illness such as anxiety, depression, and schizophrenia (Salmanzadeh et al., 2020; Scheier & Griffin, 2021; Szczepanski & Knight, 2014).

Concerns around youth joint use of marijuana and ENDS were heightened in 2019 and 2020 when the Centers for Disease Control and Prevention (CDC) documented numerous cases of EVALI (2021). Between August 2019 and February 2020, the CDC recorded 68 deaths and over 2,800 EVALI hospitalizations with symptoms ranging from shortness of breath, coughing, chest pains, and general respiratory problems, with youth and young adults representing a disproportionate share of those affected (Centers for Disease Control and Prevention, 2021). ENDS were initially suggested by CDC as a likely cause of EVALI because the majority of patients had

[16] Marijuana use could, in theory, also increase criminal behavior through their psychological effects as well as the need to finance addiction (Popovici et al., 2014). Having a criminal record early in the life course can have cascading negative effects on labor market success.

used an ENDS product in the three months prior to the death or hospitalization (Centers for Disease Control and Prevention, 2021). Over time, researchers determined that most affected persons had tampered with commercially produced ENDS products, in particular adding vitamin E acetate, and using the ENDS product to vape marijuana which is not recommended by ENDS producers (Blount et al., 2020). Thus, the EVALI outbreak is most directly linked to vaping marijuana rather than ENDS use per se among youth and young adults.

2.3 Policy Environment for Marijuana

Marijuana possession and distribution have been prohibited at the federal level since the Marihuana Tax Act of 1937 and marijuana is currently a Schedule I drug (i.e., no accepted medical use and high potential for abuse) under the Controlled Substances Act of 1970. However, beginning with California in 1996, a number of states have legalized marijuana for first medical and later recreational use. By November 2023, 38 states and the District of Columbia had legalized the medical use of marijuana for patients who receive a recommendation from a healthcare professional for treatment of a "qualifying" health condition such as chronic pain or anxiety (ProCon, 2023a), and 24 states and the District of Columbia had legalized recreational marijuana (ProCon, 2023b). All legalizing states prohibit sales to youth: the minimum legal sales ages range from 18 to 21 for medical laws (ProCon, 2023a) and are uniformly age 21 for recreational marijuana (ProCon, 2023b).

Federal marijuana reforms are also part of the current policy debate. At the time of writing, the Drug Enforcement Agency (DEA) is evaluating a recommendation from the Department of Health and Human Services (HHS) that marijuana be reclassified from a Schedule I to Schedule III drug, which would recognize that marijuana has "some accepted medical use" and "moderate to low potential for physical and psychological dependence" (Congressional Research Service, 2024).[17] Further, in 2022 and 2023, President Biden pardoned persons convicted of select federal crimes related to simple possession of marijuana (U.S. Department of Justice, 2023), signaling a further softening of the federal government's "war on marijuana."

Previous research suggests that medical and recreational marijuana legalization leads to increases in marijuana use among adults. For example, following a recreational marijuana law, adult use of this product increases by 25 percent to 40 percent (Abouk, Ghimire, et al., 2023; Cerdá et al.,

[17] If the DEA follows the recommendation of HHS, this re-scheduling could increase use of marijuana as federal prohibition will be removed, which will reduce some penalties for sellers and consumers, and reduce some costs of supplying marijuana to the market.

2020; Hollingsworth et al., 2022; Maclean et al., 2021). Changes in use stemming from medical laws are somewhat more modest in size given that these policies impact a smaller share of the population (Hollingsworth et al., 2022).

Spillover effects of recreational marijuana legalization on youths is, a priori, difficult to sign. On the one hand, increased supply of marijuana through legal dispensary sales and home cultivation could reduce the price of marijuana in illicit markets (i.e., from local drug dealers), leading to an increase in youth consumption. Additionally, and in practice, the legalization of recreational marijuana has been accompanied by robust taxation, and regulations and administrative burdens for licit marijuana businesses (ProCon, 2023b). New marijuana taxes may expand the illicit market as sellers attempt to avoid marijuana taxes while regulations and administrative burdens may inhibit the ability of legal sellers to enter the new market; an unintended effect may be an increase in sales to minors via such reinvigorated illicit markets. On the other hand, the opening of new licit marijuana markets and falling competition-driven marijuana prices could also dry up the illicit market as sellers move to more profitable endeavors (including selling of other illicit substances). Empirical evidence on the effects of recreational marijuana laws on youth marijuana use is quite mixed, with studies documenting increases, decreases, and stable use post-policy (O'Grady et al., 2022).

2.4 *Rise of the ENDS Market*

The first commercially successful ENDS were developed by Hon Lik, a pharmacist in China, as a harm reduction product for addicted smokers in 2003 (CASAA, 2023).[18] The first recorded ENDS sale in the U.S. occurred in August 2006 (CASAA, 2023). These products quickly became popular among Americans with past-30-day use of ENDS products among adults increasing from 1.0 percent in 2010 to 2.6 percent in 2013 and 5.1 percent in 2020 (Boakye et al., 2022; King et al., 2015).[19] With respect to youth vaping, in 2011, 1.5 percent of high school students reported past-30-day use of ENDS and this share had increased to 27.5 percent by 2018 (Cullen et al., 2018). By 2023, however, owed to a number of factors (including the COVID-19 pandemic, the adoption of a federal minimum legal purchasing age for ENDS and combustible tobacco products, and a myriad of regulations that curtailed access to ENDS products), just 10.0 percent of U.S. high school seniors

[18] Commercially unsuccessful ENDS products date back as far as 1930 (CASAA, 2023).
[19] Most major U.S. health surveys of adults did not include questions related to ENDS use until 2011. The Tobacco Use Supplement to the Current Population Survey added a question in 2011 but ENDS questions were not added to the NHIS until 2014 and the BRFSS until 2016.

reported using ENDS in the past 30 days in 2023 and 7.8 percent did so in 2024 (National Youth Tobacco Survey 2024).

Optimal regulation of ENDS is challenging given the heterogenous reasons consumers use these products and the health implications stemming from such uses. On the one hand, and in line with their original purpose, some smokers who cannot quit smoking turn to vaping as a less harmful way to consume nicotine (the addictive ingredient in tobacco products). Utility may increase if consumers are better able to match consumption with their preferences and public health may be improved by such "harm reduction"-motivated use as ENDS are believed by most experts to be substantially less damaging to health than combustible cigarettes.[20] ENDS use, however, is not completely safe and does pose health risks, in particular to youth vapers. Nicotine is found in the vast majority of ENDS products (Cotti et al., 2022) and nicotine is addictive and can impede brain development among youth (Centers for Disease Control and Prevention, 2024b). Nicotine addiction can have detrimental impacts on mental health for both youth and adults (Centers for Disease Control and Prevention, 2024b), and nicotine is associated with depression while quitting vaping is associated with reduced anxiety and depression and increased quality of life and overall mood. Nicotine can also cause an increase in blood pressure which can lead to heart disease (Ogunwale et al., 2017). Additionally, ENDS products contain thousands of chemicals including heavy metals and pesticides (Sassano et al., 2018), and health harms of these chemicals are not fully understood at the time of writing, but researchers note that such chemicals can harm lung health (Tehrani et al., 2021). Finally, ENDS ingredients such as acrolein can cause cancer of the lung (Bein & Leikauf, 2011). In addition to these direct health harms, public health advocates contend that access to ENDS encourages youth and young adults, who would not otherwise use tobacco products, to vape and, potentially through gateway effects (Dai et al., 2018), smoke. Such use of ENDS is likely harmful to public health (Scheier & Griffin, 2021; U.S. Department of Health Human Services, 2016; Zhong et al., 2016).

Despite evidence of important harm reduction-related benefits of ENDS, regulations aimed at reducing access to ENDS products have been proliferating. By 2016, all U.S. states and the District of Columbia implemented a minimum legal sales age ("MLSA") of 18 or higher and in December 2019, a federal T-21 law, which raised the minimum legal purchasing of all tobacco

[20] For example, in a survey of 137 tobacco control experts, Allcott and Rafkin (2022) report that the mean (median) expert believes that the impact of ENDS use on quality-adjusted life expectancy is only 37 (20) percent as large as the impact of smoking.

products (i.e., ENDS, combustible tobacco products, smokeless tobacco products) to age 21, was adopted. As of March 31, 2023, 17 states and the District of Columbia had adopted clean indoor air laws that extended to ENDS (Centers for Disease Control and Prevention, 2023), five states had adopted statewide ENDS flavor bans (Campaign for Tobacco-Free Kids, 2023), and 34 states and the District of Columbia had adopted ENDS licensure laws (Centers for Disease Control and Prevention, 2023).

One of the most popular policy strategies to curb ENDS use is to tax its sale. Minnesota was the first state to adopt an ENDS tax (August 1, 2010), imposing a tax rate of 35 percent, later raised to 95 percent in 2013; two more states (Louisiana and North Carolina) and the District of Columbia followed suit in 2015. As of November 2023, 31 states, D.C., as well as several large localities (Chicago and Cook County in IL; Montgomery County in MD) had adopted an ENDS tax (Public Health Law Center, 2023). Early taxation efforts primarily relied on excise (per ml of e-liquid) or ad valorem taxes. Several states have implemented mixed approaches to ENDS taxation which include both specific and ad valorem taxes. For example, Connecticut has an ad valorem tax of ten percent for open system ENDS and a specific tax of 40 percent per ml of nicotine for closed system products. We utilize a standardized measure of the tax rate, converted for all of these tax modalities in all jurisdictions to a standardized tax rate per ml of e-liquid, based on Cotti et al. (2021). We do not differentiate between the types of taxes, although that would be an interesting direction for future work. We use taxes for "closed" ENDS devices which rely on pre-filled cartridges (or "pods") as the source of e-liquid, as these products are more common among teens (Birdsey, 2023). Figure 1 shows the geographic and temporal variation in closed system ENDS taxes over the period 2010-2023, which corresponds to the last year of data we use in our analysis. Appendix Table 1 shows the dates of the policy changes and the precise magnitudes of the tax changes that we leverage in our empirical analyses.

2.5 Mechanisms Through Which ENDS Taxes May Affect Substance Use

There are various pathways through which ENDS taxes could impact marijuana use. These channels may be re-enforcing or offsetting. Previous research shows that ENDS taxes are nearly fully passed through to prices faced by consumers (Allcott & Rafkin, 2022; Cotti et al., 2022)[21] and that vaping declines substantially post-tax (Abouk, Courtemanche et al., 2023). . For example, a one-

[21] In particular, Cotti et al. (2022) document a pass-through rate of 0.90 in retail stores. This estimate implies that for every one-dollar tax increase, ENDS prices in retail stores increase by $0.90.

dollar increase in ENDS taxes reduces ENDS retail sales by 51.9 percent (Cotti et al., 2022). If ENDS and marijuana are economic substitutes, then the decline in the quantity of ENDS demanded should lead to an increase in the demand for marijuana. Alternatively, if the goods are economic complements, then demand for marijuana will decline following taxation of ENDS.

By increasing the price of ENDS nearly one-for-one, ENDS taxes could reduce available income and therefore "crowd out" other purchases (Busch et al., 2005). That is, even if consumers partially reduce ENDS purchases in response to the tax, the tax increase could limit resources available for other goods, leading to a ("mechanical") decline in the use of marijuana products even if the goods are neither complements or substitutes. Income effects may be particularly salient for youth who tend to have tighter budget constraints than adults and for whom co-use of marijuana and ENDS is common. For example, youth who use marijuana have a six times higher odds of using ENDS than other youth (Hershberger et al., 2020), which could suggest that crowd-out is plausible.[22] Relatedly, most e-cigarette users consume e-cigarettes using devices (e.g., pods, tank systems, and mod systems) which incur a fixed buy-in cost and that can be adapted to also vape marijuana; hence, having invested in such devices to consume nicotine reduces the cost of vaping marijuana. This pathway may be particularly salient for new initiates of e-cigarettes; by deterring initiation (Abouk, Courtemanche, et al., 2023) and thus the purchase of vaping devices, higher e-cigarette taxes would increase the cost of consuming marijuana through vaping, implying economic complementarity between nicotine and marijuana consumed through a common delivery mode.

ENDS taxes could serve as "signal" about the relative risk of vaping specifically and substance use generally (Rees-Jones & Rozema, 2023). Thus, post-tax consumers may re-evaluate risks associated with the use of all substances, and demand for substances overall may decline through a chilling effect. Furthermore, if marijuana and ENDS are used in social settings (Reboussin et al., 2021), that is their combined use with peers enhances the utility from use of both products, then post-ENDS taxation, there may be less social utility from consuming marijuana as there is a reduction in ENDS use by the overall peer group, suggesting a decline in the demand for marijuana. With respect to combustible tobacco use, marijuana use, and alcohol use, there is consistent evidence of significant and positive peer effects (Kremer & Levy, 2008; Lundborg, 2006; Powell et al., 2005). The presence of peer effects in ENDS and marijuana consumption would magnify the

[22] In our State YRBS sample (described in Section 3), nearly 12 percent of youth report using both ENDS and marijuana. Among current (past month) e-cigarette users, over 61 percent of the surveyed teens reported also using marijuana in 2023.

impact of ENDS taxes by generating a social multiplier effect. If ENDS taxes increase (decrease) the demand for marijuana, then the shift in marijuana use at the peer group level would lead to reinforcing increases (or decreases) in the demand for marijuana through the feedback loop between peer groups and the individual. Finally, there may be a biological link between ENDS and marijuana use. That is, if the use of one product increases the "high" or euphoria associated with the use of the other product (Reboussin et al., 2021), then ENDS taxes may lead to a reduction in marijuana use for those consumers who choose to use the products in combination due to the enhanced utility.

ENDS taxes may also affect marijuana use through their second-order effects on combustible tobacco products or alcohol. For instance, there is evidence that marijuana and combustible cigarettes are substitutes among adults (Choi et al., 2019; Dave et al., 2023) and that marijuana and alcohol are also substitutes among adults (Anderson et al., 2013; Anderson & Rees, 2023). Given evidence that ENDS taxes increase combustible tobacco product use (Abouk & Adams, 2017; Abouk, Courtemanche, et al., 2023; Anderson et al., 2020; Pesko & Warman, 2022) and decrease heavier drinking (Dave et al., 2024), the net marijuana effects from these second-order spillover channels are difficult to sign.

Dynamic gateway effects may be another mechanism through which ENDS taxes could shift the demand for marijuana and harder drug use. Indeed, public health experts often caution that tobacco may be a gateway drug to marijuana (Dai et al., 2018). Biologically, if ENDS use leads consumers (in particular youth) to gain a taste for addictive substances, over time consumers may be induced to seek out more potent addictive substances that activate the brain's reward system. Relatedly, gateway effects may operate through social or behavioral channels. Use of ENDS may induce consumers to socialize with others who use substances, and these relationships may promote the use of harder substances such as marijuana or other drugs. Finally, for youth, since ENDS are prohibited and thus difficult to procure, they may purchase ENDS from the illegal market, which may facilitate access to other illegal drugs.

Despite often-voiced concerns on potential gateway effects by public health officials, credible causal evidence on the gateway hypothesis is decidedly mixed, with different studies reaching distinct conclusions on the direction and strength of this relationship (Etter, 2018). Early work in health economics notes the importance of "common factors" such that may induce the use of both tobacco products and other drugs (Farrell & Fuchs, 1982), indicating a limited role for direct gateway effects. Moreover, the literature assessing this pathway has largely focused on combustible cigarettes (described in Section 2.1).

With respect to harder (non-marijuana) drug use, increases in ENDS taxes could impact such use through similar pathways as outlined above for marijuana. That is, through economic complementarity or substitutability, income effects, social network effects, information shocks, or longer-term gateway/secondary spillover effects. However, we conjecture that such relationships, if present, are likely weaker as fewer youth and young adults consume harder drugs overall (Substance Abuse and Mental Health Services Administration, 2023), and joint use of these products is much less common: for example, just 1.1 percent of youth ages 12 to 18 years report past-month ENDS use and ever use of cocaine or heroin the State YRBS (described in Section 3.1). Previous clinical research also suggests much weaker associations between youth tobacco product use and harder drugs such as cocaine and heroin than with marijuana (Silveira et al., 2018).

2.6 Preliminary Prior Work and Our Contribution

In an extension to their main analysis of cigarette taxation (discussed above in Section 2.1), Anderson et al. (2020) also offer "preliminary analysis" (page 492) on the impact of the presence of a tax on ENDS products on marijuana use among teens, while also examining the impact of an ENDS tax on vaping and smoking. In particular, they find some evidence of economic complementarity; following the initial adoption of an ENDS tax, any use of marijuana among youth declines by 1.3 percentage points (6.6 percent) while there is no observable change in the probability of more frequent use.

Our study builds on this work in several important ways. First, Anderson et al. (2020) include a binary indicator for any ENDS tax, that is the authors do not leverage differences across states and over time in the intensity of the tax rate. Given the lack of uniformity in the mode in which states tax ENDS products and the extensive variation in the rate at which they are taxed (see Appendix Table 1), the binary measure may not fully characterize differences across states in their approaches to ENDS taxation. The current study, by capitalizing on a recent standardization approach developed by Cotti et al. (2021), is able to exploit variation in ENDS taxes while standardizing the comparison across states with different tax modalities and levels.

Second, we consider data through 2023 as compared to through 2017 in Anderson et al. (2020). Anderson et al.'s "preliminary analysis" was based on identifying variation from seven (7) states as compared to our analysis, which relies on 30 states. Moreover, in five (5) of the treatment states that identified the treatment effect in Anderson et al. (2020), there was only one year of post-tax data, whereas the vast majority of our treatment states include multiple years of post-treatment

data, allowing for an examination of treatment effect dynamics. Our analysis allows us to consider experiences from 23 additional states that adopted ENDS taxes between 2018 and 2023 and capture important shifts in the ENDS market. For example, in 2017, JUUL was by far the largest ENDS producer, but this company's share declined substantially following push-back from regulators, and other retailers have entered the market, diminishing the importance of JUUL. Consequently, teen ENDS use increased sharply through much of 2019 before declining sharply following (1) the EVALI outbreak, (2) the advent of and recovery from COVID-19, and (3) adoption of other state and federal policies such as a federal ban on all tobacco product sales for those under 21 years of age. In contrast, adult use of ENDS products has continued to rise.

Along the same lines, over the period 2018-2023, there have been important changes in the marijuana market, with states continuing to legalize access to cannabis for medical and recreational use. Over this period, marijuana use continued to rise among both youth and adult populations and the potency of marijuana also substantially increased (Hinckley & Hopfer, 2021; National Institute on Drug Abuse, 2024).

Third, to identify the effects of ENDS taxes, we use recently introduced difference-in-differences methods that are robust to bias associated with a staggered policy roll-out (Goodman-Bacon 2021). Reducing bias in two-way fixed effects (TWFE) estimates caused by heterogeneous and dynamic treatment effects may be important in this context.

Fourth, we widen the lens of Anderson et al. (2020) to study dynamic effects as well as various measures and margins of marijuana use. Disentangling shorter- vs. more longer-term effects along with the distinction among various margins of marijuana consumption is revealed to be important in understanding how ENDS taxes are affecting marijuana use. Additionally, we explore outcomes that measure non-marijuana substance use among teens and adults.

Finally, our analysis explores multiple pathways through which ENDS taxes may affect marijuana use, including economic complementarities, income effects, and secondary effects through shifts in demand of other substances (cigarette and alcohol use), which help further inform the inter-relationship between the demand for ENDS and demand for marijuana. In summary, we build on the preliminary analysis in Anderson et al. (2020) and provide among the most comprehensive evidence to date on adjacent spillover impacts of taxing ENDS markets on the demand for marijuana and other substances.

3. Data

Our empirical analysis draws on several national datasets, spanning the period from 2000 through 2023, to measure outcomes related to ENDS use, marijuana use, and harder drug use. The datasets include the State and National Youth Risk Behavior Surveys (YRBS), the Behavioral Risk Factor Surveillance System (BRFSS), and the Treatment Episode Dataset (TEDS). Each dataset offers advantages and disadvantages for addressing our research question, and these data collectively allow us to comprehensively examine the relationship between ENDS taxes and marijuana use as well as other illicit drug use.

3.1 State and National Youth Risk Behavior Surveys (YRBS)

Our primary data source to measure youth ENDS and marijuana use is the State YRBS, a pooled cross-sectional dataset spanning the years 2003 through 2023. These biennial surveys are coordinated by the CDC and are distributed to those attending 9th through 12th grades (in public and private schools) by state Departments of Health and Education. The State YRBS is a school-based survey that, when weighted, produces estimates that are representative of the health behaviors of each state's high school population and can be weighted to be representative of each state's 14-to-18-year-old population.[23] Because we analyze (primarily)[24] 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 a crucial strength of these data. We match the ENDS tax rate in effect based on when each state administered its YRBS, allowing us to identify the effects of tax changes for 25 of the 30 treatment states including three large localities in two states (see Appendix Table 1).[25] We note that because of the lack of data before and after their ENDS tax changes, Minnesota, Massachusetts, Ohio, Oregon, Washington, and the District of Columbia do not contribute to the identification of the effects in our analyses with the State YRBS.

We supplement these State YRBS analyses with the National YRBS, presenting estimates based on the combined YRBS. Questions on ENDS and marijuana use are conveniently identical

[23] The person-specific sample weights we generate make the sample representative of all 14-to-18-year-olds in the U.S. Our person-specific sample weights are calculated as the product of the normalized State YRBS person weight (renormalized to sum to one in each state-year) and the state-by-year-by race/ethnicity-by gender population data on 14-to-18-year-olds available from the National Cancer Institute's Surveillance, Epidemiology, and End Results Program (SEER). We use the detailed full population data that the National Cancer Institute provides alongside cancer-related information in SEER to construct our weights. The population data are based on Census data. Thus, our weights are based on the full population, not a subset of cancer patients.

[24] Three large localities (two counties and one city) have adopted ENDS taxes (see Section 2.3).

[25] Most states administer the YRBS in the spring term (January through June) of the academic year, and some states administer the survey in the fall (September through December). We use the survey timing (term of administration), provided by the CDC, to match the ENDS tax rate in effect in each state in each wave.

across the two datasets. Even though both surveys are coordinated by the CDC, they are, in the main, administered separately, though the CDC reports that there may be some overlap in high school students who are asked questions for the separate surveys comprising the State and National YRBS. One of the advantages of the National YRBS is that the sample is representative of the U.S. population of high school students. Moreover, using these data allows us to exploit tax policy changes in Minnesota for identification. Alternatively, the National YRBS does not include pre- and post-treatment data from Kansas, and thus we cannot exploit policy changes from this state. While the addition of the National YRBS sample to the State surveys does allow us to leverage additional variation from a potentially important high-tax state (Minnesota, the first state to impose an ENDS tax, and also D.C.), the use of National YRBS data may introduce measurement error when attempting to estimate the health effects of a state policy, as the survey is not designed to be representative of state-level trends in ENDS use, marijuana use, or hard drug use (see Maclean et al. (2023) for a discussion of this issue). Moreover, with the National YRBS being nationally representative (but not representative at the state level) and the State YRBS being state representative, construction and application of appropriate survey weights for the pooled data can be a challenge. We therefore focus on the State YRBS for our main analyses, but also confirm that incorporating the national data and Minnesota for identifying variation does not alter our main findings.[26]

To estimate the first order effects of ENDS taxes on nicotine vaping among U.S. high school students we pool data from the 2015-2023 surveys. Beginning in 2015 and continuing in each subsequent wave, respondents to the YRBS 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?"

[26]Alternately, using data solely from the National YRBS for analyses is less than ideal for at least two reasons. First, the sample size in the National data is less than a tenth of the sample size of the State YRBS. With youth and adults becoming more inelastic to tobacco taxes over time (a point that we discuss below and confirm for the effects of ENDS taxation as well), detecting first-stage and downstream spillover effects can be a noisy endeavor and requires large samples to maximize statistical power. Second, given that the National YRBS is not representative at the state-level, this can further introduce measurement error and confounding from changes in the state samples over the waves.

