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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 is the first to explore the effects of ENDS taxes on substance use. We find that a one-dollar increase in ENDS taxes (2019$) is associated with a 1-to-2 percentage point decline in teen marijuana use and a 0.8 percentage point reduction in adult marijuana use. This result is consistent with e-cigarettes and marijuana being economic complements. 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 over this sample period.

Keywords: ENDS taxation; Teen marijuana use; Vaping; E-cigarette use
JEL codes: I18; I12; J13

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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 consumers to treat a variety of painful symptoms associated with chronic and acute health ailments (National Academies of Sciences 2017)[2] and 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). For instance, frequent and heavier marijuana use has been found to increase the risk of respiratory disease (National Academies of Sciences, 2017). Moreover, joint consumption of ENDS and marijuana products during the 2019-2020 "e-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, 2023a). 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).

[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 and shows no signs of abating (Maclean et al., 2022).

Marijuana use among youths and young adults is 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.[4] Early initiation of marijuana use 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). Because the brain continues to develop through one's early 20s — most notably in regions linked to executive function, reward, and impulse control (Gruber & Köszegi, 2001) — substance use 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). In addition, early initiation into marijuana use more than triples the risk for cannabis use disorder (CUD), 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 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 a growing literature that explores the spillover effects of e-cigarette-inclusive tobacco control policies on 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., 2021; Pesko & Warman, 2022). We focus on ENDS taxes, an increasingly popular policy strategy to curb nicotine vaping, particularly among youth and young adults, as well as a tool that can, when optimally set, 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).[5] Minnesota was the first state to adopt a statewide ENDS tax in August 2010, with a $0.45 per ml of e-liquid (in 2019$). Given the scope (i.e., more than half of states have adopted ENDS taxes) and size (i.e., taxes range from $0.01 to over $2.50 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.

[4] In addition, the Substance Abuse and Mental Health Services Administration (SAMHSA) calls youth marijuana use "a major public health concern" (2021).

[5] 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.

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,[6] (2) because vaping nicotine serves as a gateway to marijuana use, (3) joint consumption enhances social capital acquisition (e.g., demonstrating one's "coolness" to peers), 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.[7] These biological, social and economic channels may also explain the high degree of co-engagement, particularly among youth, in both activities.[8] In this case, an increase in ENDS taxes would decrease demand for marijuana.

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.[9] 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., 2022) 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.

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 the above. However, the effects are likely to be smaller given that harder drugs are much less likely to be

[6] 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. (2022)).

[7] 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.

[8] Almost 52 percent of teens who currently use vaping products, also consume marijuana (2019 National Youth Risk Behavior Survey).

[9] 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.

economic complements or substitutes for e-cigarettes.[10] 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 is the first to examine the spillover effects of ENDS taxes on marijuana and harder drug use. Using data from five national datasets (State and National Youth Risk Behavior Survey, Behavioral Risk Factor Surveillance Survey, National Survey on Drug Use and Health, and Treatment Episode Dataset) spanning the period 2000 to 2019, and a generalized difference-in-differences approach, we document four key findings. First, we confirm earlier studies and show that ENDS taxes are effective in curbing ENDS use, particularly among teens and younger adults. Specifically, we find that a one-dollar increase in ENDS taxes (in 2019$) leads to a 5.4 to 7.6 percentage-point (20 to 34 percent) reduction in teenage ENDS use and a 1.1 to 3.1 percentage-point (13 to 23 percent) reduction in younger (18-to-30 years) adult vaping. Both the sign and magnitude of our "first stage" effects are in line with findings form earlier studies (Abouk, Courtemanche, et al., 2023; Pesko et al., 2020). 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 two percentage-point (10 percent) reduction in marijuana use among high school students and a 0.8 percentage-point (11 percent) reduction in marijuana use among adults ages 18-and-older. Our "second stage" effects are approximately 70 percent smaller in absolute magnitude relative to the first stage effects on e-cigarette use, suggesting that second stage spillover effects are plausible. A causal interpretation of these findings is supported by event study analyses, including those generated from both two-way fixed effects and stacked difference-in-differences approaches, which in the latter case adjust for any potential biases due to heterogeneity in the treatment effects dynamically or spatially across the treated units.

Third, we find no evidence that ENDS taxes affect other discretionary purchases (i.e., soda, fast food, juices, contraception), consistent with the hypothesis that the underlying mechanism driving the observed relationship between ENDS and marijuana use is unlikely an income effect. Back-of-the-envelope calculations also corroborate that the income effect generated by a one-dollar increase in the ENDS tax is not nearly large enough to explain the estimated reduction in marijuana use. Our estimated effects of ENDS taxation on marijuana use also cannot be fully explained by any secondary effects on marijuana use margins that operate through ENDS tax-induced shifts in

[10] 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 Youth Risk Behavior Survey.

cigarette smoking. These findings support the hypothesis that ENDS and marijuana are economic complements, and the relationship is particularly strong during adolescence and young adulthood, stages of development when the use of substances (including both ENDS and marijuana) can have negative and persistent impacts on a wide range of well-being measures.[11]

Finally, we find no 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 access affects marijuana use largely on the margin of lighter or moderate 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 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 Health and Cognitive Effects of Marijuana Use

In 2021, marijuana was the most commonly used recreational drug in the U.S. with 19.6 percent of adults (18 years and older) and 10.5 percent of youth (ages 12-to-17 years) reporting past-year use of this product (Substance Abuse and Mental Health Services Administration, 2023).[12] Public health advocates raise concern that marijuana consumption, particularly when initiated at earlier ages and consumed frequently at heavier doses, increases the risk of addiction, marijuana-related psychosis, respiratory problems, and exposure to toxic ingredients such as arsenic (National Academies of Sciences, 2018; Wang et al., 2022).

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 &

[11] In addition to the discussed health implications of marijuana use, youth ENDS use (absent use of marijuana) can potentially have negative implications such as impeded brain development associated with nicotine that is found in the vast majority of ENDS products (Cotti et al., 2022; U.S. Department of Health Human Services, 2016).
[12] This statistic excludes alcohol, which was consumed by 17.8 percent of youths under the age of 18 and 66.9 percent of young adults ages 18-and-older.

Williams, 2015); increased risk for motor vehicle accidents (Hingson et al., 1982);[13] and 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., 2007).

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.[14]

Furthermore, youths may discount the longer-term costs of current consumption decisions over addictive goods (Gruber & Köszegi, 2001; Scheier & Griffin, 2021; Steinberg, 2008), which may be large. 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 (Gruber & Köszegi, 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).

[13] 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 (53 percent based on 2017 National Youth Risk Behavior Survey).

[14] 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.

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 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.

2.2 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).[15] 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., 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 may 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).

2.3 *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).[16] The first recorded ENDS sale in the U.S. occurred in August 2006 (CASAA, 2023). These products quickly became popular among Americans with current use of ENDS products among adults increasing from 3.3

[15] 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.
[16] Commercially unsuccessful ENDS products date back as far as 1930 (CASAA, 2023).

percent in 2010 to 4.4 percent in 2014 and 5.1 percent in 2020 (Boakye et al., 2022; King et al., 2015).[17] Of particular relevance to our study, youth vaping increased exponentially after the entrance of ENDS to the U.S. tobacco market. In 2011 1.5 percent of high school students reported current use of ENDS and this share had increased to 20.8 percent in 2018 (Cullen et al., 2018). By 2022, 32.1 percent of high school seniors reported using ENDS in the past year (Miech et al., 2023).

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" use as ENDS are believed by most experts to be substantially less damaging to health than combustible cigarettes. 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. Alternatively, 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 increasing over time. 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 Tobacco-to-21 ("T-21") law, which raised the minimum legal purchasing of all tobacco 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).

[17] 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 National Health Interview Survey until 2014 and the BRFSS until 2016.