ENDS Use is set equal to one if the respondent reports using an ENDS at least once in the past 30 days; it is set equal to zero otherwise. We find that 18.7 percent of respondents in the State YRBS report prior month ENDS use.

Since information on marijuana use is reported in all waves of the YRBS, we turn to earlier YRBS waves pre-dating the adoption of the first statewide ENDS tax (in 2010 in Minnesota). We draw data on marijuana use behaviors from the 2003 through 2019 waves when respondents are asked:

"During the past 30 days, how many times did you use marijuana?"

Marijuana Use is set equal to one if the respondent reports using marijuana at least once in the past 30 days; it is set equal to zero otherwise. We find that 18.8 percent of respondents in the State YRBS report prior month marijuana use. If we examine heavier marijuana use, we find 12.3 percent of respondents in the State YRBS report consuming marijuana at least three times in the last month and 7.7 percent report consuming marijuana at least ten times in the last month.[27] Appendix Figure 1 shows trends in marijuana use over the sample period for the YRBS datasets.

In addition, the State YRBS provides some information on how youth typically consume marijuana. These questions are only available in the years 2015 and 2017 for four states,[28] but are descriptively useful in assessing possible mechanisms that could link tobacco and marijuana use among teens. Analysis of the survey responses (see Appendix Figure 2) reveals that among youth marijuana users, the vast majority (84.6 percent) consume marijuana by smoking it in joints, bongs, pipes, or blunts. Smaller proportions report consuming marijuana through edibles (8.8 percent), beverages (2.0 percent), vaporization (1.9 percent), or other unspecified methods (2.8 percent), though the prevalence of consuming marijuana specifically through vaping devices has been increasing in recent years (Harrell et al., 2022).[29]

With respect to harder (i.e., non-marijuana) drug use, YRBS respondents are asked whether they have ever consumed cocaine and whether they have ever consumed heroin. We use these "ever" questionnaire items because the share of prior month hard drug use among U.S. teenagers is uniformly under two percent (*Harder Drug Use*). In our analysis sample, 6.5 percent and 3.0 percent

[27] In the National YRBS, prevalence rates are 13.3 percent and 8.6 percent respectively.
[28] The states are Alaska, Hawaii, Nebraska, and Nevada.
[29] Among high-school seniors, data from the MTF Surveys indicate that past 30-day prevalence of vaping marijuana increased from 4.9 percent (2017) to 14.0 percent (2019) to 14.8 percent (2022) (Miech et al., 2023).

of youths report having consumed cocaine and heroin, respectively. For our difference-in-differences analysis of the ever-use measure of harder drugs, 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). Appendix Table 2 reports summary statistics.

As the ENDS market becomes more regulated over time (e.g., through minimum legal sales age restrictions, taxes, and bans on use in public places and sales), vapers may be less likely to accurately report their ENDS use in survey settings such as the YRBS and BRFSS. Such measurement error could lead us to inaccurately estimate the impact of ENDS taxes on vaping. Contrariwise, as states legalize marijuana use for medicinal and recreational purposes, and reduce criminal penalties, and so forth, we might expect that survey responders may be inclined to more accurately report marijuana use in survey settings. To the extent that any reporting biases in marijuana use are orthogonal to ENDS taxes, our main estimates of the spillover effects of such taxes on marijuana use behaviors should remain unbiased.

3.2 Behavioral Risk Factor Surveillance System (BRFSS)

To study adults, we supplement our analysis of the State and National YRBS with data from the Behavioral Risk Factor Surveillance System (BRFSS). The BRFSS is a large comprehensive telephone survey administered annually by the CDC that includes data on a broad range of health-related risk behaviors, chronic health conditions, and the utilization of preventive services among U.S. residents 18 years and older. The survey is specifically designed to provide a representative snapshot of health-related factors among all U.S. adults both nationally and at the state-level. We use information on adult ENDS consumption, focusing on individuals ages 18-to-20 (i.e., adults under the minimum legal purchasing age for marijuana), younger adults aged 21-30, and adults ages 31-and-older.

Similar to the YRBS, the BRFSS captures information on ENDS use but only within a limited time window. Specifically, information on ENDS use is only available from 2016-2018 and 2020-2023, and after 2018, questions on ENDS use are included as part of a module, with a subset of states including this module in their state surveys and collecting this information. Appendix Table 1 reports that all 30 treatment states and D.C. contribute identifying variation to our estimation of the ENDS tax effects in the BRFSS, though not all of these states appear in all years we consider.

Respondents are asked about their current "usage of e-cigarettes or other electronic vaping products," with response options categorized as "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. Prevalence of ENDS use decreases with age; specifically, data from the BRFSS indicate that approximately 15.6 percent of adults ages 18-to-20, 13.2 percent of adults ages 21-to-30, and 4.2 percent of adults ages 31-and-older report current consumption of ENDS. Appendix Table 3a reports summary statistics for BRFSS. An important limitation of the BRFSS data, however, is that they do not include information on marijuana use in the main survey frame across a large number of ENDS taxing and non-ENDS taxing states.[30]

A further limitation of the BRFSS data for studying ENDS use is that the survey does not record ENDS use in all years and for all states. ENDS use questions was initially added in 2016, and were fielded to all states. However, in 2017 and 2018, ENDS use questions were included outside the core modules (an optional module) and thus only a subset of states contributed ENDS use information available in those years. In 2019, no information on ENDS use was collected for any state. In 2020, ENDS use questions were again collected only for states choosing to participate in the optional module, and in 2021 through 2023, ENDS use questions were back in the core modules and fielded for all states. Appendix Table 3b shows the years and states in which ENDS use information is available in the BRFSS. Bold text shows the states and years in which an ENDS tax is in place. Thus, we have an unbalanced panel, and while we are able to leverage at least some variation in ENDS taxes across all adopting states (30 states + D.C.), not every single tax change in each of these states contributes identifying variation, which is a limitation of our analysis of the BRFSS.

3.3 Treatment Episode Dataset (TEDS)

To partly address the lack of consistent information on marijuana use behaviors for adults in the BRFSS and to widen the lens to other substance use, we turn to data on drug treatment admissions from the Treatment Episode Dataset (TEDS) spanning 2000 through 2022, which is the most recent year of data available. Drug treatment admissions likely capture heavier, more frequent, and problematic marijuana use than available in survey sources. The TEDS compiles client-level data for substance use disorder treatment admissions from state agency data systems. State systems collect data from facilities about their admissions to treatment and discharges from treatment. The Center for Behavioral Health Statistics and Quality of SAMHSA coordinates and manages the

[30] Beginning in 2016, marijuana use was added as an optional module in the BRFSS. Unfortunately, there are too few states with and without ENDS taxes that offer this module to their residents.

collection of TEDS data from U.S. states, territories, and Compact of Free Association partners. TEDS captures approximately two million admissions to outpatient, residential, and inpatient treatment each year.

Specifically, we use the TEDS-A dataset which collects information on substance use disorder treatment admissions for individuals who are 12 years old or older.[31] For each case, demographic information is included, such as age, sex, race/ethnicity, and employment status, as well as, substance use disorder characteristics, such as substances used, age at first use, route of use, frequency of use, and number of previous admissions. Each record reports up to three substances that lead to the treatment episode.[32]

To generate our state-by-year measure of "primary" marijuana-related admissions rate, we calculate the ratio of total primary marijuana-related admissions to the population (in thousands) for minors (those ages 12-17) and adults ages 18-and-older. We also measure "any" marijuana admissions as the ratio of marijuana admissions (whether marijuana was the primary, secondary, or tertiary drug mentioned) per 1,000 age-specific population. In regressions, we take the logarithm of admission rates to account for skewness, and thus coefficient estimates have the relative interpretation of an approximation to the percent change.

We also utilize the TEDS data to conduct analyses of admission flows for specific hard drugs, including cocaine, methamphetamine and heroin. Appendix Table 4 provides the means of drug treatment admission rates for each of these substances.

We note that drug treatment admissions largely capture heavier, frequent, and potentially problematic drug use, in contrast to reported drug use measures on the extensive margin in the YRBS. Moreover, while one may be concerned that social desirability bias may bias levels (or even trends) in substance use for youth, administrative data on a drug-related outcome will provide an alternative source of measuring substance use.

In regression analysis of the TEDS, we control for the overall drug treatment admissions rate among those 18 years and older (i.e., the rate per 1,000 state residents 18 years+). We control for this rate to capture the capacity of the drug treatment delivery system and differences in reporting to TEDS (Chu, 2015) across states and over time within states. Many states have excess demand for drug treatment, in particular drug treatment that is supported by public payers such as

[31] We use what is referred to as the TEDS-A, or TEDS admissions. The TEDS system also produces a discharge file (TEDS-D or TEDS discharges) consisting of discharge records that reports all information included in TEDS-A and (a) type of service at discharge, (b) length of stay, and (c) reason for discharge or discontinuation of service.
[32] A limitation of TEDS is that this list is not necessarily a complete enumeration of all substances used at admission.

the treatment captured in TEDS (Buck, 2011), and controlling for the overall rate allows us to proxy for both system capacity and for noted differences in reporting admissions to the TEDS system.

3.4 ENDS Taxes

The main policy variable of interest in this study is the ENDS tax rate in 2023 dollars (we inflation-adjust the tax rate using the Consumer Price Index). We use an updated version of the standardized measure of the ENDS tax per fluid ml for closed-systems more commonly used by youth (Birdsey, 2023) produced by Cotti et al. (2021) that allows comparability across states and over time.[33] The standardization in terms of the nicotine-containing e-liquid is based on the premise that the demand for all tobacco products is a derived demand for nicotine (Lillard, 2020).

When there is a local ENDS tax set above and in addition to the state ENDS tax, our ENDS tax measure is set equal to the sum of the products of the local binding tax and the share of the state population covered by each tax following previous studies (Abouk, Courtemanche, et al., 2023; Dave et al., 2024); Chuo et al. (2024). Figure 1 and Appendix Table 1 show the rollout of ENDS taxes in the U.S. between 2010 and 2023, along with the magnitude of these increases.

4. Empirical Strategy

We begin our analysis by estimating a two-way fixed effects (TWFE) regression of the following form using individual-level repeated cross-sectional data from the State YRBS, the National YRBS, and the BRFSS:

$$Y_{ist} = \gamma_0 + \gamma_1 ENDS\ tax_{st} + X_{ist}\beta + Z_{st}\delta + \alpha_s + \theta_t + \varepsilon_{ist}, \quad (1)$$

where *i* indexes the individual survey respondent, *s* the state and *t* the year of the survey. Y_{ist} denotes our outcomes of interest (ENDS use, marijuana use, and harder drug use) for individual *i* in state *s* in survey wave *t*. The primary independent variable of interest is $ENDS\ tax_{st}$ which is the ENDS tax rate per fluid ml measured in 2023 dollars. The vector X_{ist} includes a set of individual controls, including gender, age, grade-in school (YRBS) or educational attainment (BRFSS), and race/ethnicity. Z_{st} is a vector of state-level variables including macroeconomic controls (the unemployment rate, the poverty rate, and deaths from COVID-19), tobacco policies (T-21 law,

[33] We thank Chad Cotti and Erik Nesson for sharing an updated version of the tax data with us.

combustible cigarette excise tax, ENDS MLSA, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, flavor bans, and ENDS licensure laws for retailers), and policies related to substances that could complement or substitute for the demand for ENDS or marijuana (beer taxes, recreational and medical marijuana laws, naloxone access laws, and must access prescription drug monitoring programs).[34] In addition, α_s is a time-invariant state effect, and θ_t is a state-invariant year-semester effect.[35] Regressions are weighted to be representative of U.S. teenagers in the State YRBS.[36]

Our ENDS tax measure and each of our right-hand side control variables are measured at the state-by-year-quarter level. We match this external information to the YRBS records based on when the survey was fielded; the National YRBS is fielded in the Spring semester, and hence we match data based on the average of the first two quarters of the survey year. For the State YRBS, some states administer their surveys in the Fall, in which case we match data based on the average of the last two quarters of the survey year. For the BRFSS, we have information on the survey month and thus match by state-year-quarter. In all regressions, standard errors are clustered at the state level (Bertrand et al., 2004).

Our key parameter of interest, γ_1, captures the reduced-form relationship between ENDS taxes and ENDS, marijuana, and harder drug use. The identifying variation that we use to estimate tax effects comes from both within-state introduction in and changes in the level of ENDS taxes.[37]

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[34] Sources for our state-level controls are: unemployment and poverty rate (Hansen et al., 2023); COVID-19 deaths (New York Times, 2023); T-21 laws (Hansen et al., 2023); flavor bans (Cotti et al., 2024); cigarette taxes and other tobacco control policies (Centers for Disease Control and Prevention, 2023); beer taxes (National Institute on Alcohol Abuse and Alcoholism, 2023); marijuana policies (Dave et al., 2023); and opioid policies (Prescription Drug Abuse Policy System, 2023).

[35] We obtain, through a special request to the CDC, information on the year and semester (spring or fall) in which the YRBS survey is fielded. In some cases, the year in which a youth completed the survey is different from the year of the YRBS survey, for example in the 2017 YRBS, some youth report data in 2017 and some in 2018. As described earlier in the manuscript, some interviews occur in the spring semester and some in the fall. While we have information at the month-year level in the BRFSS, to estimate similar regressions across these data sets, we construct year-semester fixed effects in the BRFSS, that is we code interviews that occurred in January through June as "spring" interviews in the BRFSS and those that occur in July through December as "fall" interviews. In the TEDS data, we have only year of admission and thus are not able to construct parallel time fixed-effects.

[36] As discussed below, in our analysis of the BRFSS, our preferred estimates are unweighted because our sample is stratified by respondent's age, and the use of BRFSS weights may not generate nationally representative estimates for sub-populations and could introduce measurement error; though, we also experiment with weighted regression using survey weights provided by the CDC.

[37] For two states, Illinois and Maryland, the within-state variation is generated by local taxes adopted by large localities (two counties and one city). One concern with analysis of ENDS taxes is that these taxes may be highly correlated with other tobacco control policies (Maclean et al., 2018) and state characteristics, which might impact our ability to isolate independent variation in these taxes. To explore this possibility, we regress ENDS taxes on other state policies, state fixed effects, and year fixed effects. The R-squared from this regression is 0.70 ~ 0.76, which implies a variance-inflation factor of 4.2. Adding the vector of tobacco control policies increases this R-squared to 0.80 ~ 0.85, implying a variance-

The estimate of our treatment effect will only be unbiased in the absence of (1) state-specific time-varying unobservables correlated with ENDS taxes and the outcomes, (2) reverse causality, and (3) the control states serving as a credible set of counterfactuals for the substance use trend that would have evolved in the absence of an ENDS tax increase.

One descriptive test of the common trends assumption that we undertake is an event study. We employ the approach developed by Schmidheiny and Siegloch (2023) and Rees et al. (2021) for specifying an event study for a continuous treatment variable and estimate the following regression:

$$Y_{ist} = \gamma_0 + \sum_{j=-\underline{J}}^{-1} \pi_j D_{st} + \sum_{j=0}^{\bar{J}} \emptyset_j D_{st} + X_{ist}\beta + Z_{st}\delta + \alpha_s + \theta_t + \varepsilon_{ist}, \qquad (2)$$

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*. Event time *j* = -1 to -2 (one two years before the treatment event) is omitted to normalize the estimates of π_j to zero in that wave. If the estimates of π_j are small and statistically indistinguishable from zero, this pattern of results would support the common trends assumption. We estimate the leads for 3-4 years prior to treatment, 5-6 or more years prior to treatment; we estimate lags for 0-1 years (year of adoption to one year after adoption), and 2-3 years following treatment. "Endpoints" for 7 or more years prior to an ENDS tax increase and 4 or more years following an increase are also estimated for completeness (but suppressed from presentation due to being identified off of a smaller, and quite different, set of treatment states).

An important concern with our TWFE estimates (including those used to generate event study coefficients) is that, in the presence of heterogeneous and dynamic treatment effects, estimates of γ_1 in equation (1) and π_j and $\emptyset_j$ in equation (2) may be biased (Goodman-Bacon, 2021; Sun & Abraham, 2021). To account for this possibility, we implement a stacked difference-in-differences regression (Cengiz et al., 2019) that in a continuous treatment staggered-adoption framework makes it possible to control not only for the presence of the tax, but also for 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 (six years prior to the adoption of the tax and two

inflation factor of 6.7, still leaving sufficient variation to identify the ENDS tax effects; thus, about 15 to 20 percent of the observed variation in ENDS taxes represents conditional within-state variation that we are exploiting to estimate the treatment effects (Kennedy, 2008).

years following adoption of the tax), that mitigates concerns related to differential treatment variance weights given to each treated unit in the standard difference-in-differences estimation. 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 choice of counterfactuals ensures that two-way comparisons of "later versus earlier" adopting states are eliminated from the estimated treatment effect. 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:

$$Y_{icst} = \gamma_0 + \gamma_1 ENDS\ tax_{st} + X_{ist}\beta + Z_{st}\delta + \alpha_{cs} + \theta_{ct} + \varepsilon_{icst}, \quad (3)$$

where *c* denotes the cohort. α_{cs} is cohort-specific state effects, and θ_{ct} is a cohort-specific survey wave effect. We also estimate event studies based on the stacked difference-in-differences regression approach, decomposing the treatment effect over time.

Following the above analyses of individual-level ENDS, marijuana, and harder drug use in the YRBS and ENDS use in the BRFSS, we next turn to state-level data on treatment admissions for substance use disorders from the TEDS and estimate models of the following form:

$$Y_{st} = \delta_0 + \delta_1 ENDS\ tax_{st} + X_{st}\beta + \alpha_s + \theta_t + \varepsilon_{st}, \quad (4)$$

where *s* indexes the state and *t* the year. θ_t is a vector of year fixed effects and α_s represents the vector of state fixed effects. The list of state-specific, time-varying controls in vector $\mathbf{X}_{st}$ includes those described above in addition to demographic variables, including proportion of males, Hispanics, and Blacks. Regressions are weighted using the age-specific population to recover the treatment effect for the average treated individual.

We report the impact of a one-dollar increase in the ENDS tax rate as this is a common dose within the tobacco control literature, allowing us to facilitate comparison with earlier work. However, we realize that, given the range of taxes currently in place in the U.S., a one-dollar increase in the tax is non-trivial in size. As a result, we also convert our effect sizes into estimated elasticities and effects standardized for a one standard deviation increase in the tax rate, as alternate means of comparison and gauge of the effect magnitude.

5. Results

In Section 5.1, we report findings for ENDS and marijuana use among teens utilizing data from the YRBS. Section 5.2 discusses findings for adult vaping based on the BRFSS. An exploratory analysis of some potential mechanisms is reported in Section 5.3, and in Section 5.4 we report ENDS tax effects on harder drug use and heavier measures of marijuana use from the State YRBS and TEDS data.

5.1 YRBS Findings on ENDS Use and Marijuana Use

ENDS Use. Table 1 presents estimates of the own-tax response of ENDS use among U.S. high school students. We begin in panel I with the State YRBS, our primary dataset for analysis of youth substance use. Controlling for state fixed effects, period fixed effects, and individual demographic characteristics (age, gender, race/ethnicity, grade in school), we find that a one-dollar increase in the ENDS tax leads to statistically significant 1.8 percentage-point decline in prior-month e-cigarette use among U.S. high school students (column 1). The inclusion of macroeconomic controls (state unemployment rate and 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 excise taxes on cigarettes, indoor smoking restrictions, indoor vaping restrictions, bans on flavored e-cigarettes, and ENDS licensure laws) increases the absolute magnitude of the estimated treatment effect to indicate a decline of 2.9 percentage points.

In our preferred, fully saturated specification (column 6), which also includes controls for alcohol and marijuana as well as non-marijuana related drug policy controls (medical and recreational marijuana laws and beer taxes, naloxone access laws, and mandatory must access prescription drug monitoring programs), we find that a one-dollar increase in e-cigarette taxes is associated with a similar statistically significant 2.9 percentage-point decline in e-cigarette use. To place this effect magnitude in context, this corresponds to a 14 percent decline in ENDS use relative to the baseline mean of ENDS use in the treatment states.[38] Alternately, standardizing the treatment dose to a one standard deviation increase in the ENDS tax rate implies a 1.3 percentage point (six percent)

[38] In supplementary analyses (Appendix Table 5), we examine whether certain margins of ENDS use, that is frequent (≥ 20 days in the past month) or daily ENDS use, are more or less responsive to ENDS taxes. These results indicate that higher ENDS taxes are effective in significantly reducing both frequent and daily use of ENDS products as well as infrequent or non-daily use. The effect magnitudes across these margins imply that about a third to 40 percent of the own-tax response on ENDS participation (Tables 1 and 2) is coming from a decrease in frequent use and the remainder (approximately 60 percent to two-thirds) is driven by a decline in participation in infrequent and non-daily use.

reduction in youth ENDS participation.[39] The estimated own-tax elasticity for ENDS use is -0.08.[40] While these findings corroborate that ENDS taxes have their intended effect of reducing youth vaping, the magnitude of the own-tax response is smaller than previously estimated (Abouk, Courtemanche, et al., 2023). We attribute this moderation in the own-tax response to our application of more recent post-pandemic data, which suggests that youth consumption of ENDS may have become more inelastic over time.[41]

In panel II, we also present results using the combined YRBS. Across specifications, the pattern of results continues to demonstrate 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 1.3 to 2.6 percentage-point decline in prior-month ENDS use among U.S. high school students.

In order to test for differential pre-treatment trends, we follow two approaches. First, as reported in Table 2, we include leads of the ENDS tax rate in our baseline specification (equation 1). These leads are statistically insignificant with close-to-zero magnitudes, and the main effect of the tax remains virtually unchanged (indicating two to three percentage-point reduction), for both the State YRBS and the combined YRBS samples. Second, we implement a continuous version of an event study analysis based on equation (2), decomposing the main treatment effect into a series of leads and lags (Figure 2, panels a & b). The panel data used in our analysis provides a sufficiently long timeframe to capture pre-treatment and post-treatment trends (2015-2023). We find no evidence that ENDS use is declining (or increasing) faster in treatment as compared to control states before changes in the ENDS tax rate; the lead coefficient estimates are close to zero, and declines in ENDS use materialize only after a state has increased the tax.

In the presence of heterogeneous and dynamic treatment effects, our coefficient estimates in the TWFE and event study analyses could be biased. To address this issue, we implement an event

[39] When a state or locality has adopted or raised the ENDS tax, the average amount of the increase (in 2023 $) has been approximately $0.58 per ml of e-liquid. Scaling the treatment dose to this increase implies a decrease in youth ENDS use by about 1.7 percentage points.

[40] We compute the tax elasticity ε_{Tax} as $\gamma_1 \cdot \mathbb{E}(x)/\mathbb{E}(y)$, where $\mathbb{E}(x)$ and $\mathbb{E}(y)$ are calculated using data points from the treated units over the sample period. Thus, this measure of the elasticity corresponds to the average treatment effect on the treated (ATT). The price elasticity can be imputed from the tax elasticity as: $\varepsilon_{Price} = \varepsilon_{Tax}$ * (1/tax pass-through) * (1/share of tax in the price). The tax pass-through rate is almost 1-to-1 (estimated as 0.9 in Cotti et al., 2022), and ENDS taxes comprise about 21 percent of the observed retail price (see Abouk, Courtemanche, et al. (2023)). Under these considerations, the implied own-price elasticity of ENDS use for youth is 0.42.