One of the most popular policy strategies to curb ENDS use is to tax its sale via an excise tax (per ml of e-liquid) or an ad valorem tax. As of November 2023, 31 states and the District of Columbia had adopted an ENDS tax (Public Health Law Center, 2023). Minnesota was the first state to adopt an ENDS tax (August 1, 2010), imposing an excise tax of 35 percent, later raised to 95 percent in 2013. In 2015, two more states (Louisiana and North Carolina) and the District of Columbia adopted an ENDS tax followed by two more states (Pennsylvania and West Virginia) in 2016, two more in 2017 (California, Kansas), two more in 2018 (Delaware, New Jersey), eight in 2019 (Connecticut, Illinois, New Mexico, New York, Ohio, Vermont, Washington, and Wisconsin), and 13 more (Colorado, Georgia, Indiana, Kentucky, Maine, Maryland, Massachusetts, Nevada, New Hampshire, Oregon, Utah, Virginia, and Wyoming) by the end of 2022. In addition, over this period two large counties also adopted ENDS taxes: Cook County, Illinois (in 2016) and Montgomery County, Maryland (in 2015). Figure 1 shows the geographic and temporal variation in ENDS taxes over the period 2010-2019, 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 we exploit in our empirical analyses.

2.4 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)[18] and that vaping declines substantially post-tax (Abouk, Courtemanche, et al., 2023; Cotti et al., 2022). For example, a one-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 (and nearly one-for-one based on the findings of Cotti et al. (2022)), 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.

[18] 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.

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.[19] 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 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.

[19] 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 half (51.8 percent) of the surveyed teens in the 2019 National YRBS reported also using marijuana.

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., 2022), the net marijuana effects from these second-order spillover channels are difficult to sign.

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 12 to 18 years report past-month ENDS use and ever use of cocaine or heroin the State Youth Risk Behavior Survey (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).

2.5 Literature on Tobacco and Marijuana Use

Public health experts often claim that tobacco may be a gateway drug to marijuana (Dai et al., 2018), but the evidence using methods designed to estimate causal effects to support this hypothesis is decidedly mixed, with different studies reaching distinct conclusions on the direction and strength of this relationship. The literature assessing this pathway has largely focused on combustible cigarettes.

In an early study, Pacula (1998) 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.[20] Using data from the National Household Survey on Drug Abuse for the period 1990–1996, Farrelly et al. (2001) 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

[20] 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 variable bias.

data from Monitoring the Future over the period 1992 to 1994, Chaloupka et al. (1999) 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, but findings are based on the U.S. tobacco market in the 1980s and 1990s, which is quite different from the current market.

On the other hand, 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. In an extension to the main analysis, the authors examine the impact of introducing an ENDS tax on marijuana use and find evidence of economic complementarity.[21] In particular, 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. 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. A recent study by Hansen et al. (2021) exploits data from the 2009-2019 State Youth Risk Behavior Survey to study the effect of T-21 laws on youth tobacco, alcohol, and marijuana 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.[22] There is very little causal evidence on the impact of recreational marijuana legalization on youth tobacco consumption.

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[21] The authors use a measure of "any" ENDS tax and therefore do not compensate for the intensity of the tax. Further, in using data through spring of 2017 (as we describe in Section 2.3), the authors are only able to exploit the introduction of ENDS taxes in ten states. Finally, the authors only consider just two marijuana use measures, and do not consider the use of other illicit substances. Thus, we build on this study in important ways.

[22] 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).

This study advances the above literature by being the first to comprehensively explore the impact of e-cigarette taxation on marijuana and harder drug use. While our focus is on youth and adult marijuana use, we also explore spillovers to drug treatment admissions and harder drug use, which could be affected through gateway type spillovers from effects on marijuana consumption.