[41] In comparison, Abouk, Courtemanche, et al. (2023)), using YRBS data through 2019, estimate an own-tax response of -0.071 (7.1 percentage point decline associated with a one-dollar increase in the ENDS tax rate) and an elasticity of -0.164. We confirm that when we restrict analyses through 2019, we obtain very similar point estimates (-0.066 ~ -0.076) and implied elasticity estimates (approximately -0.15 ~ -0.20). A similar diminution of the own-tax response for youth cigarette smoking over time has also been documented in the literature (Anderson et al., 2020; Hansen et al., 2023).

study from a stacked difference-in-differences estimator where we select an approximately balanced event time window (three waves prior to tax enactment and one wave following enactment) and limit the set of counterfactual states to those that never implemented ("never adopters") and have not-yet adopted an ENDS tax ("not-yet-adopters"). As before, our findings (reported in panels c and d, Figure 2) continue to show that a decline in ENDS use manifests only after the implementation of an ENDS tax increase. [42] Moreover, flat pre-treatment trends add a degree of confidence to our choice of counterfactuals and help validate the parallel trends assumption.[43]

Marijuana Use. We next turn to our key spillover outcomes for youth and focus on the State 2015-2019 YRBS dataset in Table 3. Panel I shows estimates of the effect of ENDS taxes on ENDS participation using an overlapping sample of YRBS respondents that provide non-missing information on both ENDS use and marijuana use. The findings in panel I are quantitatively similar to those reported in Table 1. In panel II, we find strong evidence that marijuana use is negatively related to higher ENDS taxes. The results in panel II suggest that a one-dollar increase in ENDS taxes leads to a 1.3 to 1.4 percentage-point reduction in prior-month marijuana use among U.S. high school students.[44] Relative to the baseline prevalence of marijuana use in the treatment states, these effects correspond to a seven to eight percent reduction in marijuana use.[45]

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

[43] One limitation of conventional pre-trends tests in the context of an event study analysis is that they may be low-powered (Roth, 2022). Alternately, we present pre-treatment trends in our key outcomes (ENDS use, marijuana use, and hard drug use; see Appendix Figures 3-5 respectively for each outcome) separately across treated states (states that have adopted a high ENDS tax, defined as a tax rate above the median of ~ $0.52 per ml of e-liquid) and non-treated states (defined as states that do not adopt an ENDS tax and those that adopt taxes below the median value). While expectedly noisy, both unconditional and conditional trends (adjusted for fixed effects and tobacco control policies) track fairly similarly across the treated and non-treated states prior to the adoption of a high ENDS tax; we do not find any compelling indication that substance use outcomes were increasing or declining relatively faster in states that adopted the ENDS tax. We view this weight of the evidence across the standard and stacked difference-in-differences event study analyses, lead effects that are close to zero in magnitude (in Table 2 and the event study analyses), robustness of our main treatment effects to controlling for the lead tax effects, and similarly evolving unadjusted pre-treatment trends (Appendix Figures 3-5) across high tax states and control states as reassuring in support of the credibility of the counterfactual assumption.

[44] These equate to a cross-tax elasticity of between -0.037 and -0.041, roughly half of the own-tax elasticity. Estimates for past month marijuana use, based on the combined YRBS (Appendix Table 6), suggest similar spillover responses, on the order of a significant 1.1 to 1.3 percentage point decline.

[45] In Appendix Table 7, we report coefficient estimates for the other included ENDS-related policies from our main specification (Table 3, panel II, model 6) in order to facilitate cross-comparison of the treatment effect for different ENDS-related regulations. Comparing these coefficients with the ENDS tax effect underscores three points. First, only the impact of the ENDS tax on youth marijuana use is statistically significant; for all other ENDS regulations, we cannot reject the null of no effect. Second, while some of the coefficient magnitudes for a few other policies (e-cigarette MLSA, online shipments ban, T-21 law) appear similar to that for ENDS taxation (one to two percentage points), these are not directly comparable due to differences in measurement and the treatment dose; when standardizing the treatment dose

Since information on marijuana use is available over a broader time frame, in panel III, we replicate the marijuana analysis by extending the sample period back from 2003 through 2023. The results remain very similar, as we continue to observe a consistent negative relationship between ENDS taxes and marijuana use. This alignment of findings suggests a complementary relationship between these two substances among teens. Further, we note that the estimated second-order treatment effects on marijuana use, from our preferred specification (column 6 of panels II and III), show an effect size that is about 50 to 60 percent smaller than the "first stage" effect on ENDS use (column 6, panel I, Table 1), thus suggesting that our estimated spillover effect sizes that are plausible.

The reduced form estimates of e-cigarette taxes on marijuana use in Table 3 represent the average causal response, which is the continuous analog of an "intention-to-treat" (ITT) effect. If we assume that the only pathway through which these taxes would impact marijuana use is through a change in e-cigarette use, then we can derive a crude version of "treatment-on-the-treated" (TOT) by taking the ratio of the estimates in Table 3 to the first stage effects in Table 1. Doing so suggests an "average causal response on the treated" of around 0.38 to 0.49. Thus, for about every two to three e-cigarette users who are deterred from vaping nicotine due to higher e-cigarette taxes, one of them is also deterred from using marijuana. That this "marginal" effect (0.38 ~ 0.49) is similar to the "average" effect (0.48 based on the 2019 YRBS; about one out of two past-month e-cigarette users also used marijuana) is ex post validating. These "TOT" imputations should be interpreted with caution and are meant to be suggestive, since they assume that all channels from a change in e-cigarette taxes load through the first-stage effect on e-cigarette use; if there are other independent pathways, notably income effects or information signals conveyed in the taxes (which we assess and largely rule out), then the imputed "TOT" effects would be an over-estimate.

Addressing any potential bias stemming from group-specific and dynamic heterogeneity, Table 4 presents findings from a stacked difference-in-differences regression model. Treatment effects derived here are strikingly consistent with our TWFE estimates. In our fully saturated

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to a one standard deviation increase or to an elasticity, ENDS taxes appear to have the largest spillover impact on youth marijuana use. Third, the insignificant effect of T-21 laws on marijuana use is in contrast to the results reported in Hansen et al. (2023) who find preliminary evidence that these access restrictions generate some spillover complementary declines in marijuana use among youth. Notable differences in the sample may be driving this disparity in results; Hansen et al. (2023) document effects on marijuana use only for the sub-sample of 18 year old high school students and limit their analyses to pre-pandemic periods through 2019. Recent years have seen a multitude of additional access restrictions (bans on the sales of flavored ENDS products, bans on online shipments, strengthening of ENDS licensure laws) and a federal T-21 law which may interact with age-based restrictions focused on youth and young adults and lead to heterogeneous effects.

specification, our findings indicate that a one-dollar increase in ENDS taxes leads to a 1.5 percentage-point (eight percent) reduction in marijuana use among teens.

Figure 3 depicts the results of formal event study analyses. Encouragingly, an examination of the pre-treatment trends for marijuana use supports the validity of the common trends assumption, which holds true for both the TWFE (panels a & b) and stacked difference-in-differences (panels c & d) models. Our findings show that a decline in marijuana use between treatment and control states becomes evident following the implementation of an increase in taxes on ENDS products.[46]

Given the "first stage" and spillover effects described above, it is not surprising that when we explore the impact of ENDS taxes on the *joint* behaviors of past month ENDS use and marijuana use, we find consistent evidence of substantial declines in these joint behaviors. Specifically, in Table 5 (panel I), our preferred specification (column 3) shows that a one-dollar increase in ENDS taxes leads to a 1.6 percentage-point (15 percent) reduction in the probability of co-using ENDS products *and* marijuana in the past month. In panels II and III, we assess effects on other margins of co-use in order to inform which ENDS users (light/infrequent or heavier users) are reducing their consumption of marijuana following ENDS tax increases. Interestingly, we find that the decline in marijuana use is driven by co-use of marijuana with both lighter (panel II) and heavier (panel III) ends use. Specifically, a one-dollar higher ENDS tax rate leads to a 1.9 percentage point (11 percent) reduction in co-participation in lighter ENDS use and marijuana use, and an approximately one percentage point (32 percent) reduction in co-participation in marijuana use with heavier ENDS use. The larger relative effect in the latter case may reflect sort of a "dose-response" relation, in that the pathways which may link ENDS use with marijuana use (social, biological, and economic) may be more magnified for more frequent/heavier ENDS users; it is also possible that the income effect from higher taxes may present a larger bite for more frequent ENDS users, a point that we assess below.

Robustness Checks. We conduct a series of checks to ensure that our main findings are not sensitive to alternate specifications, samples, controls, and modeling assumptions. First, we assess the importance of cross-border spillovers due to differences in ENDS taxes across neighboring states, by controlling for border state ENDS taxes in two ways: i) the average tax among bordering states; and ii) an indicator for whether any neighboring state has an ENDS tax in place and zero otherwise. Our results are not sensitive to controlling for border effects; in our preferred TWFE

[46] We have tested whether the two lag variables are equal and we do not reject the null in any specification.

regression specification, we continue to find a significant decline in youth marijuana use, on the order of 1.1 to 1.4 percentage points. Second, we control for the general sales tax in effect in the state Tax Policy Center (2023) to account for cross-state differentials in the final cost to consumers, given that tobacco products are subject to the state's sales tax in addition to any tobacco-specific taxes. Again, our results remain virtually unchanged to adding these measures to our specification.

Third, in order to identify dynamics in the policy response over a longer post-treatment period, we estimate event study models, focusing on a set of early-adopting ENDS tax states (specifically, states that adopted or increased their ENDS taxes in 2019 or earlier) and drawing on the never adopters for a counterfactual. For these early adopters, we are able to identify responses for four or more years post-treatment. Event study analyses (shown in Appendix Figure 6) uncover two interesting points. First, while there is a marked decline in youth ENDS use following an increase in the ENDS tax, this response appears to moderate over the longer term. Specifically, we find that a higher ENDS tax significantly reduces ENDS use by between 3.1 and 4.1 percentage points through the first year post-treatment and by slightly less (between 2.1 and 3.6 percentage points) two to three years post-treatment; after four or more years on average, however, the effect diminishes to 1.3 to 2.9 percentage points (Panels a and b).[47] This moderation in the own-tax response over time is consistent with our earlier discussion comparing elasticity magnitudes from prior work (based on older or pre-pandemic data) compared to the estimates from this study.[48] Second, expectedly, as the own-tax response moderates over the longer term, so do the spillover effects on marijuana use (Panel c and d). The strongest impact on marijuana use materializes about three years post-treatment (approximately 2.1 percentage-point decline), which then diminishes substantially after four years and becomes statistically insignificant.

Fourth, in addition to testing effects for a continuous measure of the ENDS tax, which imposes a linearity assumption in the treatment effect, we undertake supplementary analyses to assess non-linear responses in the intensity of the tax. To do so, while retaining sufficient density in the treatment categories, we re-specify the ENDS tax with a series of binary indicators capturing whether a state has enacted a high (tax rate exceeding the median), low (tax rate is positive but at or below the median), or no ENDS tax. These models indicate some evidence of non-linear effects.

[47] Confidence intervals for the lagged treatment effects overlap, and we cannot reject the null of equal-sized tax responses across the different post-treatment windows reported.

[48] The longer-term moderation uncovered in this analysis of early adopters is consistent with consumers potentially becoming more adept at tax avoidance strategies over time or with the most elastic consumers in the market being selected out as ENDS taxes increase and thus leaving a pool of relatively more inelastic ENDS users over time.

Low ENDS tax rates do not have any bite; effects are invariably close to zero and statistically insignificant in most cases. Rather, it is when a state or locality imposes a high ENDS tax or increases the tax rate by a substantial amount (exceeding $0.52 per ml of e-liquid) that elicits the strongest response from youth consumption. Specifically, we find that high ENDS tax rates are associated with a 3.1 to 3.4 percentage point (15 ~ 17 percent) decline in ENDS use and a complementary 1.1 to 1.4 percentage point (six ~ seven percent) decline in marijuana use.[49]

Fifth, we examine demographic heterogeneity in ENDS tax impacts (Figure 4) by estimating separate models for boys and girls; Whites, Blacks, and Hispanics; and younger (less than 18 years) and older (18 years and older) youth. Overall, these stratifications suggest that the probability of using marijuana declines in all groups post-tax hike. While confidence intervals overlap, preventing us from drawing strong conclusions about differential effects across groups, we note that the absolute effect size is particularly large among white youth and that ENDS taxes do not appear to alter marijuana use propensities among Black youth.[50] Taken together, the weight of the evidence from our main and supplementary YRBS-based findings provide strong evidence of complementary spillover effects of ENDS taxes on marijuana use for most youths.

Finally, we explore policy interactions. In particular, we interact ENDS taxes with a metric capturing marijuana legalization in the state. We code states that have either adopted a recreational marijuana law or a medical marijuana law as one and all other states as zero. Thus, we are capturing any legalization of marijuana for recreational or medical purposes by states.[51] Through this analysis, we find that the decline in marijuana use which follows higher ENDS taxes appears to be largely driven among states where access to marijuana, for recreational or medical purposes, is more restricted (Appendix Table 8)

5.2 BRFSS Results on Adult ENDS Use

[49] TWFE and stacked difference-in-differences event study analyses based on a dichotomous "high tax rate" treatment measure are qualitatively similar to those based on the continuous ENDS tax rate. Pre-treatment trend differentials are close to zero and statistically insignificant, and declines in ENDS and marijuana use become evident only after the adoption of the (higher) ENDS tax. Analyses of early adopters, based on the dichotomous "high tax rate" treatment also show a very similar pattern to those discussed above for our main continuous tax measure, with some indication of own-tax and spillover effects moderating over the longer term.

[50] While marijuana use is largely similar among Black and non-Hispanic White youth, ENDS use is lower among Blacks. In our prior work (Abouk, Courtemanche, et al., 2023), we have also found the first-stage impact of ENDS taxes on ENDS use to be substantially lower among Blacks, which can explain the absence of further downstream effects.

[51] Of note, to date, all states that have legalized recreational marijuana previously legalized medical use of this product, but all marijuana laws prohibit possession among those under 21 (recreational) or 18 to 21 (medical). Thus, while marijuana access has been expanded in liberalizing states, youth possession remains illegal.

Next, we delve into the effects of ENDS taxes on ENDS use among adults, with particular attention to those younger and older than the MLSA (i.e., age 21). For younger adults ages 18-to-30 (Table 6, panel I), we find that a one-dollar increase in ENDS taxes leads to a statistically significant 0.8 to 1.1 percentage point decline in prior month ENDS use, which translates to a six to nine percent decline relative to the pre-treatment mean. Similarly, for everyday ENDS use, we find that a one-dollar increase in ENDS taxes is associated with a statistically significant 0.6 to 0.8 percentage point reduction, translating to a 11 to 15 percent decline.

When we further differentiate these younger adults based on the MLSA cut-off, we find estimated tax effects that are somewhat larger for those aged 18-20 (panel II) as compared to those aged 21-30, though we cannot reject the hypothesis that the estimated effects are statistically equivalent. We find that higher ENDS taxes by one dollar are associated with a 0.8 to 1.6 (0.8 to 1.1) percentage-point reduction in current (daily) ENDS use among 18-20-year-olds compared with a 0.8 to 1 (0.5 to 0.7) percentage point reduction in current (daily) ENDS use among 21-30-year-olds.[52] Turning to older adults (panel IV), we find no statistically significant evidence across any of the specifications that ENDS taxes are effective at reducing ENDS use among those over age 30.[53]

These estimates underscore two points. First, overall, they indicate potential moderation in the tax response with the extension of the study period to the post-pandemic years, consistent with hypothesis that the young adult population's ENDS use is also becoming relatively more inelastic over time. Second, the weaker tax response among younger adults and the null response among older adults suggest that any spillover effects of ENDS taxes on marijuana (and other substances) are likely to be concentrated among teens and perhaps young adults.[54]

5.3 Mechanisms

Our finding that ENDS taxes reduce marijuana use could be driven by several channels (see Section 2.4). In this Section, we attempt to shed light on some of these potential mechanisms.

[52] These effects translate into own-tax elasticity estimates for ENDS use (daily ENDS use) of -0.026 to -0.054 (-0.068 to -0.096) for young adults ages 18-20, and -0.032 to -0.042 (-0.021 to -0.030) for those ages 21-30 years of age, with the saturated models indicated tax responses at the lower end of these ranges. While Pesko et al. (2020) do not directly report ENDS tax elasticity estimates, for comparison, their point estimates combined with the reported means imply an approximate own-tax elasticity of -0.067 for current ENDS use and -0.063 for daily ENDS use for adults under 40 years of age, using data through 2018.

[53] We formally tested for equality of the treatment effects across panels II and III and were unable to reject the null.

[54] Appendix Table 9 reports BRFSS analysis using survey weights provided by the CDC, with estimates that are largely similar albeit less precise compared with those discussed here.

In prior work using data from the state and national YRBS and MTF through 2019, a one-dollar increase in ENDS taxes has been shown to lead some youth to substitute into smoking, thereby raising youth smoking by about one percentage point (Abouk, Courtemanche, et al., 2023). Updating this prior work for our extended YRBS study period through 2023 (Appendix Table 10), we find a similar 0.9 to 1.1 percentage point increase in smoking, with some indication of a magnified response over time, based on the combined YRBS analyses (Panels III & IV). Point estimates based on the state YRBS analyses (Panels I & II), in contrast, indicate much weaker and imprecise effects on smoking participation (0.5 to 0.7 percentage points) in the more parsimonious specifications, and no significant or meaningful effects in our preferred specifications. This difference could partly be driven by the combined YRBS analyses being able to leverage additional high ENDS tax states for identification (i.e. MA, MN, OR, DC; see Appendix Table 1), which may generate stronger downstream responses and greater precision in these estimated responses.

As described in Section 2.1, most of the prior causal evidence (relying on tobacco policy variation over earlier periods) points to cigarettes and marijuana use being economic complements. In this context, our results suggest that the reduced demand for marijuana generated by reduced ENDS use more than offsets any (potential) complementary increase in marijuana consumption that may be driven by higher smoking. A priori, the net effect of ENDS taxation will be determined by these two channels – direct effects generated by changes in vaping and secondary effects generated by changes in smoking (or other substances). Given that the first-order effects of ENDS taxes on ENDS use are several orders of magnitude larger than the second-order effects of these taxes on smoking, the dominant channel would expectedly operate through the link from reduced vaping through its relations with marijuana.[55]

Nevertheless, we investigate this relationship more directly, by assessing how ENDS taxation is impacting co-use of cigarettes and marijuana (panels IV and V in Table 5). Estimates in panel IV suggest a small but statistically insignificant decline in the co-consumption of cigarettes and marijuana, substantially smaller than the decline in the co-use of ENDS and marijuana (panel I). The decline identified in panel IV, however, may still capture primary shifts through changes in the demand for vaping and is an imperfect test. Analyses in panel V subsequently exclude vapers from the sample, thereby isolating potential effects on marijuana use that may operate solely from ENDS

[55] Assuming a structural causal effect of smoking on marijuana use of about 0.25 to 0.57 (Dee, 1999), consistent with economic complementarity, this would imply that the secondary channel (ENDS taxes increase smoking by one percentage-point) would at most lead to approximately a 0.25 to 0.57 percentage-point increase in marijuana use, in which case our estimated effects (1.1 to 1.4 percentage points) are net of this pathway.

tax-induced changes in cigarette smoking. While excluding vapers likely leads to a selected sample, we find no significant or meaningful effects on co-participation in smoking and marijuana use for this group. Overall, we interpret the weight of this evidence to suggest that any spillover effects on marijuana use through ENDS tax-induced secondary effects on smoking behaviors are negligible.

Recent work has also highlighted important spillovers of ENDS taxation on problem drinking behaviors among youth (Dave et al., 2024), thus secondary effects on marijuana use may potentially operate through these tax-induced decreases in alcohol consumption.[56] In panels VI and VII, we explore the strength of these secondary alcohol-driven channels by assessing co-use of alcohol consumption and marijuana, and again do not find these effects to be substantial enough to be able to explain our main effects on marijuana consumption.

ENDS taxes may lead to a reduction in marijuana use through the "income shock" – a reduction in the nominal purchasing power of teens and young adults' nominal income levels – caused by higher ENDS taxes. To this end, we perform a back-of-the-envelope calculation for teens – the age group for whom e-cigarette use is the most prevalent and for whom we also find the largest spillover reductions in marijuana use – to gauge how much of the estimated effect on their marijuana use can be attributed to the negative income shock. We calibrate this analysis based on observed average spending on ENDS products and income levels among youth, estimates of the income elasticity of marijuana for teens, and the price pass-through of ENDS taxes from the literature (Chaloupka et al., 1999; Cotti et al., 2022).[57] Under the premise that marijuana is a normal good, which is supported by the positive income elasticity estimates from the literature, these calculations indicate that the negative income effect generated by higher ENDS taxes is negligible and could at most explain six to seven percent (0.08 percentage point) of the estimated decline in marijuana use (1.1 to 1.4 percentage points; Table 3 panels II and III, column 6). If marijuana use, and in particular heavy use, is an inferior good among teens and young adults, then our estimates of

[56] Prior evidence on the inter-relationship between alcohol and marijuana use among youth and young adults is markedly mixed. Using variation in the beer tax, Pacula (1998) finds that alcohol and marijuana are economic complements. Using variation in the minimum legal drinking age, studies have found these substances to be economic complements, substitutes, or unrelated, with results varying across datasets and margins of marijuana use under study (Crost and Rees, 2013; Crost and Guerrero, 2012; Yoruk and Yoruk, 2011). See Subbaraman (2016) for a broader review of the literature on alcohol and marijuana use.

[57] Specifically, we assume the following: average annual income among teens (ages 12-19) is $4,423 (2019 CPS Annual Social and Economic Supplement (Flood et al., 2022)); annual spending on ENDS among regular users is about $1,000 (Sears et al., 2016); income elasticity for marijuana of 0.26 (see Chaloupka et al. (1999); we use the largest income elasticity estimate from the range in the literature to derive the maximal contribution of an income effect to our findings; see Chaloupka et al. (1999); Pacula et al. (2001); and Markowitz and Tauras (2009) for various income elasticity 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).

the ENDS tax-induced decline in marijuana use would be moderately understated. We interpret these findings to suggest that the income effect is not a dominant channel and the shock generated by a one-dollar increase in the ENDS tax is not nearly large enough to explain the estimated reduction in marijuana use.

5.4 Illicit Drug Use and Substance Use Disorder Treatment Admissions

In Table 7, we consider if ENDS taxation has generated further downstream spillovers on harder drug use among youth by examining whether the respondent had ever used cocaine heroin.[58] However, our analysis does not reveal any evidence suggesting a relationship between ENDS taxes and the use of harder drugs. Because any potential gateway effects operating from ENDS or tobacco use to marijuana use to other illicit substances may take time to materialize, we again conduct supplementary event study analyses (Appendix Figure 6, Panel c) that focus on a set of early adopting states (which adopted an ENDS tax prior to 2019), thus allowing us to identify effects four or more years post tax increase. We continue to find no discernible effects on harder drug use within this extended observable post-policy window.

In Table 8, we examine outcomes related to specific margins of marijuana use in order to inform whether the reduction in marijuana use that we observe among teens is driven by light or more frequent/heavy users. We find that the estimated decrease in use, in particular for older teens, is largely due to a transition from relatively lighter use (mostly from less than three times in the past month) to no use (column 1); the coefficient estimate for participation in light/infrequent marijuana use (-0.014) is similar to our corresponding main coefficient estimate for any participation. For younger teens (ages 12-17), the decline in marijuana use is expectedly smaller (given the lower prevalence), and again most of the decline appears to be driven by a shift among relatively less frequent users (less than ten times in the past month) to no use. There is also a statistically significant and meaningful decline in ever-use of marijuana, which is more reflective of the initiation margin. Coefficient estimates in column 4 become smaller in absolute magnitude and turn positive and statistically indistinguishable from zero, for marijuana use ten or more times in the last month, suggesting no statistically or economically significant effects on heavier or chronic marijuana use.