3. Data

Our empirical analysis draws on five national datasets to measure youth and adult marijuana use, as well as harder drug use, spanning the period 2000-2019. The datasets include the State and National Youth Risk Behavior Surveys (YRBS), the Behavioral Risk Factor Surveillance System (BRFSS), the National Survey on Drug Use and Health (NSDUH), 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. We describe each dataset in turn.[23]

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 2019. 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.[24] Because we analyze (primarily)[25] a *state* policy change, the use of survey data designed to generate population-based estimates of *state-level* trends in risky health behaviors of high school students is an important advantage. Over the 2003-2019 period, the State YRBS were largely distributed in the Spring of the academic year (January through June), allowing us to identify the effects of ENDS taxes for eight of 17 treatment states as well as three large localities in two additional states (see Appendix Table 1). We note that because of the lack of data before and after

[23] We truncate the sample in 2019 to avoid confounding from the COVID-19 pandemic.
[24] The person-specific sample weights we generate make the sample representative of all 14-to-18-year-olds in the U.S. Our person-specific sample weights are calculated as the product of the normalized State YRBS person weight (renormalized to sum to one in each state-year) and the state-by-year-by race/ethnicity-by gender population data on 14-to-18-year-olds from the National Cancer Institute's Surveillance, Epidemiology, and End Results Program (SEER).
[25] Two counties have adopted ENDS taxes (see Section 2.3).

their ENDS tax changes, Minnesota 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. Questions on ENDS and marijuana use are conveniently identical 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. 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). For this reason, we view the State YRBS as our preferred dataset for youth ENDS and marijuana use.

To estimate "first stage" effects of ENDS taxes on nicotine vaping among U.S. high school students we pool data from the 2015-2019 surveys. Beginning in 2015 and continuing in each subsequent wave, respondents to the State and National 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?"

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 21.1 percent of respondents in the State YRBS and 23.6 percent of respondents in the National YRBS report prior month ENDS use.

Next, we turn to our marijuana use measure, for which we can turn to earlier YRBS waves pre-dating the adoption of the first statewide ENDS tax (in 2010 in Minnesota). We draw marijuana data 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 19.9 percent of respondents in the State YRBS and 22.0 percent of respondents in the National YRBS report prior month marijuana use. If we examine heavier marijuana use, we find 13.0 percent of respondents in the State YRBS report consuming marijuana at least three times in the last month and 8.2 percent report consuming marijuana at least ten times in the last month.[26] Appendix Figure 1 shows the time trends in marijuana use for the full sample period.

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,[27] 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).[28]

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 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 for the State and National YRBS.

3.2 Behavioral Risk Factor Surveillance System (BRFSS)

To study adults, we supplement our analysis of the State and National YRBS first with data from the Behavioral Risk Factor Surveillance System (BRFSS). The BRFSS is a large comprehensive

[26] In the National YRBS, these numbers are 14.5 percent and 9.2 percent respectively.
[27] The states are Alaska, Hawaii, Nebraska, and Nevada.
[28] Among high-school seniors, data from the Monitoring the Future (MTF) Surveys indicate that past month prevalence of vaping marijuana increased from 4.9 percent (2017) to 14.0 percent (2019) to 14.8 percent (2022) (Miech et al., 2023).

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. 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) and adults ages 21-and-older.

Similar to the YRBS, the BRFSS captures information on ENDS use but only within a limited time window spanning from 2016 to 2018. 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. We find that approximately 13.5 percent of adults ages 18-to-20, 8.1 percent of adults ages 21-to-30, and 2.7 percent of adults ages 31-and-older report current consumption of ENDS. Appendix Table 3 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.[29] For such analyses, we turn to another source, the National Survey on Drug Use and Health (NSDUH), described in the next section.

3.3 National Survey on Drug Use and Health (NSDUH)

The NSDUH, collected and coordinated by SAMHSA, is a household survey representative of the U.S. non-institutionalized population which is administered in individuals' homes, including private homes, public housing, and non-institutional group quarters (i.e., college dorms, rooming houses, shelters).[30] Information on health behaviors is collected via an individual audio computer-assisted self-administered interview to increase privacy and the likelihood of a truthful response. This is an advantage over the pencil-and-paper YRBS survey and the telephone-based BRFSS survey, where individuals could worry about privacy surrounding answers. We rely on publicly available two-year overlapping state-by-year averages following recent economic work (Balestra et al., 2021; Dave et al., 2022).