[58] Within state changes in ever-use reflect changes either in initiation and/or cessation. Since cessation is less salient for the teen sample, any effects on ever-use for youths are typically interpreted as reflecting an impact on their initiation of use (see Abouk, Courtemanche, et al. (2023) and Dave et al. (2024) for a discussion of these metrics).

Together, these results suggest that the margin most affected by ENDS taxation is the "experimental" or light/infrequent margin of marijuana use.

In the remaining columns, we explore the effect of ENDS taxes on drug treatment admission flows, first examining primary (column 5) and then any marijuana-related drug treatment admission (column 6), using data from the TEDS. Overall, our results indicate that ENDS taxes do not have any meaningful effects on marijuana-related admissions.[59] Moreover, we find no evidence of any effects whatsoever on admissions not related to marijuana, or admissions related to specific harder drugs such as heroin or cocaine. The estimated effects are statistically insignificant across all categories. Furthermore, the event study analyses presented in Figure 5, for either the TWFE regression or the stacked difference-in-differences regression, do not provide significant evidence of any causal effects on marijuana-related treatment admissions for either youths or adults. The corresponding event study figures for illicit drug use not related to marijuana are presented in Appendix Figure 7. Consistently, we find that the coefficient estimates from these event study analyses are statistically indistinguishable from zero.

Notably, effects on more severe measures of use such as heavy drug use or admissions to drug treatment may take time to develop and we may not have sufficient post-period data – given that most ENDS taxes are recent policies – to fully explore this question. An interesting direction for future research, as more time passes, would be to more carefully trace out the potential effects of ENDS taxes on such measures.[60]

Given that we test multiple hypotheses using various different sub-measures for each broader outcome of interest, we confirm that our inferences are not biased towards an over-rejection of the null. We follow the method proposed by Anderson (2008) and report adjusted p-values ("sharpened q-values") that account for the multiple comparisons. Our main findings and inferences remain robust (see Appendix Table 12).

6. Conclusion

[59] In Table 8, we use log transformed admissions variables. In Appendix Table 11 we use the non-logged admission rate levels. Results are not appreciably different for most outcomes, though we do observe some decreases in admissions for cocaine or methamphetamines as the primary substance (ages 12-17) and heroin as the primary substance (ages 18+). We suspect that these declines may be driven by marijuana that is not recorded on the admission record. TEDS records up to three substances and thus marijuana may be used by the patient at admission, but this substance (which is arguably less harmful than other substances) may not be recorded or may be recorded as a secondary or tertiary substance of use.
[60] Focusing the TEDS analyses on early adopters (states that adopted an ENDS tax in 2019 or earlier), permitting a post-treatment window of at least four years, we continue to find no meaningful effects on marijuana or other drug related treatment admission, either for adolescents or adults, within this observation window (see Appendix Figure 8).

Marijuana is the most commonly used illicit drug with one in five adults and one in ten youth consuming the product in 2021 (Substance Abuse and Mental Health Services Administration, 2023). At the same time, ENDS use first grew dramatically from 2011-2019 and then has sharply declined subsequently with 7.8 percent of U.S. high school students reporting prior-month e-cigarette use in 2024 (National Youth Tobacco Survey 2024). Among high school students nationally, almost 11 percent are dual users of ENDS and marijuana, and among those who use ENDS products over 60 percent also use marijuana (2023 National YRBS). While both products potentially confer health benefits to adults, public health advocates caution that greater access to, and use of, these products can have serious and negative health implications, particularly for youths and young adults. Despite frequent calls from public health advocates regarding the health harms associated with early initiation of marijuana use, and the risks associated with joint use of ENDS and marijuana, no study has comprehensively examined the spillover effects of anti-vaping policies on marijuana and other illicit drug use.

To fill this critical gap in the literature, we provide a comprehensive evaluation of the effects of raising ENDS taxes — one of the most recent and prominent policies adopted by states and local governments to curb vaping — on marijuana use and harder drug consumption among youths and adults. We leverage multiple large-scale national datasets in conjunction with generalized difference-in-differences methods and find robust evidence that a one-dollar increase in the ENDS tax leads to a 6 to 8 percent decline in marijuana use and a 13 to 15 percent decline in co-use of marijuana and e-cigarettes among youth. Our TWFE results do not appear to be driven by differential pre-trends or bias from dynamic and heterogeneous treatment effects. Furthermore, the relative absolute magnitude of our "reduced form" effects for marijuana, which are less than half the size of the "first stage" effects for nicotine vaping, appear reasonable.

The evidence suggests that the likely pathways through which this relationship can be explained are not solely through income effects or secondary effects that may operate through shifts in cigarette smoking or alcohol use. Rather, our results are consistent with the hypothesis that e-cigarettes and marijuana are direct economic complements. In addition, we note that our finding that marijuana use declines post-ENDS tax appears to be largely driven by relatively light or experimental marijuana users, and not heavy consumers. We do not find any further downstream effects on youth illicit drug use or any changes in any change in drug treatment admissions for youth or adults. Our estimates represent average treatment effects on the treated over the post-treatment windows available for the tax-adopting states. These windows are approximately four years. If

gateway effects on harder drugs and flows into substance abuse treatment facilities take longer to unfold, future research will be necessary to detect them.

Overall, results from our study add to the growing literature exploring the broader impacts of ENDS taxation on public health and social welfare. Much of this spillover analysis has focused on general equilibrium effects on combustible tobacco use (e.g., Allcott and Rafkin (2022); Abouk, Courtemanche, et al. (2023); Chuo et al. (2024); and Cotti et al. (2022)). Given that smoking is believed to be substantially more harmful than vaping by tobacco control experts (Allcott & Rafkin, 2022), this change could suggest an unintended negative effect on tobacco-related public health.[61] However, recent work has begun to explore spillovers of ENDS taxation into non-tobacco-related adjacent markets, and provide some evidence of non-tobacco-related health benefits, particularly for youths. For instance, Dave et al. (2024) document that ENDS taxes reduce heavier drinking (e.g., binge drinking) among teens and drunk driving-related traffic fatalities among those ages 16-20. Interestingly, we observe that "lighter" use of marijuana is more elastic to ENDS taxation, which hints at potentially nuanced and complex patterns of youth co-substance use that future work could explore to guide optimal regulation of ENDS and other addictive goods.

Finally, while our study demonstrates a non-tobacco related health benefit attributable to higher ENDS taxes, given the above-noted harms associated with smoking, any benefits from ENDS taxes must be carefully weighed against these costs. This study underscores the importance of assessing general equilibrium effects of public policies that affect access to e-cigarettes to understand their broader public health and social welfare effects. Moreover, optimal taxation of ENDS products would then not only depend on the relative risk of ENDS vis-à-vis combustible tobacco but also on the relative risk vis-à-vis other impacted addictive substances in conjunction with the potential substitution responses and/or complementarities at play.

[61] As discussed earlier, our re-analysis of this question using post-pandemic data, however, now points to much weaker substitution responses into cigarette smoking.

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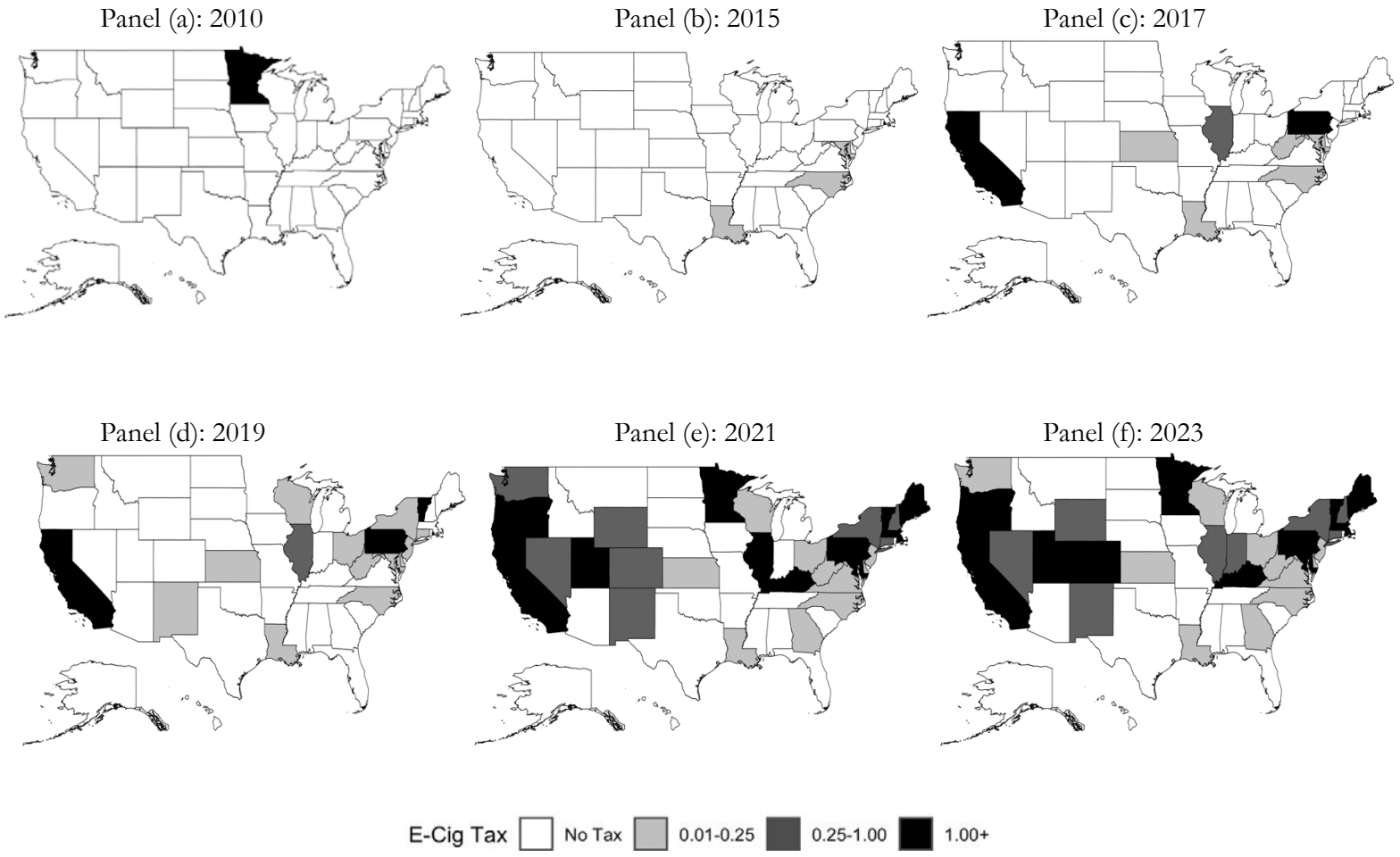
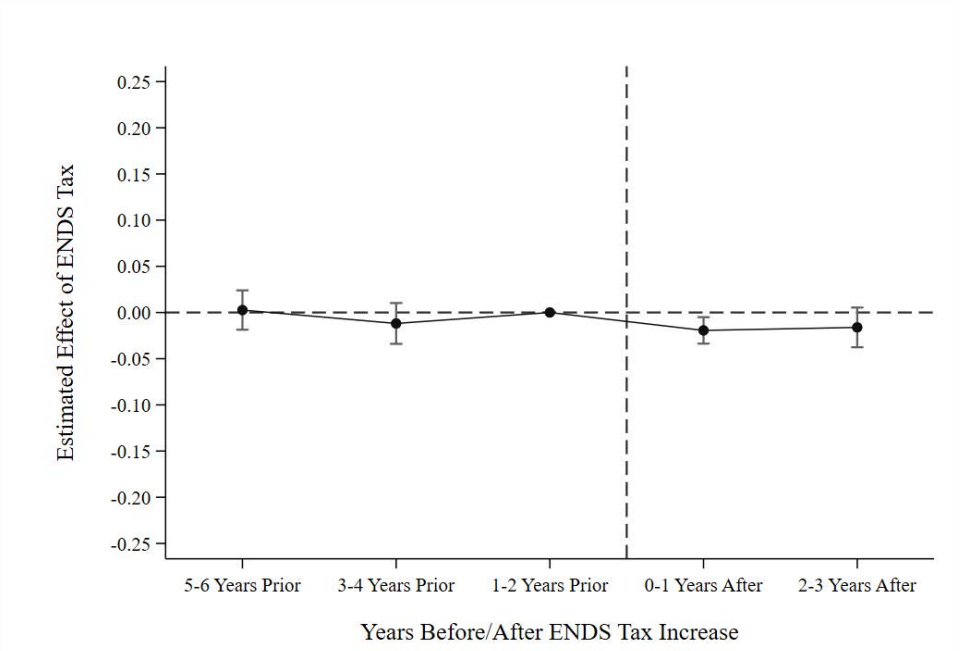
Figure 1. Geographic and Temporal Variation in ENDS Taxes



Notes: Standardized ENDS taxes per mL of e-liquid (liquid nicotine) are in 2023 dollars and are obtained from Cotti et al (2024).

Figure 2. Dynamic Effects of ENDS Taxes on ENDS Use Among Youths, State YRBS 2015-2023

Panel (a): TWFE Estimates (no time-varying covariates)



Panel (b): TWFE Estimates (time-varying covariates)

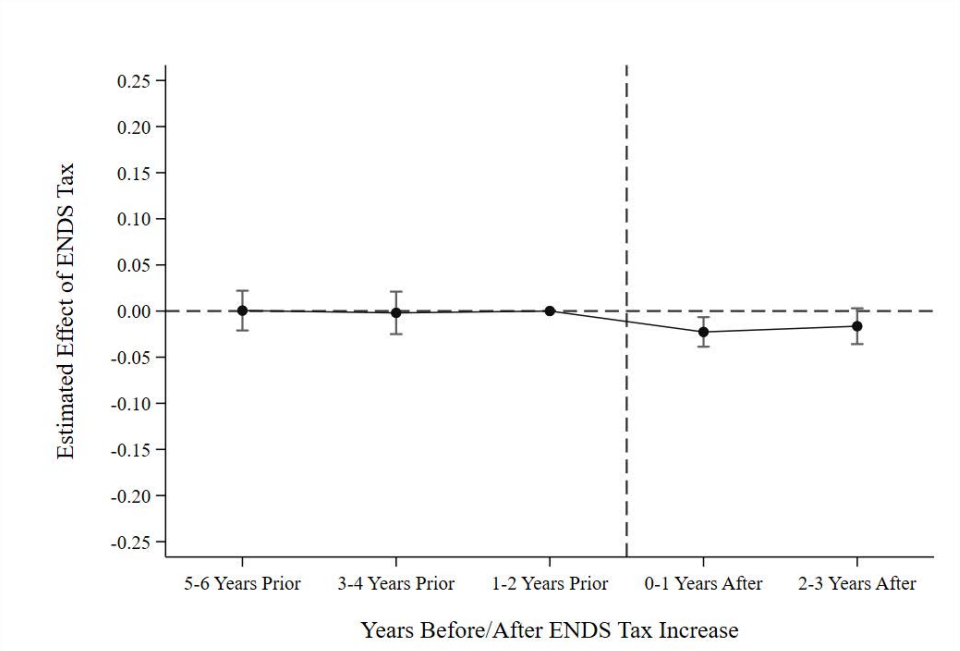
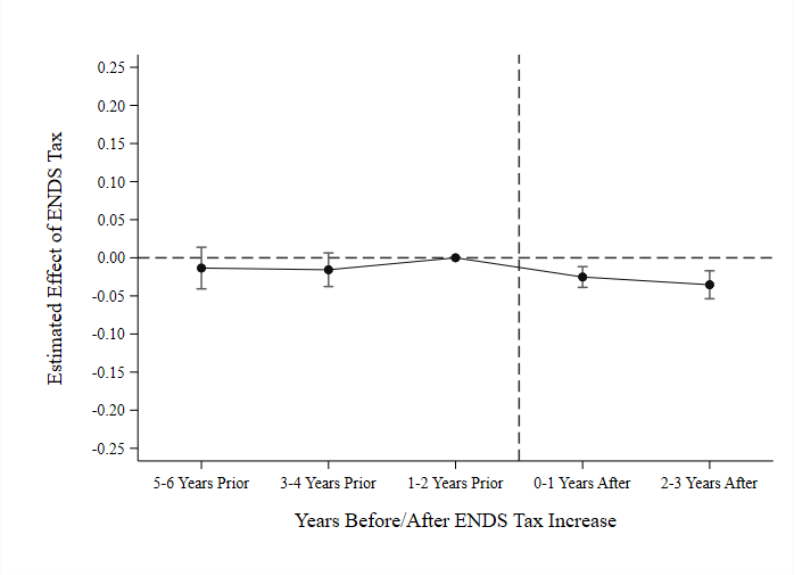
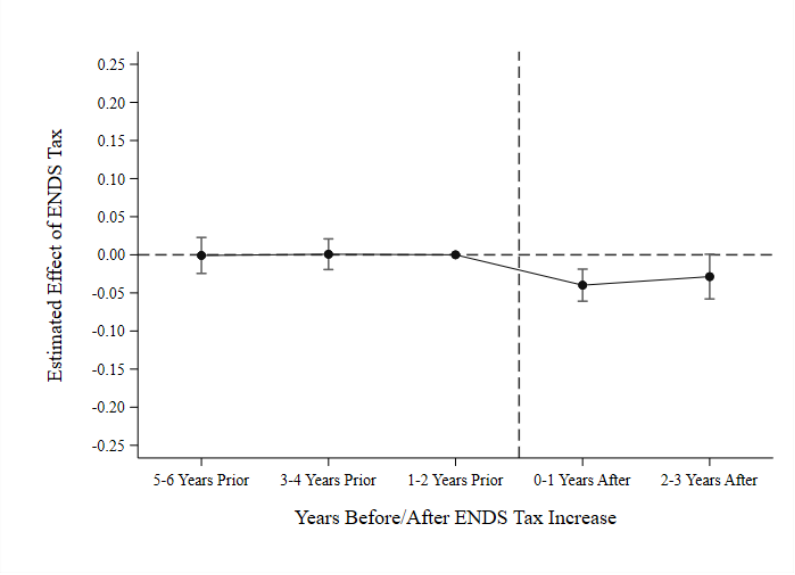


Figure 2, continued

Panel (c): Stacked DD Estimates (no time-varying covariates)



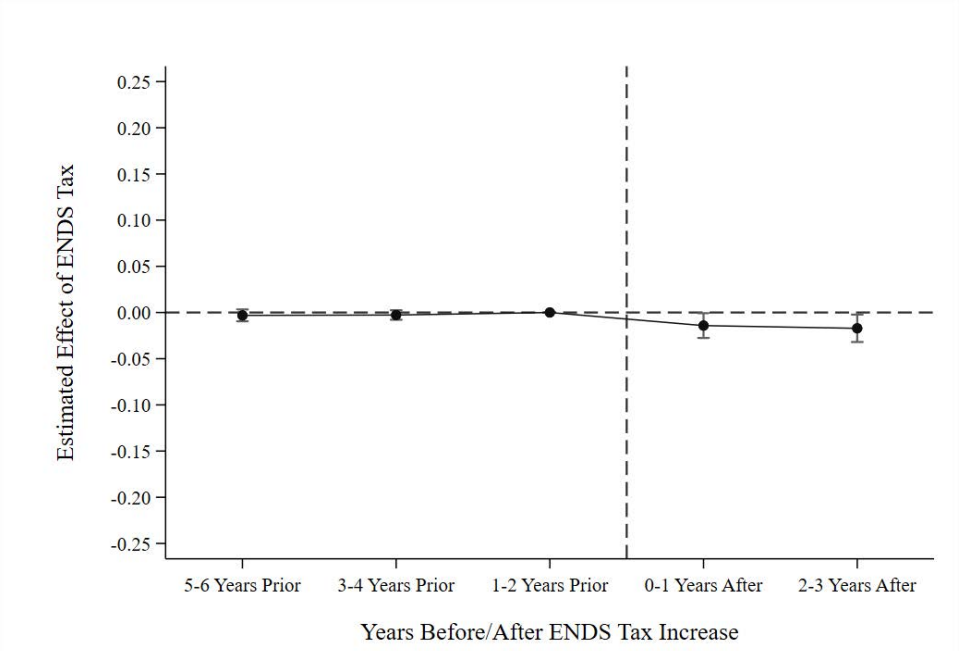
Panel (d): Stacked DD Estimates (time-varying covariates)



Notes: Estimates in Panels (a) and (b) are generated using weighted OLS estimates from a TWFE event study regression using the 2015-2023 waves of the State YBRS, Panel (a) includes only fixed effects and Panel (b) also includes time-varying covariates. Estimates in Panels (c) and (d) are generated with a stacked event study regression using the 2015-2023 waves of the State YBRS, Panel (c) includes only fixed effects and Panel (d) also includes time-varying covariates. For stacked DD regressions, each treated state's controls include states that had never implemented an ENDS tax ("never adopters") or have not-yet implemented an ENDS tax ("not-yet-adopters") over the sample period. The event-time window ranges from six years prior to tax adoption to two years following adoption. The reference period is 1-2 years prior to tax adoption. The adjusted regressions in Panels (b) and (d) control for state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, and non-marijuana drug policy controls. Data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Circles indicate coefficient estimates. 95 percent confidence intervals that account for within state clustering are reported with vertical lines.

Figure 3. Dynamic Effects of ENDS Taxes on Marijuana Use Among Youths, State YRBS 2003-2023

Panel (a): TWFE Estimates (no time-varying covariates)



Panel (b): TWFE Estimates (time-varying covariates)

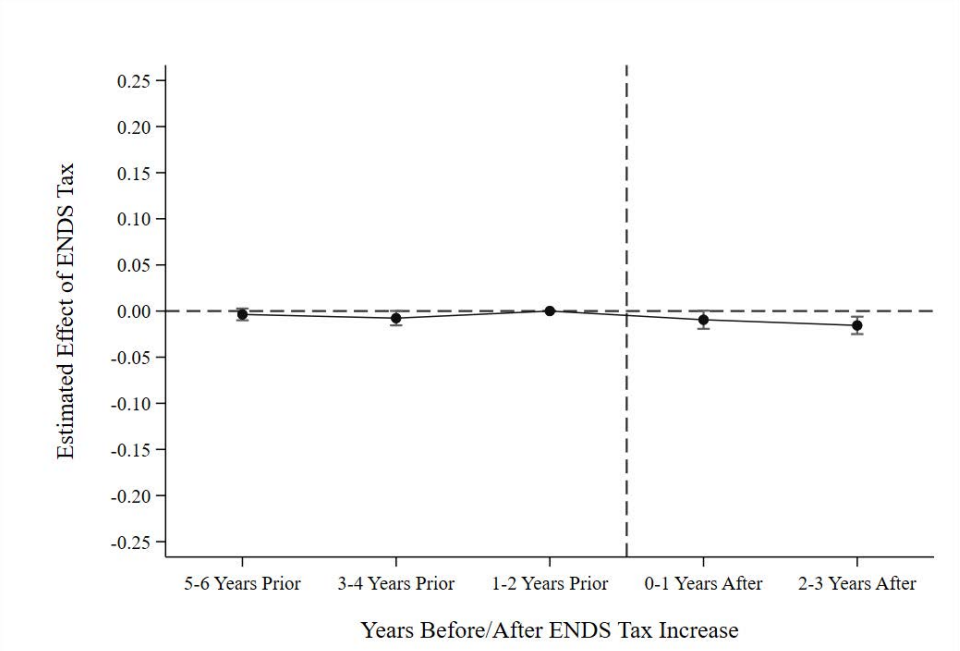
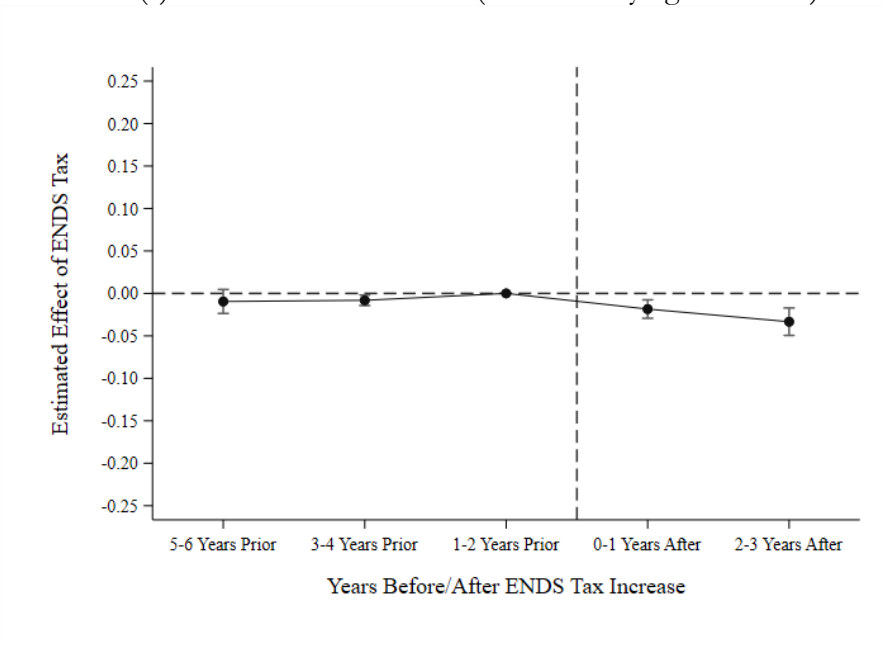
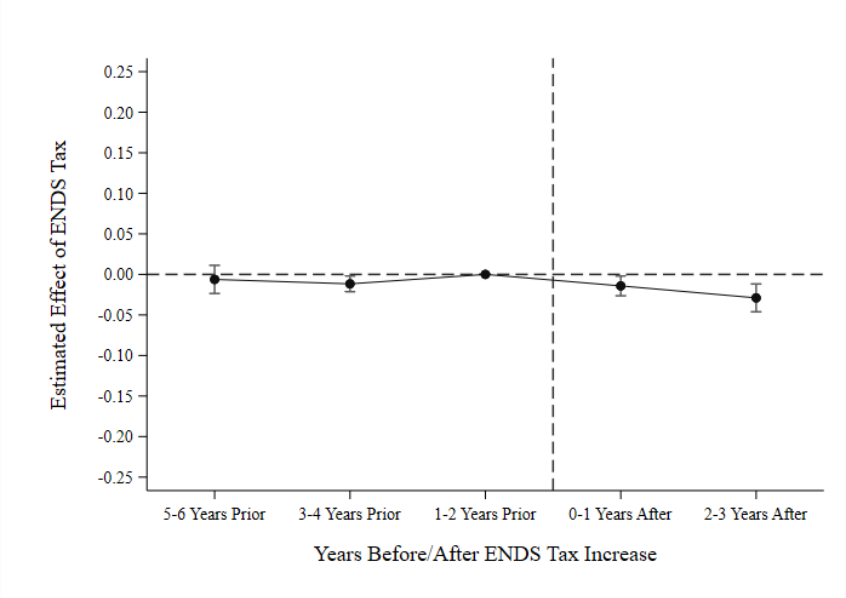


Figure 3, continued

Panel (c): Stacked DD Estimates (no time-varying covariates)

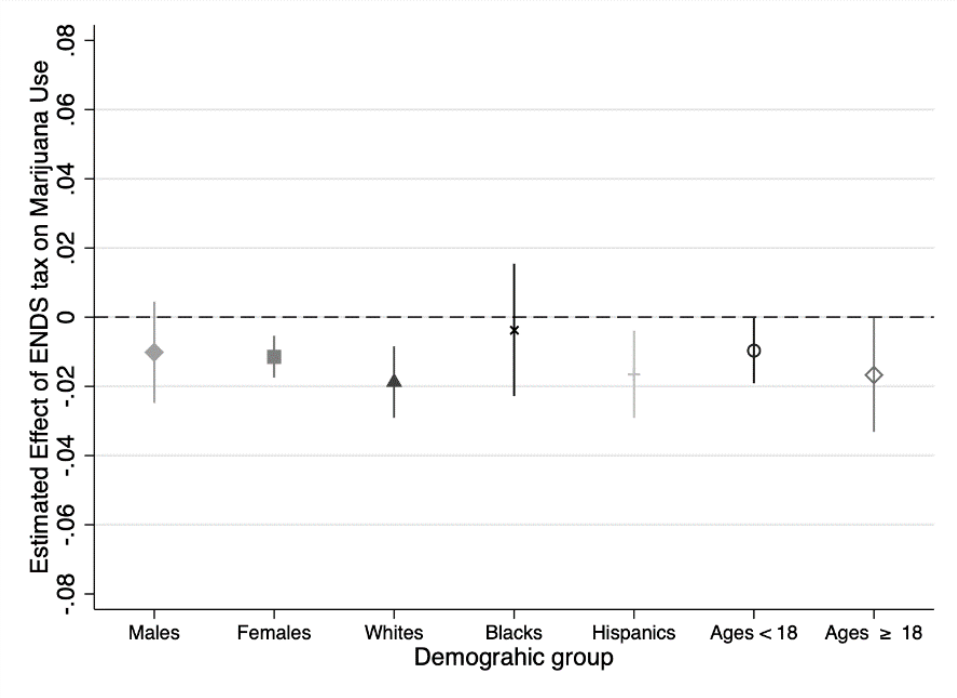


Panel (d): Stacked DD Estimates (time-varying covariates)



Notes: Estimates in Panels (a) and (b) are generated using weighted OLS estimates from a TWFE event study regression using the 2003-2023 waves of the State YBRS, Panel (a) includes only fixed effects and Panel (b) also includes time-varying covariates. Estimates in Panels (c) and (d) are generated with a stacked event study regression using the 2003-2023 waves of the State YBRS, Panel (c) includes only fixed effects and Panel (d) also includes time-varying covariates. For stacked DD regressions, each treated state's controls include states that had never implemented an ENDS tax ("never adopters") or have not-yet implemented an ENDS tax ("not-yet-adopters") over the sample period. The event-time window ranges from six years prior to tax adoption to two years following adoption. The reference period is 1-2 years prior to tax adoption. The adjusted regressions in Panels (b) and (d) control for state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, and non-marijuana drug policy controls. Data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Circles indicate coefficient estimates. 95 percent confidence intervals that account for within state clustering are reported with vertical lines.

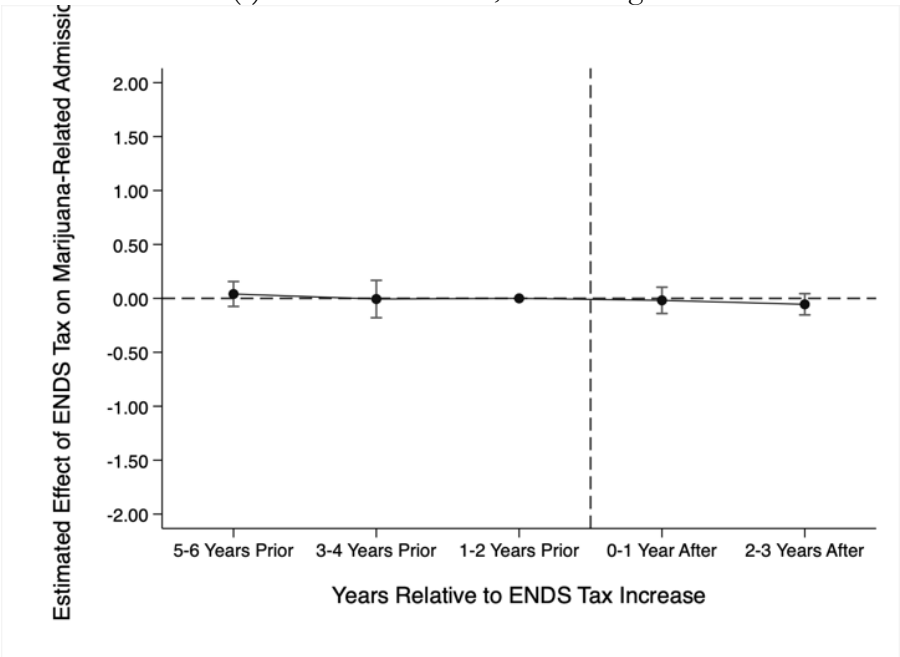
Figure 4. Heterogeneity in the Effects of ENDS Taxes on Marijuana Use Among Youths, State YRBS 2003-2023



Notes: Weighted OLS estimates from a TWFE difference-in-differences regression for each sample noted on the x-axis are shown using the 2003-2023 waves of the State YBRS. The regressions control for state and year per semester fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, and non-marijuana drug policy controls. Data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Circles indicate coefficient estimates. 95 percent confidence intervals that account for within state clustering are reported with vertical lines.

Figure 5. Dynamic Effects of ENDS Taxes on Marijuana-Related Drug Treatment Admissions, TEDS 2000-2022

Panel (a): TWFE Estimates, Youths Ages 12-17



Panel (b): TWFE Estimates, Adults Ages 18+

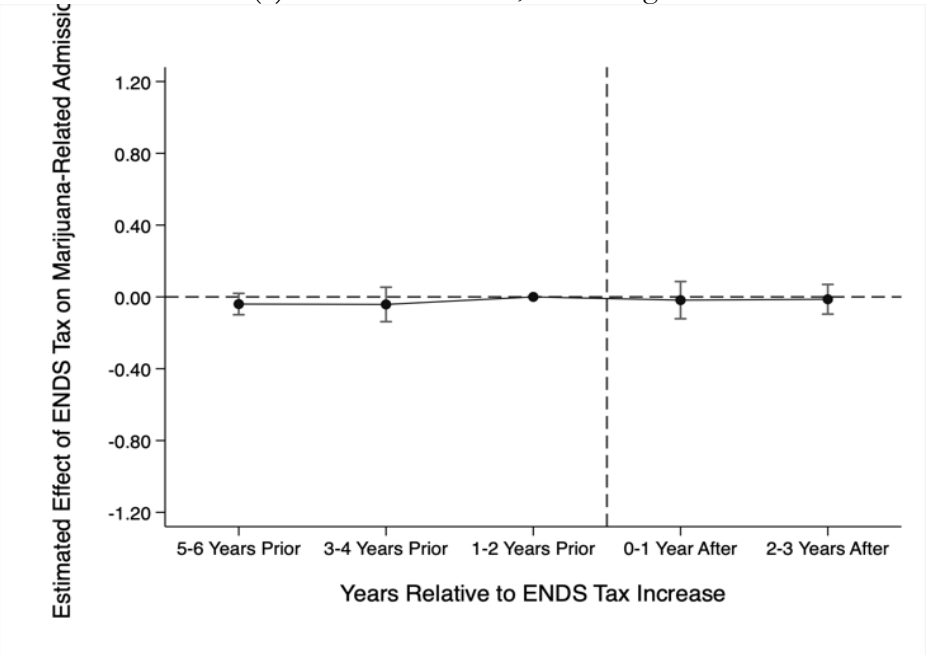
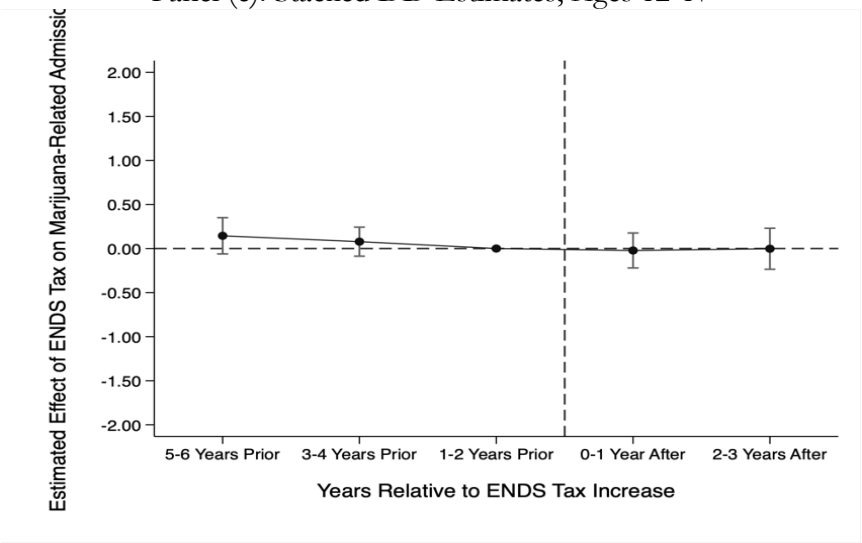
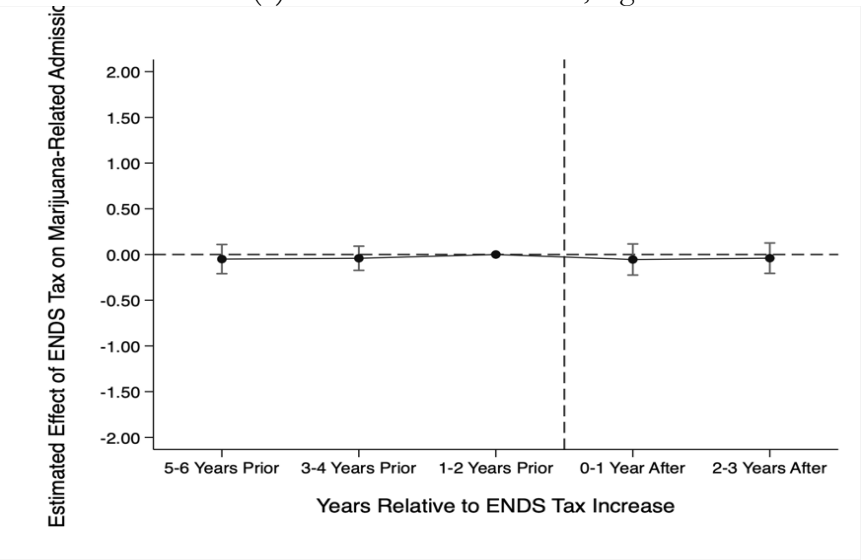


Figure 5, Continued

Panel (c): Stacked DD Estimates, Ages 12-17



Panel (d): Stacked DD Estimates, Ages 18+



Notes: Estimates in Panels (a) and (b) are generated using weighted OLS estimates from a TWFE event study regression using the 2000-2022 TEDS. Estimates in Panels (c) and (d) are generated with a stacked event study regression using the 2000-2022 TEDS. The sample used in Panels (a) and (c) includes all individuals aged 12-to-17 and the sample used in Panels (b) and (d) includes all individuals aged 18 and older. The dependent variable is the natural log of the marijuana-related drug treatment admissions rate. For stacked DD regressions, each treated state's controls include states that had never implemented an ENDS tax ("never adopters") or have not-yet implemented an ENDS tax ("not-yet-adopters") over the sample period. The event-time window ranges from six years prior to tax adoption to two years following adoption. The reference period is 1-2 years prior to tax adoption. The regressions control for state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, and non-marijuana drug policy controls and a proxy for drug treatment capacity and state reporting. Data are weighted by the age-specific state population. Circles indicate coefficient estimates. 95 percent confidence intervals that account for within state clustering are reported with vertical lines.

Table 1. TWFE Estimates of Effect of ENDS Taxes on ENDS Use Among Youths, YRBS Surveys 2015-2023

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel I: State YRBS			
ENDS Tax ($)	-0.0180***	-0.0160***	-0.0286**	-0.0289**	-0.0277**	-0.0292**
	(0.0042)	(0.0048)	(0.0117)	(0.0117)	(0.0113)	(0.0113)
N	735109	735109	735109	735109	735109	735109
Pre-Treatment Mean of Dep Variable	0.204	0.204	0.204	0.204	0.204	0.204
			Panel II: Combined State & National YRBS			
ENDS Tax ($)	-0.0258***	-0.0210***	-0.0174**	-0.0148*	-0.0134*	-0.0164*
	(0.0037)	(0.0037)	(0.0078)	(0.0084)	(0.0077)	(0.0082)
N	807753	807753	807753	807753	807753	807753
Pre-Treatment Mean of Dep Variable	0.228	0.228	0.228	0.228	0.228	0.228
State, Year-by-Semester FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic and COVID-19 Controls?	No	Yes	Yes	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes	Yes	Yes
Alcohol Policy Control?	No	No	No	Yes	Yes	Yes
Marijuana Policy Controls?	No	No	No	No	Yes	Yes
Non-marijuana Drug Policy Controls?	No	No	No	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2015-2023 waves of the State (Panel I) and Combined State and National (Panel II) YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Combined YRBS data are weighted using population weights generated from the SEER data to be nationally representative. Standard errors are clustered at the state level and are reported in parentheses.

Table 2. Lead Effects of ENDS Taxes on ENDS Use, YRBS Surveys 2015-2023

	(1)	(2)	(3)
	Panel I: State YRBS		
Lead 2 ENDS Tax (0/1)	-0.002	0.008	0.010
	(0.014)	(0.012)	(0.011)
Lead 1 ENDS Tax (0/1)	-0.009	-0.0007	-0.003
	(0.015)	(0.012)	(0.012)
ENDS Tax ($)	-0.0214***	-0.028**	-0.0300**
	(0.0075)	(0.012)	(0.012)
N	735109	735109	735109
Pre-Treatment Mean of Dep Variable	0.205	0.205	0.205
	Panel II: Combined State & National YRBS		
Lead 2 ENDS Tax (0/1)	-0.0189	0.0097	0.0084
	(0.0214)	(0.0253)	(0.0248)
Lead ENDS Tax (0/1)	-0.0024	-0.0071	-0.0080
	(0.0063)	(0.0081)	(0.0090)
ENDS Tax ($)	-0.0269***	-0.0155*	-0.0190**
	(0.0042)	(0.0083)	(0.0094)
N	807753	807753	807753
Pre-Treatment Mean of Dep Variable	0.208	0.208	0.208
State, Year-by-Semester FE?	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes
Macroeconomic and COVID-19 Controls?	No	Yes	Yes
Tobacco Policy Controls?	No	Yes	Yes
Alcohol Policy Control?	No	Yes	Yes
Marijuana Policy Controls?	No	Yes	Yes
Non-marijuana Drug Policy Controls?	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2015-2023 waves of the State (Panel I) and Combined State and National (Panel II) YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Combined YRBS data are weighted using population weights generated from the SEER data to be nationally representative. Standard errors are clustered at the state level and are reported in parentheses.

Table 3. TWFE Estimates of the Effects of ENDS Taxes on Marijuana Use Among Youths, State YRBS

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel I: ENDS Use, 2015-2023[a]			
ENDS Tax ($)	-0.0181***	-0.0163***	-0.0280**	-0.0284**	-0.0276**	-0.0288**
	(0.0043)	(0.0049)	(0.0114)	(0.0114)	(0.0112)	(0.0111)
N	713954	713954	713954	713954	713954	713954
Pre-Treatment Mean of Dep Variable	0.201	0.201	0.201	0.201	0.201	0.201
			Panel II: Marijuana Use, 2015-2023[a]			
ENDS Tax ($)	-0.0142***	-0.0135***	-0.0129**	-0.0142**	-0.0139**	-0.0142**
	(0.0030)	(0.0028)	(0.0062)	(0.0063)	(0.0065)	(0.0064)
N	713954	713954	713954	713954	713954	713954
Pre-Treatment Mean of Dep Variable	0.181	0.181	0.181	0.181	0.181	0.181
			Panel III: Marijuana Use, 2003-2023			
ENDS Tax ($)	-0.0126***	-0.0127***	-0.0120**	-0.0120**	-0.0117**	-0.0110**
	(0.0045)	(0.0042)	(0.0048)	(0.0048)	(0.0049)	(0.0048)
N	1418034	1418034	1418034	1418034	1418034	1418034
Pre-Treatment Mean of Dep Variable	0.197	0.197	0.197	0.197	0.197	0.197
State, Year-by-Semester FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic and COVID-19 Controls?	No	Yes	Yes	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes	Yes	Yes
Alcohol Policy Control?	No	No	No	Yes	Yes	Yes
Marijuana Policy Controls?	No	No	No	No	Yes	Yes
Non-marijuana Drug Policy Controls?	No	No	No	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

[a] The sample for these regressions are limited to respondents who provided non-missing information on both ENDS use and marijuana use.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2015-2023 waves of the State YRBS in Panel I and II and the 2003-2023 waves of the State YRBS in Panel III. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Standard errors are clustered at the state level and are reported in parentheses.

Table 4. Stacked DD Estimates of Effects of ENDS Taxes on Marijuana Use Among Youths, State YRBS 2003-2023

	(1)	(2)	(3)	(4)	(5)	(6)
ENDS Tax ($)	-0.0172***	-0.0160***	-0.0143**	-0.0143**	-0.0143**	-0.0148**
	(0.0037)	(0.0040)	(0.0057)	(0.0058)	(0.0062)	(0.0061)
N	9,417,592	9,417,592	9,417,592	9,417,592	9,417,592	9,417,592
Pre-Treat Mean of Dep Variable	0.184	0.184	0.184	0.184	0.184	0.184
State and Year-by-Semester FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic & COVID-19 Controls?	No	Yes	Yes	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes	Yes	Yes
Alcohol Policy Control?	No	No	No	Yes	Yes	Yes
Marijuana Policy Controls?	No	No	No	No	Yes	Yes
Non-marijuana Drug Policy Controls?	No	No	No	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a Stacked TWFE difference-in-differences regression using the 2003-2023 waves of the State YRBS. Each treated state's controls include states that had never implemented an ENDS tax ("never adopters") or have not-yet implemented an ENDS tax ("not-yet-adopters") over the sample period. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. Standard errors are clustered at the state level and are reported in parentheses.

Table 5. TWFE Estimates of the Effects of ENDS Taxes on Dual ENDS and Marijuana Use Among Youths, State YRBS 2015-2023

	(1)	(2)	(3)
	Panel I: Any ENDS Use and Any MJ Use		
ENDS Tax ($)	-0.014***	-0.015**	-0.016***
	(0.002)	(0.006)	(0.006)
N	660357	660357	660357
Pre-Treatment Mean of Dep Variable	0.106	0.106	0.106
	Panel II: Lighter ENDS Use (< 20 Days) vs No ENDS Use and Any MJ Use		
ENDS Tax ($)	-0.005	-0.016*	-0.019**
	(0.004)	(0.008)	(0.009)
N	643232	643232	643232
Pre-Treatment Mean of Dep Variable	0.170	0.170	0.170
	Panel III: Heavier ENDS Use (≥ 20 Days) and Any MJ Use		
ENDS Tax ($)	-0.012***	-0.009**	-0.009**
	(0.002)	(0.004)	(0.004)
N	660357	660357	660357
Pre-Treatment Mean of Dep Variable	0.028	0.028	0.028
	Panel IV: Any Cigarette Use and Any MJ Use		
ENDS Tax ($)	0.001	-0.005	-0.005
	(0.002)	(0.003)	(0.003)
N	699152	699152	699152
Pre-Treatment Mean of Dep Variable	0.048	0.048	0.048
	Panel V: Any Cigarette Use (excluding ENDS Users) and Any MJ Use		
ENDS Tax ($)	0.000	-0.001	-0.001
	(0.002)	(0.001)	(0.001)
N	636308	636308	636308
Pre-Treatment Mean of Dep Variable	0.011	0.011	0.011
	Panel VI: Any Binge Drinking (excluding ENDS Users) and Any MJ Use		
ENDS Tax ($)	0.001	-0.002	-0.002
	(0.001)	(0.001)	(0.002)
N	479773	479773	479773
Pre-Treatment Mean of Dep Variable	0.014	0.014	0.014
	Panel VII: Any Alcohol (excluding ENDS Users) and Any MJ Use		
ENDS Tax ($)	0.002**	0.003	0.003
	(0.001)	(0.002)	(0.002)
N	625325	625325	625325
Pre-Treatment Mean of Dep Variable	0.041	0.041	0.041
State, Year-by-Semester FE?	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes
Macroeconomic & COVID-19 Controls?	No	Yes	Yes
Tobacco Policy Controls?	No	Yes	Yes
Alcohol Policy Control?	No	Yes	Yes
Marijuana Policy Controls?	No	Yes	Yes
Non-Marijuana Drug Policy Controls?	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: MJ = marijuana. Estimates are generated with a TWFE difference-in-differences regression using the 2015-2023 waves of the State YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate,

state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 25 for details). Standard errors are clustered at the state level and are reported in parentheses. The sample for these regressions is limited to respondents who provided non-missing information on both ENDS use and marijuana use.