[29] 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.
[30] The NSDUH does not include residents of hospitals and jails and homeless individuals living outside of shelters.

We use data on marijuana and harder drugs consumption prevalence rates among those ages 12-17 and ages 18-and-older. Marijuana prevalence rates are compiled using a survey item that asks respondents to report the number of days in the last month on which they "use[d] marijuana or hashish." A calculation of weighted means shows that over the 2002-2019 period, 7.1 percent of those ages 12-17 and 7.5 percent of respondents ages 18-and-older reported marijuana use on a positive number of days during the past month.[31]

In addition, we also measure illicit drug use other than marijuana (i.e., harder drugs). Such drugs include "heroin, hallucinogens, inhalants, cocaine, and the nonmedical use of prescription-type pain relievers, tranquilizers, stimulants, and sedatives." We find that 4.0 percent of those ages 12-17 and 3.4 percent of individuals ages 18-and-older reported using non-marijuana illicit drugs at least once during the past year. When we disaggregate the prevalence of non-marijuana illicit drug use into specific drugs, we find that among individuals aged 12-17, 1.0 percent report using cocaine during the past year and 0.2 percent report using methamphetamine during the past year. For individuals aged 18-and-older, these prevalence rates increase to 2.1 percent and 0.7 percent respectively. Finally, very few youths (0.07 percent of those aged 12-17) and 0.3 percent of respondents aged 18-and-older report heroin use in the past year.[32] Summary statistics are reported in Appendix Table 4.

[31] Prevalence rates for marijuana use for the NSDUH sample are somewhat lower than those computed from the YRBS (reported in Appendix Table 2). We conjecture several factors that may be driving this difference. First, there are far fewer 12- and 13-year-olds in the YRBS (0.5 percent) given the sampling of high school students; along the same line, about 14 percent of the YRBS sample includes individuals ages 18-years-or-older. That the age-range represented in the YRBS (99.5 percent are ages 14-18+ high school students) does not fully overlap with the public-use NSDUH (ages 12-17) would serve to lower the prevalence numbers in the NSDUH. Second, all students in the YRBS sample are eligible to answer all questions on marijuana use (including those on current use); in other words, the question on current consumption is not restricted to only those who reported non-zero lifetime use. In contrast, for the NSDUH, follow-up questions on current use and frequency of current use are only asked of respondents who answered "yes" to the lead-in question of ever having used marijuana in their lifetime. If the lack of a lead-in question in the YRBS allows the sampling to capture marijuana use that is more social, non-recurring, or experimental, then this survey feature would also lead to a higher prevalence rate; over 42 percent of ever-users in the National YRBS have consumed the substance less than ten times in their lifetime, and over a third (34 percent) of the current users have consumed the substance only one or two times in the past month. This pattern of results suggests that reported marijuana use in the NSDUH could possibly be skewed towards more regular or heavier users. Finally, differences in the sampling design (population of high school students vs. civilian non-institutionalized individuals; and YRBS is administered in a classroom setting vs. in-home computer assisted interviewing in the NSDUH) would also be expected to play some role in the variance in the estimated prevalence.

[32] When we disaggregate adult marijuana consumption by age using publicly available NSDUH data, we find that 18.7 percent of 18-25-year-olds and 5.6 percent of those ages 26-and-older used marijuana in the prior month. Appendix Figure 3 shows the time trends in marijuana use for each of these age groups over the full sample period. In contrast to the prevalence rate among youth, which has been largely stable since 2010, use among adults ages 18+ has been steadily increasing.

3.4 Treatment Episode Dataset (TEDS)

Finally, we turn to data on drug treatment admissions from the Treatment Episode Dataset (TEDS). 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 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.[33] For every 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.[34]

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 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, meth and heroin. Appendix Table 5 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 our drug use measures on the extensive margin in the survey data sources. Moreover, while one may be concerned that social desirability bias may bias levels (or

[33] 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.
[34] A limitation of TEDS is that this list is not necessarily a complete enumeration of all substances used at admission.

even trends) in substance use, 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 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.