Table 6. TWFE Estimates of Effect of ENDS Taxes on ENDS Use Among Young Adults, BRFSS 2016-2023

	(1)	(2)	(3)	(4)	(5)	(6)
	Current ENDS Use			**Daily ENDS Use**		
			Panel I: Aged 18-30 Years			
ENDS Tax ($)	-0.0113***	-0.0104***	-0.0080*	-0.0081***	-0.0068***	-0.0058*
	(0.0017)	(0.0018)	(0.0042)	(0.0015)	(0.0016)	(0.0029)
N	289491	289491	289491	289491	289491	289491
Pre-Treatment Mean of Dep Variable	0.1315	0.1315	0.1315	0.0552	0.0552	0.0552
			Panel II: Aged 18-20 Years			
ENDS Tax ($)	-0.0157***	-0.0158***	-0.0075	-0.0111***	-0.0099***	-0.0078*
	(0.0043)	(0.0049)	(0.0070)	(0.0038)	(0.0035)	(0.0043)
N	57123	57123	57123	57123	57123	57123
Pre-Treatment Mean of Dep Variable	0.1525	0.1525	0.1525	0.0597	0.0597	0.0597
			Panel III: Aged 21-30 Years			
ENDS Tax ($)	-0.0100***	-0.0089***	-0.0077	-0.0072***	-0.0060**	-0.0050
	(0.0024)	(0.0025)	(0.0049)	(0.0020)	(0.0025)	(0.0034)
N	232368	232368	232368	232368	232368	232368
Pre-Treatment Mean of Dep Variable	0.1245	0.1245	0.1245	0.0537	0.0537	0.0537
			Panel IV: Aged > 30 Years			
ENDS Tax ($)	0.0010	0.0015	0.0017	-0.0004	-0.00001	0.00003
	(0.0016)	(0.0015)	(0.0016)	(0.0006)	(0.0006)	(0.0007)
N	2096021	2096021	2096021	2096021	2096021	2096021
Pre-Treatment Mean of Dep Variable	0.0421	0.0421	0.0421	0.0174	0.0174	0.0174
State and Year-by-Semester FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macro & COVID-19 Controls?	No	Yes	Yes	No	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	No	No	Yes
Alcohol Policy Control?	No	No	Yes	No	No	Yes
Marijuana Policy Controls?	No	No	Yes	No	No	Yes
Non-Marijuana Drug Policy Controls?	No	No	Yes	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2016-2023 waves of the BRFSS dataset. Semester is defined as one for interviews fielded January to June and two for interviews fielded July to December. Demographic controls include age, gender, education (no high school, high school, some college), race (white, black, and Hispanic), and marital status Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. Regressions are weighted and include state and year by month fixed effects. Standard errors are clustered at the state level and are reported in parentheses.

Table 7. Effects of ENDS Taxes on Prevalence of Ever Use of Cocaine or Heroin among Youth, State YRBS 2003-2023

	(1)	(2)	(3)	(4)	(5)	(6)
ENDS Tax ($)	-0.0037	-0.0036	-0.0081	-0.0086	-0.0055	-0.0047
	(0.0066)	(0.0090)	(0.0061)	(0.0065)	(0.0063)	(0.0063)
N	1,135,739	1,135,739	1,135,739	1,135,739	1,135,739	1,135,739
Pre-Treat Mean of Dep Variable	0.074	0.074	0.074	0.074	0.074	0.074
State and Year-by-Semester FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macro & COVID-19 Controls?	No	Yes	Yes	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes	Yes	Yes
Alcohol Policy Control?	No	No	No	Yes	Yes	Yes
Marijuana Policy Controls?	No	No	No	No	Yes	Yes
Non-MJ Drug Policy Controls?	No	No	No	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a Stacked TWFE difference-in-differences regression using the 2003-2023 waves of the State YRBS. Each treated state's controls include states that had never implemented an ENDS tax ("never adopters") or have not-yet implemented an ENDS tax ("not-yet-adopters") over the sample period. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs.. Data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Standard errors are clustered at the state level and are reported in parentheses.

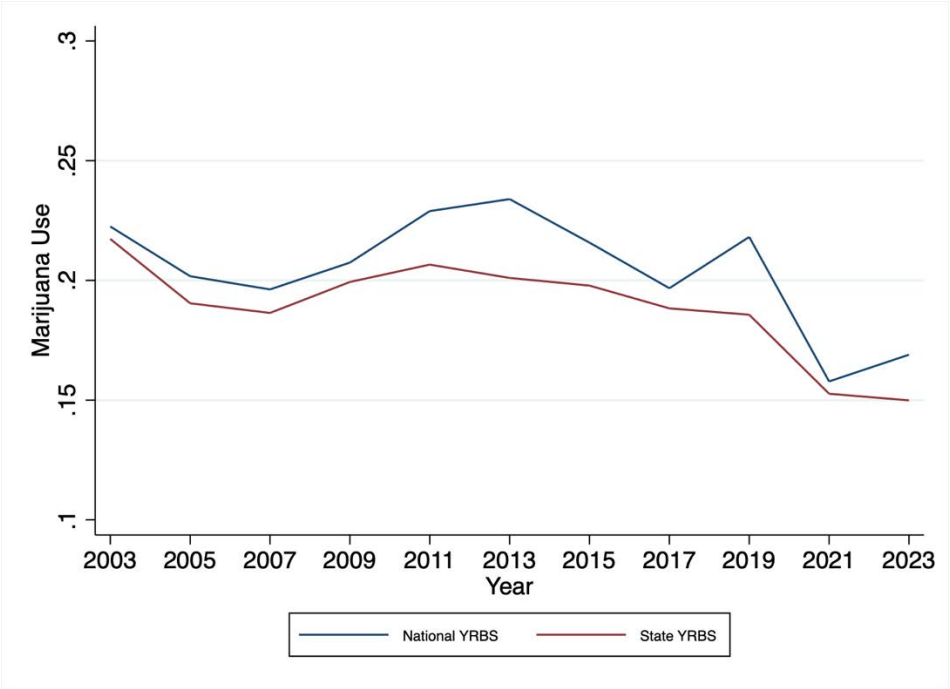
Table 8. Effects of ENDS Taxes on Drug Treatment Admissions and Heavier Marijuana Use, State YRBS 2003-2023 and TEDS 2000-2022

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	MJ Use less than 3 Times Last Month vs No Use	Ever Used MJ	MJ Use 3 or More Times Last Month	MJ Use 10 or More Times Last Month	Marijuana (Primary)	Marijuana (Any)	Non-Marijuana (Any)	Heroin (Primary)	Cocaine or Meth (Primary)
	YRBS	YRBS	YRBS	YRBS	TEDS	TEDS	TEDS	TEDS	TEDS
					Panel I: Aged 12-17 Years				
ENDS Tax ($)	-0.006	-0.079**	-0.005*	0.001	0.0113	0.0268	-0.109	-0.155	-0.112
	(0.004)	(0.037)	(0.003)	(0.001)	(0.0751)	(0.0795)	(0.120)	(0.216)	(0.118)
N	1127549	929339	1281449	1281449	1130	1130	1130	1130	1130
Pre-Treat Mean DV	0.077	0.372	0.119	0.073	3.989	4.858	0.798	0.072	0.352
					Panel II: Aged ≥ 18 Years				
ENDS Tax ($)	-0.014*	-0.089**	-0.006	0.005	0.0179	-0.0160	-0.0340	-0.0871	0.0179
	(0.007)	(0.037)	(0.006)	(0.009)	(0.0493)	(0.0498)	(0.0349)	(0.106)	(0.0703)
N	111780	107673	136585	136585	1130	1130	1130	1130	1130
Pre-Treat. Mean DV	0.099	0.515	0.181	0.124	0.820	2.083	4.729	1.554	1.657

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

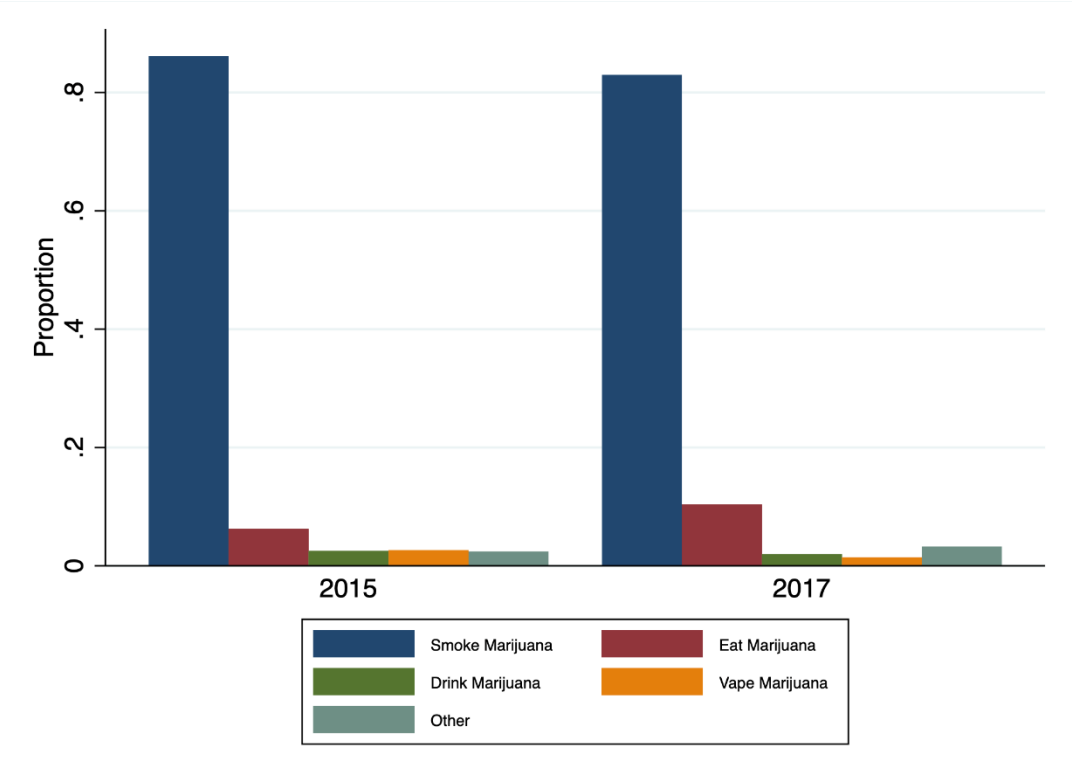
Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2003-2023 waves of the State YRBS and the 2000-2022 TEDS. In columns 1 through 4, the dependent variable is a State YRBS respondent outcome. In columns 5 to 9, the dependent variables are the log of indicated drug treatment admissions. All regressions control for state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, non-marijuana drug policy controls. YRBS regressions control for year-by-semester fixed effects. TEDS regressions also control for a proxy for treatment capacity and state reporting. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details) and TEDS data are weighted by the age-specific state population. Standard errors are clustered at the state level and are reported in parentheses.

Appendix Figure 1. Marijuana Use Among Youths Over Time, State and National YRBS 2003-2023



Notes: Time trends in marijuana consumption. Data are from the 2003-2023 waves of the State and National YRBS. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details) and National YRBS data are weighted by YRBS-provided weights.

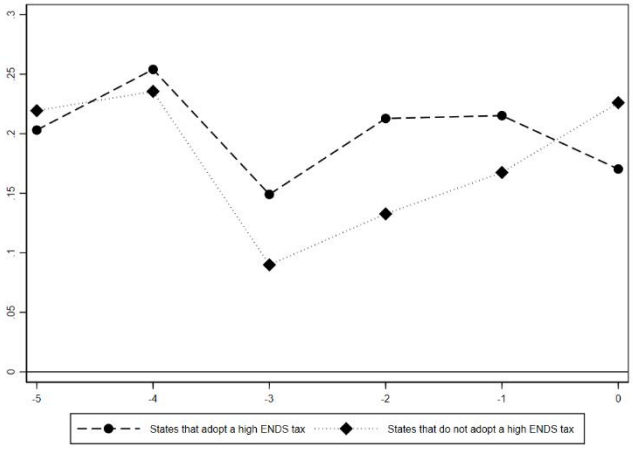
Appendix Figure 2. Prevalence Rate in Ways of Consuming Marijuana, State YRBS 2015-2023



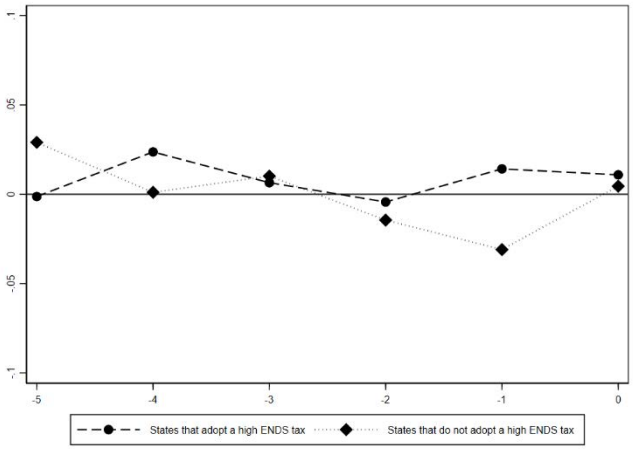
Notes: Proportion of respondents in the 2015-2017 waves of the State YRBS that smoke, eat, drink, and vape marijuana. The sample includes Alaska, Hawaii, Nebraska, and Nevada. Data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details).

Appendix Figure 3. Pre-Treatment Trends in ENDS Use between High ENDS Tax-adopting States and Control States, State YRBS 2015-2023

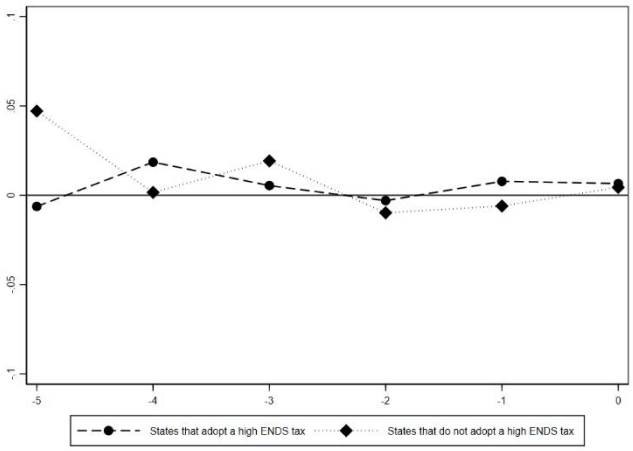
Panel (a): Unadjusted



Panel (b): Adjusted for state and year-by-semester fixed effects

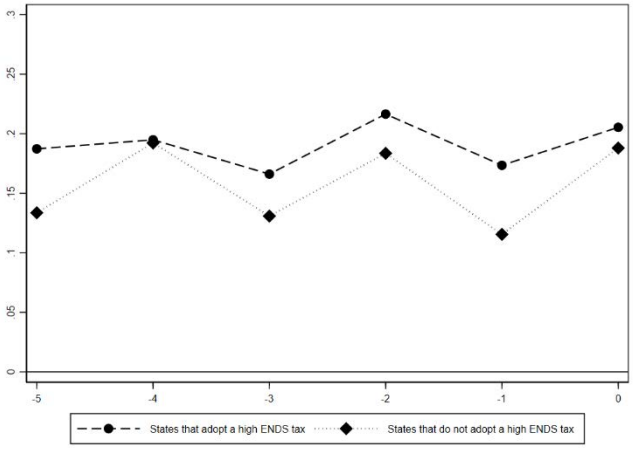


Panel (c). Adjusted for state and year-by-semester fixed effects, and tobacco control policies

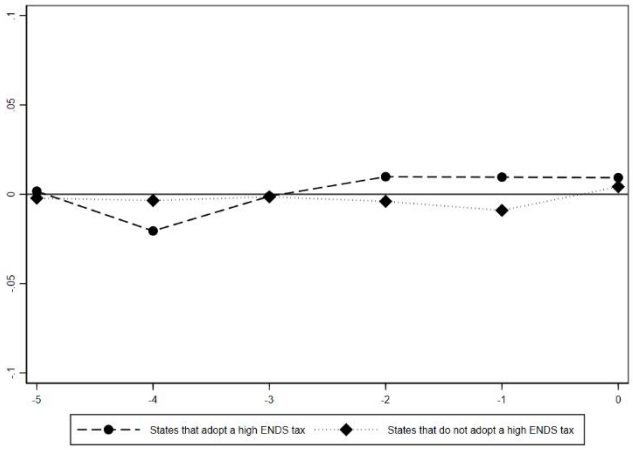


Appendix Figure 4. Pre-Treatment Trends in Marijuana Use between High ENDS Tax-adopting States and Control States, State YRBS 2015-2023

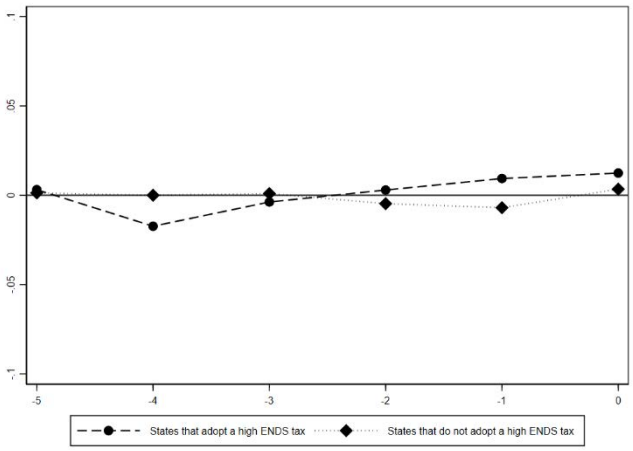
Panel (a): Unadjusted



Panel (b): Adjusted for state and year-by-semester fixed effects

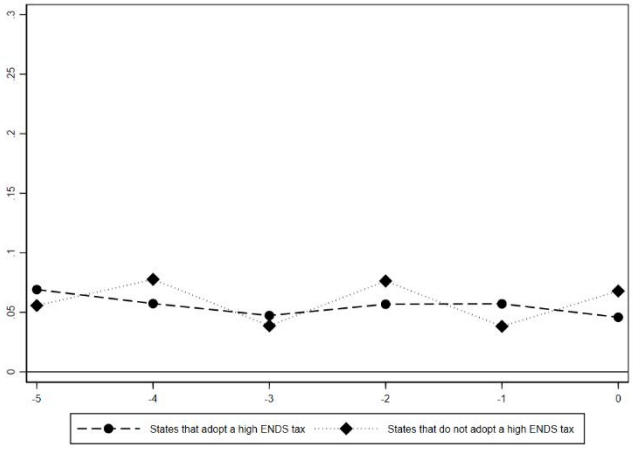


Panel (c). Adjusted for state and year-by-semester fixed effects, and tobacco control policies

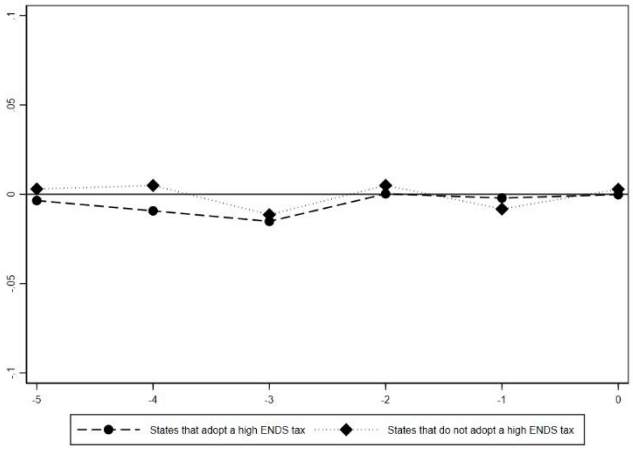


Appendix Figure 5. Pre-Treatment Trends in Ever Hard Drug Use between High ENDS Tax-adopting States and Control States, State YRBS 2015-2023

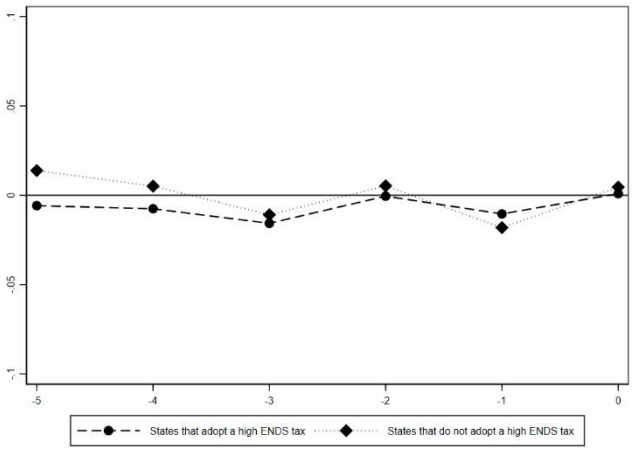
Panel (a): Unadjusted



Panel (b): Adjusted for state and year-by-semester fixed effects

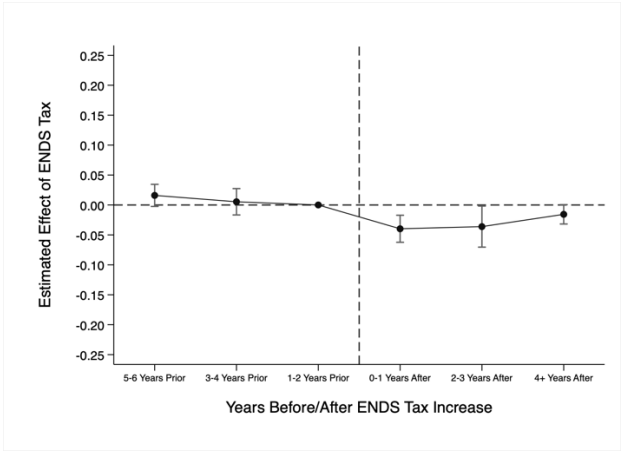


Panel (c). Adjusted for state and year-by-semester fixed effects, and tobacco control policies

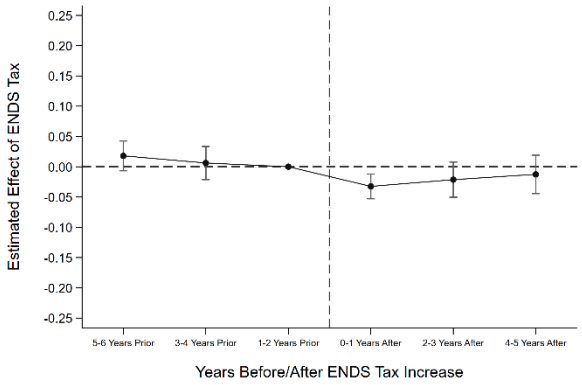


Appendix Figure 6. Dynamic Effects of ENDS Taxes on Substance Use using Early-adopting Tax States, State YRBS, 2015-2023