3.5 ENDS Taxes

The main policy variable of interest in this study is the ENDS tax rate in 2019 dollars (we inflation-adjust the tax rate using the Consumer Price Index). ENDS products are taxed either through an ad valorem tax on wholesale prices, as an excise tax per unit or fluid ml of e-liquid, or through a special sales tax. We use the standardized measure of tax per fluid ml produced by Cotti et al. (2021) that allows comparability across states and over time. 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 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., 2022). Figure 1 and Appendix Table 1 show the rollout of ENDS taxes in the U.S. between 2010 and 2019, 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 the consumption of 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 per fluid ml measured in 2019 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 and the poverty rate), tobacco policies (T-21 law, combustible cigarette excise tax, ENDS MLSA, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions), and policies related to substances that could be complements or substitutes for ENDS or marijuana (beer taxes, recreational and medical marijuana laws, naloxone access laws, and must access prescription drug monitoring programs).[35] In addition, α_s is a time-invariant state effect, and θ_t is a state-invariant (biennial) wave effect. Regressions are weighted to be representative of U.S. teenagers in the State YRBS or U.S. high school students in the National YRBS.[36] Our ENDS tax measure and each of our right-hand side control variables are measured at the state-by-year-quarter level. Given that the National and State YRBS surveys are fielded primarily in the Spring semester, we match data based on the average of the first 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 within-state introduction in and changes in the level of ENDS taxes.[37] The estimate of our treatment effect will only be unbiased in the absence of (1) state-specific time-

[35] Sources for our state-level controls are: unemployment and poverty rate (Hansen et al., 2021); T-21 laws (Hansen et al., 2021); 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).

[36] As discussed below, in our analysis of the BRFSS, we use unweighted regression because our sample is stratified by respondent age (ages 18-20 and 21+) thus the use of weights may not generate nationally reprehensive estimates, 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 0.546, which implies a variance-inflation factor of 2.2 and that over 45 percent of the observed variation in ENDS taxes represents conditional within-state variation, indicating that we have sufficient variation with which to identify ENDS tax effects (Kennedy, 2008).

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 drug 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 or more years after treatment.

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 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 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 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 marijuana and harder drug use in the YRBS and BRFSS, we next turn to state-level data from the NSDUH and 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 plus some demographic variables, including proportion of males, Hispanics, and Blacks.[38] Regressions are weighted using the age-specific population to recover the treatment effect for the average treated individual.

5. Results

Our main findings appear in Tables 1 through 9, and Figures 2 through 5. Supplemental analyses may be found in the Appendix.

5.1 YRBS Findings on ENDS Use and Marijuana Use

First Stage ENDS Use. Table 1 presents "first stage" estimates of the effect of ENDS taxes on 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, wave fixed effects, and individual demographic characteristics (age, gender, race/ethnicity, grade in school), we

[38] The NSDUH data are provided in two-year averages; we align our key treatment variable ($ENDS\ tax_{st}$) and each control variable with the first year in the data series to ensure that trends in marijuana use do not precede changes in ENDS taxes. One can interpret the effect, therefore, as a (partially) lagged effect of ENDS taxes in the NSDUH.

find that a one-dollar increase in the ENDS tax leads to statistically significant 3.5 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, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions) increases the absolute magnitude of the estimated treatment effect to -0.068 (or 6.8 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 statistically significant 7.6 percentage-point decline in e-cigarette use. This corresponds to a 34 percent decline in ENDS use relative to the pre-treatment mean of ENDS use in the treatment states. This finding suggests that ENDS taxes have their intended effect of reducing youth vaping and in terms of magnitude is in line with earlier work (Abouk, Courtemanche, et al., 2023).

In panel II, we also present results using the National 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 5.4 to 8.5 percentage-point (20 to 32 percent) decline in prior-month ENDS use among U.S. high school students.