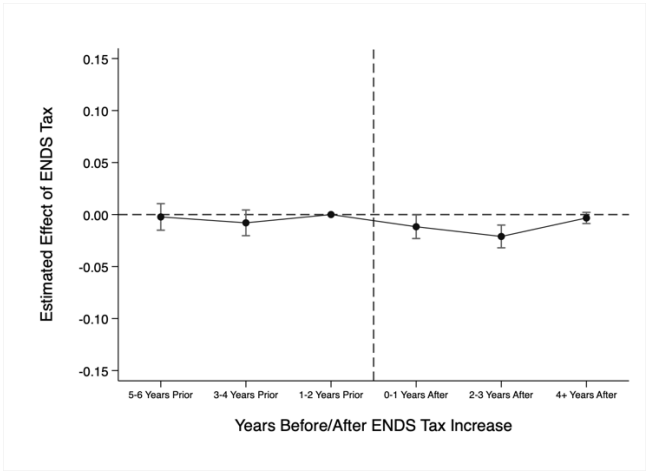
Panel (a): ENDS Use, TWFE Estimates



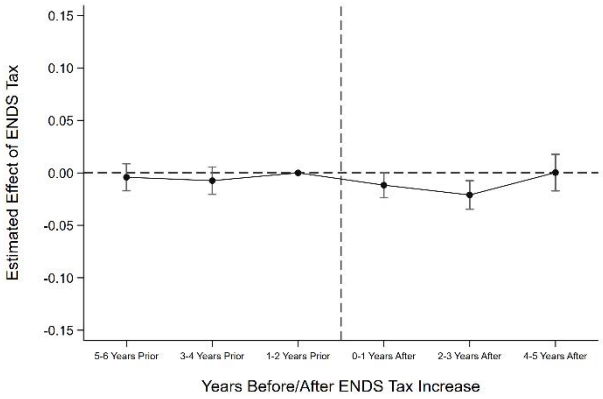
Panel (b): ENDS Use, Stacked DD Estimates



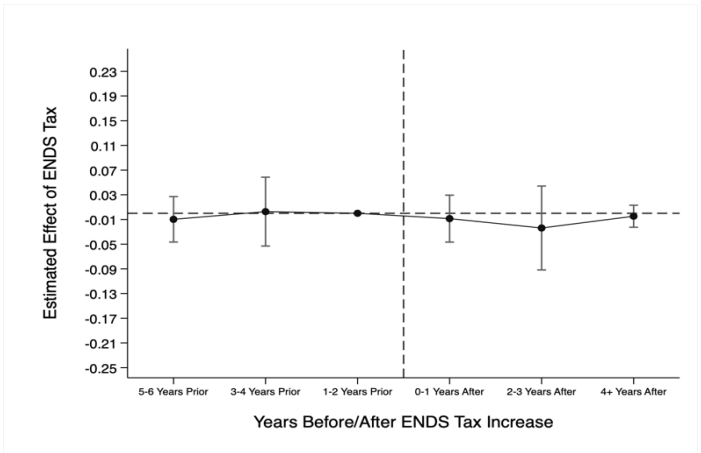
Panel (c): Marijuana Use, TWFE Estimates



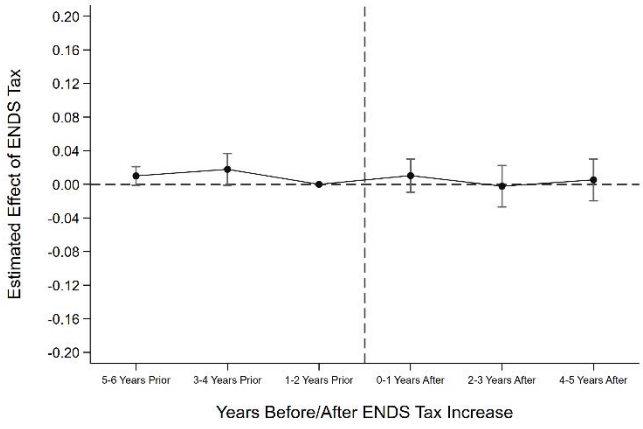
Panel (d): Marijuana Use, Stacked DD Estimates



Panel (e): Ever Hard Drug Use, TWFE Estimates



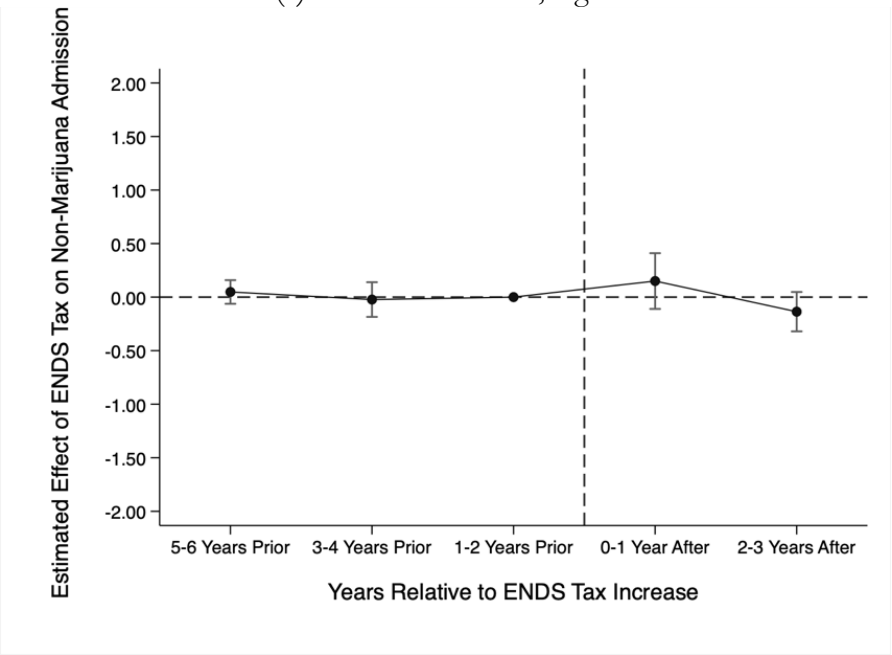
Panel (f): Ever Hard Drug Use, Stacked DD Estimates



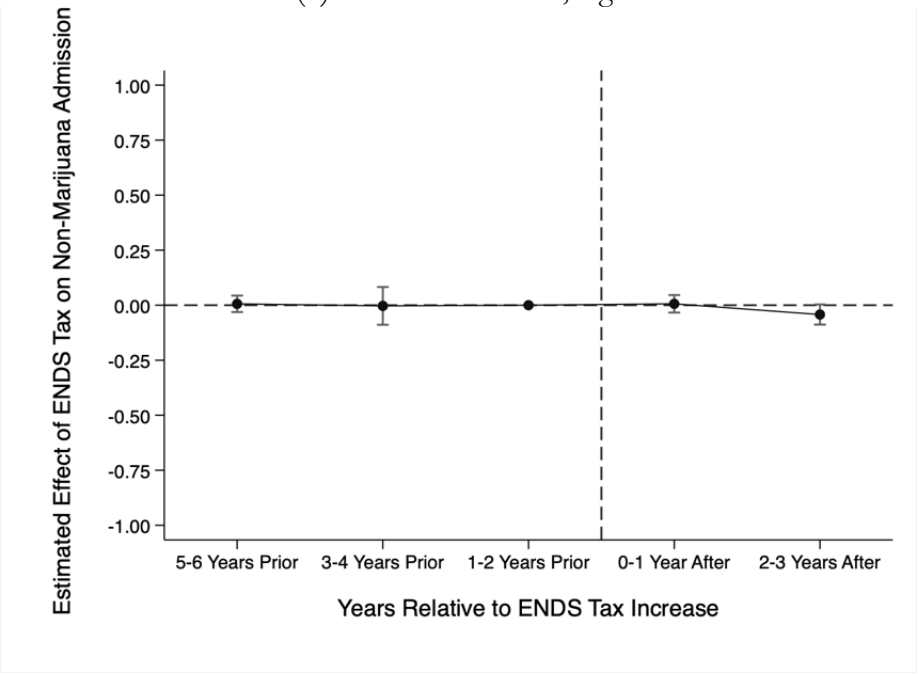
Notes: Estimates are generated using TWFE event study and stacked DD regressions, as noted, using the 2015-2023 State YRBS. The regressions control for state and year per semester fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, and non-marijuana drug policy controls. Data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Circles represent coefficient estimates. 95 percent confidence intervals that account for within state clustering are reported with vertical lines. The reference period is 1-2 years prior to tax adoption. Treatment states are those which adopted an ENDS tax in 2019 or earlier; control states are those that did not adopt an ENDS tax over the entire sample period.

Appendix Figure 7. Dynamic Effects of ENDS Taxes on Non-Marijuana Drug Admissions, TEDS, 2000-2022

Panel (a): TWFE Estimates, Ages 12-17

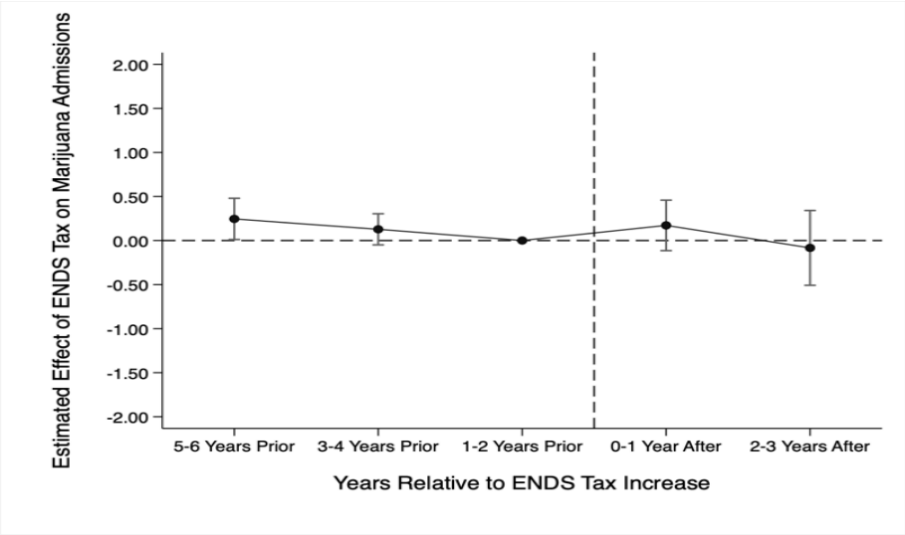


Panel (b): TWFE Estimates, Ages 18+

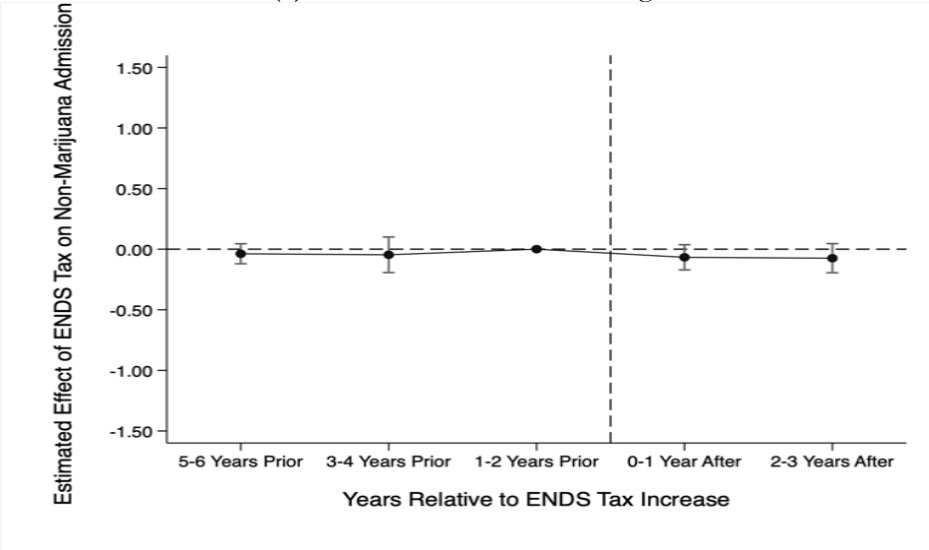


Appendix Table 7, Continued

Panel (c): Stacked DD Estimates, Ages 12-17



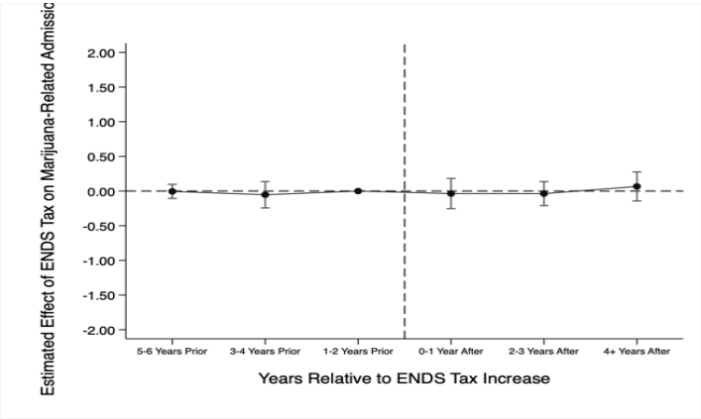
Panel (d): Stacked DD Estimates, Ages 18+



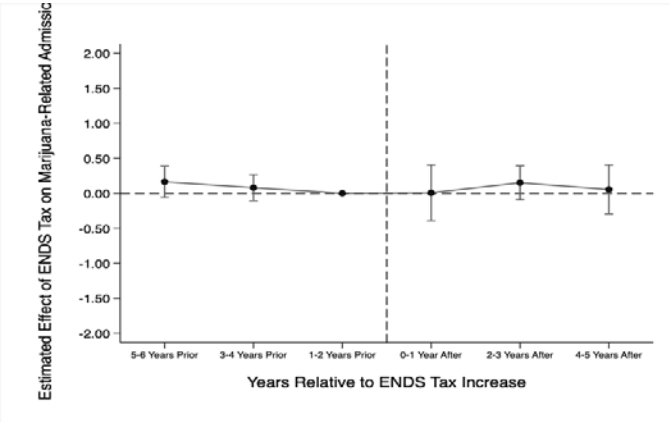
Notes: Estimates in Panels (a) and (b) are generated using weighted OLS estimates from a TWFE event study regression using the 2000-2022 TEDS. Estimates in Panels (c) and (d) are generated with a stacked event study regression using the 2000-2022 TEDS. The sample used in Panels (a) and (c) includes all individuals aged 12-to-17 and the sample used in Panels (b) and (d) includes all individuals aged 18 and older. The dependent variable is the natural log of the marijuana-related drug treatment admissions rate. For stacked DD regressions, each treated state's controls include states that had never implemented an ENDS tax ("never adopters") or have not-yet implemented an ENDS tax ("not-yet-adopters") over the sample period. The event-time window ranges from six years prior to tax adoption to two years following adoption. The reference period is 1-2 years prior to tax adoption. The regressions control for state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, and non-marijuana drug policy controls and a proxy for drug treatment capacity and state reporting. Data are weighted by the age-specific state population. Circles indicate coefficient estimates. 95 percent confidence intervals that account for within state clustering are reported with vertical lines.

Appendix Figure 8. Dynamic Effects of ENDS Taxes on Marijuana and Non-Marijuana Admissions using Early-Adopting Tax States, TEDS, 2000-2022

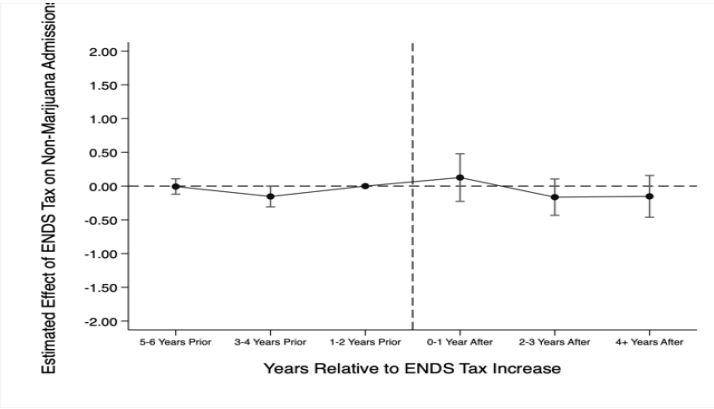
Panel (a): Marijuana, Ages 12-17, TWFE Estimates



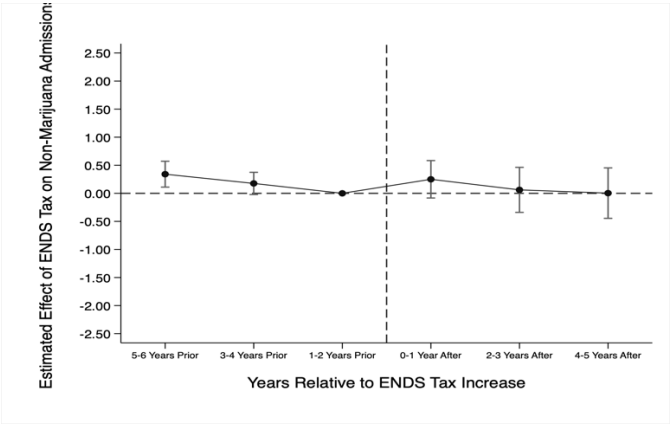
Panel (b): Marijuana, Ages 12-17, Stacked DD Estimates



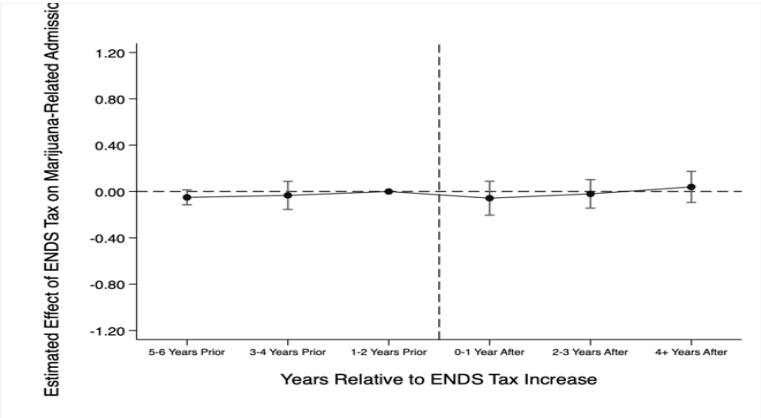
Panel (c): Non-Marijuana, Ages 12-17, TWFE Estimates



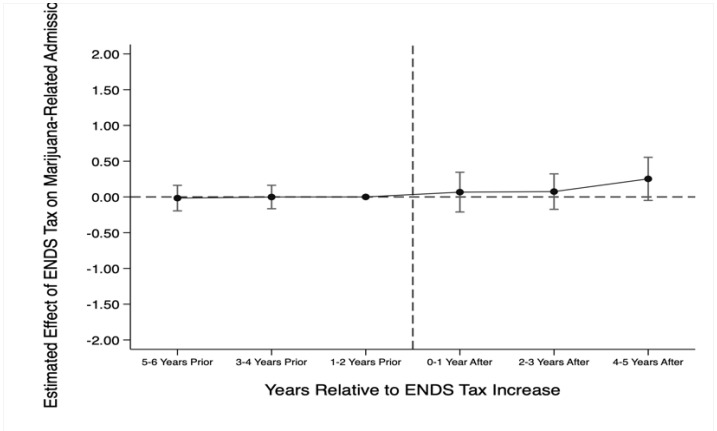
Panel (d): Non-Marijuana, Ages 12-17, Stacked DD Estimates



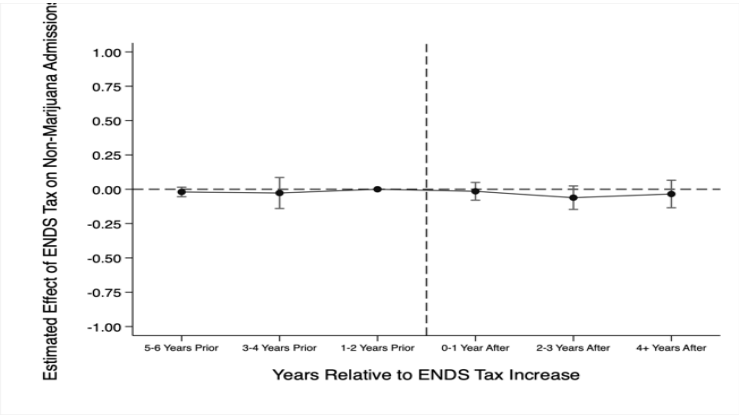
Panel (e): Marijuana, Ages 18+, TWFE Estimates



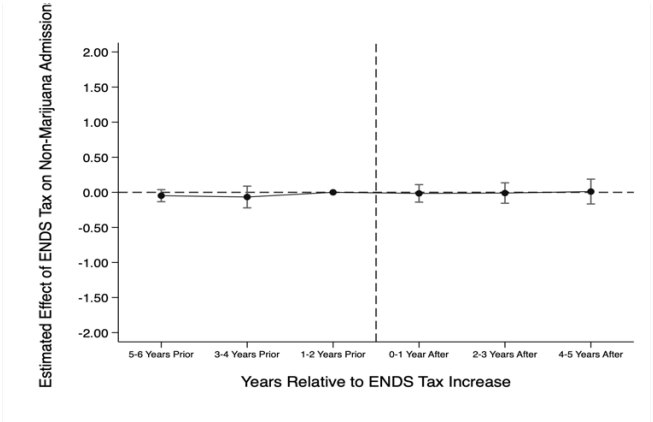
Panel (f): Marijuana, Ages 18+, Stacked DD Estimates



Panel (g): Non-Marijuana, Ages 18+, TWFE Estimates



Panel (h): Non-Marijuana, Ages 18+, Stacked DD Estimates



Notes: Estimates are generated using TWFE event study or stacked DD event study regression, as noted, regression using the 2000-2022 TEDS. Data are weighted by the age-specific state population. Circles represent coefficient estimates. 95 percent confidence intervals that account for within state clustering are reported with vertical lines. Treatment states are those which adopted an ENDS tax in 2019 or earlier; control states are those that did not adopt an ENDS tax over the entire sample period.

Appendix Table 1. ENDS Tax Adoption

Jurisdiction	Contributes to Identifying Variation?			Tax per mL Fluid, Q1-4 Average (2023 $)					
State	*State YRBS*	*National YRBS*	*BRFSS*	*2010*	*2015*	*2017*	*2019*	*2021*	*2023*
California	Yes	Yes	Yes	$0.00	$0.00	$1.49	$2.21	$2.06	$2.30
Colorado	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$1.02	$1.52
Connecticut	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.12	$0.45	$0.40
Delaware	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.06	$0.06	$0.05
Georgia	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$0.06	$0.05
Illinois	Yes	Yes	Yes	$0.00	$0.00	$0.43	$1.01	$1.22	$1.08
Indiana	Yes	No	Yes	$0.00	$0.00	$0.00	$0.00	$0.00	$0.46
Kansas	Yes	Yes	Yes	$0.00	$0.00	$0.16	$0.06	$0.06	$0.05
Kentucky	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$1.50	$1.33
Louisiana	Yes	Yes	Yes	$0.00	$0.03	$0.06	$0.06	$0.06	$0.10
Massachusetts	No	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$2.56	$2.28
Maine	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$1.47	$1.31
Maryland	Yes	Yes	Yes	$0.00	$0.07	$0.20	$0.19	$2.16	$2.37
Minnesota	No	Yes	Yes	$1.24	$3.71	$3.59	$3.44	$3.24	$2.89
Nevada	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$1.02	$0.91
New Hampshire	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$0.34	$0.30
New Jersey	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.12	$0.11	$0.10
New Mexico	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.26	$0.50	$0.44
New York	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.08	$0.92	$0.82
North Carolina	Yes	Yes	Yes	$0.00	$0.04	$0.06	$0.06	$0.06	$0.05
Ohio	No	Yes	Yes	$0.00	$0.00	$0.00	$0.02	$0.11	$0.10
Oregon	No	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$2.22	$1.97
Pennsylvania	Yes	Yes	Yes	$0.00	$0.00	$1.51	$1.45	$1.37	$1.21
Utah	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$1.91	$1.70
Vermont	Yes	Yes	Yes	$0.00	$0.00	$0.00	$1.67	$3.14	$2.79
Virginia	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$0.07	$0.07
District of Columbia	No	Yes	Yes	$0.00	$0.65	$2.41	$3.43	$3.01	$2.40
Washington	No	Yes	Yes	$0.00	$0.00	$0.00	$0.08	$0.30	$0.27
West Virginia	Yes	Yes	Yes	$0.00	$0.00	$0.09	$0.09	$0.08	$0.08
Wisconsin	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.01	$0.06	$0.05
Wyoming	Yes	Yes	Yes	$0.00	$0.00	$0.00	$0.00	$0.51	$0.46

Notes: Standardized ENDS taxes are from Cotti et al (2024).

Appendix Table 2. Descriptive Statistics, State and National YRBS, 2003-2023

Survey	State	National
Dependent Variables		
E-cigarette Use[a]	0.187	0.207
	(0.390)	(0.405)
	[N=735,109]	[N= 72,644]
Marijuana Use[b]	0.188	0.203
	(0.391)	(0.402)
	[N=1,418,034]	[N=160,243]
Use Marijuana Less Than 3 Times[b]	0.074	0.080
	(0.262)	(0.271)
	[N=1,239,329]	[N=138,258]
Use Marijuana More Than 3 Times[b]	0.123	0.133
	(0.328)	(0.340)
	[N=1,418,034]	[N=160,243]
Use Marijuana More Than 10 Times[b]	0.077	0.086
	(0.267)	(0.281)
	[N=1,418,034]	[N=160,243]
Ever Use Marijuana[b]	0.372	0.410
	(0.483)	(0.492)
	[N=1,037,012]	[N=122,183]
Ever Use Harder Heroin or Cocaine[b]	0.072	0.059
	(0.258)	(0.236)
	[N= 1,135,739]	[N=151,518]
Individual Controls		
Male	0.506	0.510
	(0.500)	(0.500)
Age	4.994	4.992
	(1.238)	(1.232)
Non-Hispanic White	0.547	0.566
	(0.498)	(0.497)
Non-Hispanic Black	0.170	0.137
	(0.375)	(0.344)
Latino/Hispanic	0.203	0.199
	(0.402)	(0.399)
Grade	2.414	2.419
	(1.119)	(1.118)
Independent Variables		
ENDS Tax (2021 $)	0.150	0.297
	(0.459)	(0.750)
Cigarette Tax (2021 $)	1.855	1.916
	(1.300)	(1.204)
Beer Tax (2021 $)	0.393	0.362
	(0.358)	(0.337)
Tobacco 21 Law	0.221	0.242
	(0.415)	(0.429)
ENDS MLSA	0.491	0.473
	(0.499)	(0.499)
Indoor Smoking Restrictions	0.556	0.597
	(0.494)	(0.490)

Appendix Table 2 Descriptive Statistics, State and National YRBS, 2003-2023, Continued

Indoor ENDS Smoking Restrictions	0.126	0.151
	(0.332)	(0.358)
ENDS Licensure Laws	0.175	0.221
	(0.379)	(0.414)
ENDS Flavor Restrictions	0.036	0.055
	(0.180)	(0.220)
Online ENDS Bans	0.028	0.021
	(0.166)	(0.144)
Recreational Marijuana Law	0.111	0.138
	(0.313)	(0.343)
Medical Marijuana Law	0.350	0.443
	(0.476)	(0.495)
Unemployment Rate	5.718	5.852
	(2.103)	(2.246)
Poverty Rate	13.005	12.573
	(2.995)	(2.981)
Covid Deaths Rate	0.0005	0.001
	(0.001)	(0.001)
Naloxone Access Laws	0.488	0.506
	(0.496)	(0.497)
Prescription Drug Monitoring Programs	0.330	0.309
	(0.469)	(0.460)
N	1,467,595	163,921

Notes: Means and standard deviations (in parenthesis) are reported. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). National YBRS data are weighted by YRBS-provided weights.

[a] Dependent variable is based on questions asked in the 2015-2023 YRBS.

[b] Dependent variable is based on questions asked in the 2003-2023 YRBS.

Appendix Table 3A. Descriptive Statistics, BRFSS 2016-2023

	Ages 18-to-30	Ages 18-to-20	Ages 21-to-30	Ages 31-and-older
Dependent Variables				
Current ENDS Use	0.138	0.156	0.132	0.042
	(0.345)	(0.363)	(0.338)	(0.201)
Daily ENDS Use	0.061	0.065	0.059	0.018
	(0.239)	(0.246)	(0.237)	(0.133)
Individual Control Variables				
Age	23.860	18.976	25.489	54.545
	(3.829)	(0.819)	(2.952)	(14.533)
Female	0.481	0.471	0.484	0.521
	(0.500)	(0.499)	(0.500)	(0.500)
Married	0.189	0.024	0.243	0.590
	(0.391)	(0.155)	(0.429)	(0.492)
No High School	0.108	0.144	0.095	0.129
	(0.310)	(0.351)	(0.294)	(0.335)
High School	0.349	0.513	0.295	0.256
	(0.477)	(0.500)	(0.456)	(0.436)
Some College	0.336	0.332	0.338	0.302
	(0.473)	(0.471)	(0.473)	(0.459)
College Degree	0.207	0.012	0.272	0.313
	(0.405)	(0.107)	(0.445)	(0.464)
Non-Hispanic White	0.514	0.499	0.519	0.640
	(0.500)	(0.500)	(0.500)	(0.480)
Non-Hispanic Black	0.117	0.120	0.117	0.114
	(0.322)	(0.325)	(0.321)	(0.318)
Latino/Hispanic	0.229	0.228	0.229	0.144
	(0.420)	(0.420)	(0.420)	(0.351)
N	289,491	57,123	232,368	2,096,021

Notes: Weighted means and standard deviations (in parenthesis) are reported.

Appendix Table 3B. States Included in the BRFSS ENDS Module by Year

Year:	2016	2017	2018	2020	2021	2022	2023
Alabama	Y			Y	Y	Y	Y
Alaska	Y	Y	Y	Y	Y	Y	Y
Arizona	Y				Y	Y	Y
Arkansas	Y	Y	Y	Y	Y	Y	Y
California	Y				**Y**	**Y**	**Y**
Colorado	Y	Y	Y		**Y**	**Y**	**Y**
Connecticut	Y	Y	Y	**Y**	**Y**	**Y**	**Y**
Delaware	Y	Y	**Y**	**Y**	**Y**	**Y**	**Y**
District of Columbia	Y				**Y**	**Y**	**Y**
Florida	Y	Y	Y	Y	Y	Y	Y
Georgia	Y	Y	Y	Y	**Y**	**Y**	**Y**
Hawaii	Y	Y	Y	Y	Y	Y	Y
Idaho	Y	Y	Y	Y	Y	Y	Y
Illinois	Y			**Y**	**Y**	**Y**	**Y**
Indiana	Y	Y	Y	Y	Y	**Y**	**Y**
Iowa	Y	Y	Y		Y	Y	Y
Kansas	Y	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Kentucky	Y			**Y**	**Y**	**Y**	**Y**
Louisiana	**Y**	**Y**	**Y**		**Y**	**Y**	**Y**
Maine	Y	Y	Y	**Y**	**Y**	**Y**	**Y**
Maryland	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Massachusetts	Y	Y	Y	**Y**	**Y**	**Y**	**Y**
Michigan	Y	Y	Y	Y	Y	Y	Y
Minnesota	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Mississippi	Y	Y	Y	Y	Y	Y	Y
Missouri	Y	Y	Y	Y	Y	Y	Y
Montana	Y	Y	Y	Y	Y	Y	Y
Nebraska	Y	Y	Y	Y	Y	Y	Y
Nevada	Y			**Y**	**Y**	**Y**	**Y**
New Hampshire	Y	Y	Y	**Y**	**Y**	**Y**	**Y**
New Jersey	Y			**Y**	**Y**	**Y**	**Y**
New Mexico	Y			**Y**	**Y**	**Y**	**Y**
New York	Y	Y	Y	**Y**	**Y**	**Y**	**Y**
North Carolina	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
North Dakota	Y	Y	Y	Y	Y	Y	Y
Ohio	Y	Y	Y	**Y**	**Y**	**Y**	**Y**
Oklahoma	Y				Y	Y	Y
Oregon	Y	Y	Y	Y	**Y**	**Y**	**Y**
Pennsylvania	**Y**			**Y**	**Y**	**Y**	**Y**
Rhode Island	Y	Y	Y	Y	Y	Y	Y
South Carolina	Y				Y	Y	Y
South Dakota	Y	Y	Y	Y	Y	Y	Y
Tennessee	Y	Y	Y	Y	Y	Y	Y
Texas	Y	Y	Y	Y	Y	Y	Y

Utah	Y	Y	Y	**Y**	**Y**	**Y**	**Y**
Vermont	Y			**Y**	**Y**	**Y**	**Y**
Virginia	Y	Y	Y	**Y**	**Y**	**Y**	**Y**
Washington	Y			**Y**	**Y**	**Y**	**Y**
West Virginia	**Y**			**Y**	**Y**	**Y**	**Y**
Wisconsin	Y	Y	Y		**Y**	**Y**	**Y**
Wyoming	Y	Y	Y	**Y**	**Y**	**Y**	**Y**

Notes: Data source is the 2016-2023 Behavioral Risk Factor Surveillance Survey. Y = state provides ENDS use questions. In some years, ENDS questions are included in the core BRFSS survey and all states have ENDS use information while in other years, ENDS use information is included in an optional module and not all states opt into this module and thus there is no ENDS use information for those states in those years. Blank = state does not participate in the BRFSS optional ENDS module. Bold text indicates state-years in which an ENDS tax is in place and the state provides ENDS use information in the BRFSS.

Appendix Table 4. Descriptive Statistics, TEDS 2000-2022

Dependent Variables	
Primary Marijuana-Related Admissions, Ages 12-to-17	3.017
	(0.089)
Primary Marijuana-Related Admissions, Ages 18-and-older	0.834
	(0.027)
Any Marijuana-Related Admissions, Ages 12-to-17	3.684
	(0.109)
Any Marijuana-Related Admissions, Ages 18-and-older	2.298
	(0.076)
Any No-Marijuana-Related Admissions, Ages 12-to-17	0.702
	(0.033)
Any No-Marijuana-Related Admissions, Ages 18-and-older	5.072
	(0.164)
Primary Heroin-Related Admissions, Ages 12-to-17	0.048
	(0.003)
Primary Heroin-Related Admissions, Ages 18-and-older	1.383
	(0.068)
Primary Cocaine and Meth-Related Admissions, Ages 12-to-17	0.211
	(0.013)
Primary Cocaine and Meth-Related Admissions, Ages 18-and-older	1.340
	(0.040)
N	1,130

Notes: Means and standard deviations (in parenthesis) are reported**.** Data are weighted the age-specific state population.

Appendix Table 5. TWFE Estimates of the Effects of ENDS Taxes on Frequent and Daily ENDS Use Among Youths, State YRBS 2015-2023

	(1)	(2)	(3)
	Panel I: Frequent ENDS Use		
ENDS Tax ($)	-0.016***	-0.014**	-0.013**
	(0.002)	(0.006)	(0.006)
N	735109	735109	735109
Pre-Treatment Mean of Dep Variable	0.042	0.042	0.042
	Panel II: Daily ENDS Use		
ENDS Tax ($)	-0.013***	-0.011**	-0.010**
	(0.002)	(0.005)	(0.005)
N	735109	735109	735109
Pre-Treatment Mean of Dep Variable	0.029	0.029	0.029
	Panel III: Infrequent ENDS Use[a]		
ENDS Tax ($)	-0.005	-0.017**	-0.019**
	(0.004)	(0.008)	(0.009)
N	0.170	0.170	0.170
Pre-Treatment Mean of Dep Variable	696910	696910	696910
	Panel IV: Non-Daily ENDS Use[b]		
ENDS Tax ($)	-0.008**	-0.020**	-0.022**
	(0.004)	(0.009)	(0.009)
N	0.181	0.181	0.181
Pre-Treatment Mean of Dep Variable	707541	707541	707541
State and Year-by-Semester FE?	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes
Macroeconomic & COVID-19 Controls?	No	Yes	Yes
Tobacco Policy Controls?	No	Yes	Yes
Alcohol Policy Control?	No	Yes	Yes
Marijuana Policy Controls?	No	Yes	Yes
Non-marijuana Drug Policy Controls?	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2015-2023 waves of the State YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). National YRBS data are weighted by YRBS-provided weights. Standard errors are clustered at the state level and are reported in parentheses.

[a] Individuals who vaped on less than 20 days in the past month compared to non-users (excluding frequent ENDS users).

[b] Individuals who vaped on less than 30 days in the past month compared to non-users (excluding daily ENDS users).

Appendix Table 6. TWFE Estimates of the Effects of ENDS Taxes on Marijuana Use Among Youths, Combined State & National YRBS 2015-2023

	(1)	(2)	(3)	(4)
ENDS Tax ($)	-0.0132***	-0.0110***	-0.0102	-0.0119*
	(0.0038)	(0.0040)	(0.0068)	(0.0067)
N	858682	858682	858682	858682
Pre-Treat Mean of Dep Var	0.186	0.186	0.186	0.186
State & Year-by-Semester FE?	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes
Macro & COVID-19 Controls?	No	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes
Alcohol Policy Control?	No	No	No	Yes
Marijuana Policy Controls?	No	No	No	Yes
Non-MJ Drug Policy Controls?	No	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2015-2023 waves of the Combined State and National YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. Combined YRBS data are weighted using population weights generated from the SEER data to be nationally representative. Standard errors are clustered at the state level and are reported in parentheses.

Appendix Table 7. TWFE Estimates of the Effects of ENDS Taxes on Marijuana Use Among Youths, State YRBS 2015-2023 [a]

ENDS Policy Variables	Coefficient estimate (standard error)
ENDS Tax ($)	-0.0142**
	(0.0064)
E-cigarette MLSA	-0.0116
	(0.0125)
Tobacco 21 Law	0.0162
	(0.0097)
E-cigarette Licensure Law	-0.0022
	(0.0074)
Indoor Vaping Ban	0.0029
	(0.0069)
Flavored Vape Ban	-0.0010
	(0.0133)
E-cigarette Online Shipments Ban	-0.0122
	(0.0130)
N	713954
Pre-Treatment Mean of Dep Variable	0.1815
State and Year-by-Semester FE?	Yes
Full set of Controls?	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

[a] The sample for these regressions are limited to respondents who provided non-missing information on both ENDS use and marijuana use.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2015-2023 waves of the State YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Standard errors are clustered at the state level and are reported in parentheses.

Appendix Table 8. Interactive Effects of Marijuana Policy Environment with ENDS Taxes, State YRBS 2003-2023

	(1)
	Marijuana use 12-18 years
ENDS Tax ($)	-0.011**
	(0.004)
ENDS Tax * Marijuana Liberalized	0.0002
	(0.008)
Medical Marijuana Law	0.002
	(0.004)
Recreational Marijuana Law	-0.005
	(0.005)
N	1,411,893
Pre-Treatment Mean of Dep Variable	0.197
State and Year-by-Semester FE?	Yes
Full Controls?	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: The variable "Marijuana liberalized" is equivalent to a state recreational marijuana law or a state medical marijuana law. Estimates are generated with a TWFE difference-in-differences regression using the 2003-2023 State YRBS. All regressions control for state and year-by-semester fixed effects, demographic controls, macroeconomics controls, tobacco policy controls, marijuana policy controls, alcohol policy control, non-marijuana drug policy controls. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Standard errors are clustered at the state level and are reported in parentheses.

Appendix Table 9. Unweighted TWFE Estimates of Effect of ENDS Taxes on ENDS Use Among Young Adults, BRFSS 2016-2023

	(1)	(2)	(3)	(4)	(5)	(6)
	Current ENDS Use			**Daily ENDS Use**		
			Panel I: Ages 18-30			
ENDS Tax ($)	-0.0097***	-0.0080***	-0.0041	-0.0068***	-0.0054***	-0.0020
	(0.0024)	(0.0026)	(0.0044)	(0.0016)	(0.0017)	(0.0028)
N	289491	289491	289491	289491	289491	289491
Pre-Treatment Mean of Dep Variable	0.1307	0.1307	0.1307	0.0567	0.0567	0.0567
			Panel II: Ages 18-20			
ENDS Tax ($)	-0.0058	-0.0017	-0.0003	-0.0063*	-0.0031	-0.0013
	(0.0062)	(0.0056)	(0.0075)	(0.0037)	(0.0031)	(0.0048)
N	57123	57123	57123	57123	57123	57123
Pre-Treatment Mean of Dep Variable	0.1706	0.1706	0.1706	0.0697	0.0697	0.0697
			Panel III: Ages 21-30			
ENDS Tax ($)	-0.0109***	-0.0099***	-0.0047	-0.0070***	-0.0060***	-0.0021
	(0.0023)	(0.0027)	(0.0048)	(0.0016)	(0.0020)	(0.0030)
N	232368	232368	232368	232368	232368	232368
Pre-Treatment Mean of Dep Variable	0.1206	0.1206	0.1206	0.0534	0.0534	0.0534
			Panel IV: Ages > 30			
ENDS Tax ($)	-0.0003	-0.0001	0.0007	-0.0008*	-0.0005	0.0003
	(0.0008)	(0.0008)	(0.0010)	(0.0003)	(0.0004)	(0.0006)
N	2096021	2096021	2096021	2096021	2096021	2096021
Pre-Treatment Mean of Dep Variable	0.0324	0.0324	0.0324	0.0132	0.0132	0.0132
State and Year-by-Semester FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macro & COVID-19 Controls?	No	Yes	Yes	No	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	No	No	Yes
Alcohol Policy Control?	No	No	Yes	No	No	Yes
Marijuana Policy Controls?	No	No	Yes	No	No	Yes
Non-Marijuana Drug Policy Controls?	No	No	Yes	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2016-2023 waves of the BRFSS dataset. Semester is defined as one for interviews fielded January to June and two for interviews fielded July to December. Demographic controls include age, gender, education (no high school, high school, some college), race (white, black, and Hispanic), and marital status Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. Regressions are unweighted and include state and year by month fixed effects. Standard errors are clustered at the state level and are reported in parentheses.

Appendix Table 10. TWFE Estimates of Effect of ENDS Taxes on Cigarette Smoking Among Youths, YRBS 2015-2023

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel I: State YRBS			
ENDS Tax ($)	0.007	0.005	-0.002	-0.004	-0.003	-0.003
	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.005)
			Panel II: State YRBS Lagged Effect			
0-1 Years After	0.008	0.006	-0.001	-0.002	-0.002	-0.001
	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)
2-3 Years After	0.004	0.002	-0.003	-0.005	-0.005	-0.005
	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.005)
4+ Years After	0.002	0.002	0.004	0.001	0.001	0.001
	(0.006)	(0.006)	(0.008)	(0.008)	(0.007)	(0.007)
N	776429	776429	776429	776429	776429	776429
Pre-Treatment Mean of Dep Variable	0.074	0.074	0.074	0.074	0.074	0.074
			Panel III: Combined State & National YRBS			
ENDS Tax ($)	0.011***	0.011***	0.011*	0.011*	0.009	0.009
	(0.003)	(0.004)	(0.006)	(0.006)	(0.006)	(0.006)
			Panel IV: Combined State & National YRBS Lagged Effect			
0-1 Years After	0.011**	0.010**	0.014**	0.014*	0.013**	0.014**
	(0.005)	(0.004)	(0.007)	(0.007)	(0.007)	(0.007)
2-3 Years After	0.006	0.006	0.007	0.007	0.005	0.005
	(0.004)	(0.005)	(0.006)	(0.006)	(0.005)	(0.006)
4+ Years After	0.013***	0.013***	0.023***	0.024***	0.023***	0.024***
	(0.003)	(0.004)	(0.008)	(0.008)	(0.007)	(0.008)
N	851179	851179	851179	851179	851179	851179
Pre-Treatment Mean of Dep Variable	0.082	0.082	0.082	0.082	0.082	0.082
State, Year-by-Semester FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic & COVID-19 Controls?	No	Yes	Yes	Yes	Yes	Yes
Tobacco Policy Controls?	No	No	Yes	Yes	Yes	Yes
Alcohol Policy Control?	No	No	No	Yes	Yes	Yes
Marijuana Policy Controls?	No	No	No	No	Yes	Yes
Non-marijuana Drug Policy Controls?	No	No	No	No	No	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2015-2023 waves of the State (Panel I) and Combined State and National (Panel II) YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate, state poverty rate, and Covid death rates. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans. State alcohol policy control is the beer tax (2023$). State marijuana policy controls include medical marijuana laws, and recreational marijuana laws. State non-marijuana drug policy controls include naloxone access laws, and prescription drug monitoring programs. State YRBS data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details). Combined YRBS data are weighted using population weights generated from the SEER data to be nationally representative. Standard errors are clustered at the state level and are reported in parentheses.

Appendix Table 11. Effects of ENDS Taxes on Drug Treatment Admission (Level Per Population), TEDS 2000-2022

	(1)	(2)	(3)	(4)	(5)
	Marijuana (Primary)	Marijuana (Any)	Non-Marijuana (Any)	Heroin (Primary)	Cocaine or Meth (Primary)
	TEDS	TEDS	TEDS	TEDS	TEDS
			Panel I: Ages 12-17		
ENDS Tax ($)	0.066	0.078	-0.128	-0.002	-0.093***
	(0.150)	(0.198)	(0.092)	(0.017)	(0.020)
N	1130	1130	1130	1130	1130
Pre-Treat Mean DV	3.989	4.858	0.798	0.072	0.352
			Panel II: Ages 18 and older		
ENDS Tax ($)	0.017	0.039	-0.039	-0.307**	0.083
	(0.038)	(0.116)	(0.116)	(0.150)	(0.113)
N	1130	1130	1130	1130	1130
Pre-Treat. Mean DV	0.820	2.083	4.729	1.554	1.657

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2000-2022 TEDS. The dependent variable are the indicated drug treatment admissions. All regressions control for state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, non-marijuana drug policy controls. TEDS regressions also control for a proxy for treatment capacity and state reporting. TEDS data are weighted by the age-specific state population. Standard errors are clustered at the state level and are reported in parentheses.

Appendix Table 12. Accounting for Multiple Comparisons (Anderson, 2008), State YRBS 2003-2023

Outcome (location in text)	p-value	Sharpened q-value
E-cigarette use in the past month (Table 1 Panel I column 6)	0.010	0.042
Marijuana use in the past month (Table 3 Panel II column 6)	0.027	0.048
Dual use of e-cigarettes and marijuana in the past month (Table 5 Panel I column 3)	0.008	0.042
Ever hard drug use defined as cocaine or heroin (Table 7 Panel I column 6)	0.434	0.379
Marijuana use three or more times in the past month (Table 8 Panel I column 3)	0.549	0.379
Marijuana use ten or more times in the past month (Table 8 Panel I column 4)	0.030	0.048
Cigarette smoking in the past month (Appendix Table 10 Panel I column 6)	0.317	0.340

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2003-2023 waves of the State YRBS. All regressions control for: demographic controls (age, gender, grade, and race/ethnicity); macroeconomic controls (state unemployment rate, state poverty rate, and Covid death rates); state tobacco policy controls (T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, an index for indoor ENDS restrictions, ENDS flavor restrictions, ENDS licensure laws, and ENDS online shipment bans); state alcohol policy control (beer tax (2023$)); state marijuana policy controls (medical marijuana laws, and recreational marijuana laws); and state non-marijuana drug policy controls (naloxone access laws, and prescription drug monitoring programs). Data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details).