In Table 2 we include a dummy for the first lead of the ENDS tax to test for both the presence of pre-trends and for the robustness of our first stage.[39] Results show no evidence that ENDS use is declining (or increasing) faster in treatment as compared to control states before the ENDS tax was implemented. In our State YRBS sample, we find that a one-dollar increase in ENDS taxes leads to a statistically significant 7.2 percentage-point decline in ENDS use (column 3, panel I). Similar findings are observed in the National YRBS (panel II).

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 use using a 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 shown in Table 1. In

[39] We lack sufficient years of ENDS use data in the State and National YRBS to estimate a formal event study. We follow Abouk, Courtemanche, et al. (2023) and include the tax lead as an alternative.

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 1.2 to 2.3 percentage-point reduction in prior-month marijuana use among U.S. high school students. Relative to pre-treatment means in these outcomes in the treatment states, these effects correspond to a 5.5 to 10.8 percent reduction in marijuana use.[40] In panel III, we replicate the marijuana use analysis utilizing a broader time frame, spanning from 2003 to 2019. The results are very similar to those in our previous analysis, as we observe a consistent negative relationship between ENDS taxes and marijuana use. This alignment of findings suggests a complementary relationship between these two goods among teens. Further, we note that the estimated marginal effects from our preferred specification (column 6 of panels II and III) show an effect size that is about 70 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.[41] While less precisely estimated, we find a similar pattern of findings in the National YRBS, with a one-dollar increase in ENDS taxes associated with a 0.6 to 2.8 percentage-point decline in youth marijuana use (see Appendix Table 7). Our results are robust to controlling for border state ENDS tax policies as well as general state sales tax policies.[42]

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[40] One indirect pathway through which ENDS taxation may impact marijuana (and other substance) use is by conveying an information signal regarding the relative risks of tobacco and other substances. Alternately, ENDS taxes may be an endogenous marker for concurrent shifts towards pro-health attitudes. In order to assess the importance of this channel, we test whether higher ENDS taxes are associated with changes in the perceived risk of using marijuana, combustible cigarettes, or alcohol (Appendix Table 6). There is some evidence for youth (ages 12-17) that increases in the ENDS tax are associated with lower perceived harm of using marijuana (~0.9 percentage point decrease) and using combustible cigarettes (~0.6 percentage points decrease), contrary to ENDS taxes being broadly reflective of changing pro-health state norms regarding tobacco and addictive substances. All else equal, this shift in marijuana use perceived as being less risky would be predicted to increase marijuana use among teens. While the associations with perceived risk are small in magnitude, our estimated reduction in marijuana use among teens represents the net effect largely reflective of economic complementarity but also slightly moderated from this mediating and/or confounding informational signal effect.

[41] 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 0.26 to 0.31. Thus, for about every three to four 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 (0.26 ~ 0.31) is similar to the "average" effect (0.51 based on the 2019 National YRBS; about one out of two current e-cigarette users also use 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.

[42] We conduct two additional robustness checks. First, we control for bordering states that have adopted an ENDS tax to assess the importance of cross-border effects. We control for border state ENDS taxes in two ways: i) the average tax among bordering states (inflated to 2019 dollars using the Consumer Price Index) and ii) an indicator variable coded one if any border state has an ENDS tax in place and zero otherwise. Our results are not sensitive to controlling for border effects; in our preferred TWFE regression specification (i.e., full set of control variables) using the State YRBS data from 2003 to 2019 when utilizing the average tax of bordering states (presence of a tax in at least one border state) the

In the presence of heterogeneous and dynamic treatment effects, our TWFE coefficient estimates could be biased. To address this issue, in Table 4, we present findings from a stacked DD regression 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"). Our stacked difference-in-differences estimates, shown in Table 4, are strikingly consistent with our TWFE estimates. In our fully saturated specification, our findings indicate that a one-dollar increase in ENDS taxes leads to a 1.9 percentage-point (9.8 percent) reduction in marijuana use among teens.

Figure 2 depicts the results of formal event study analyses conducted for our primary outcome: marijuana use among teenagers in the State YRBS. The panel data used in our analysis provides a sufficiently long timeframe to capture pre-treatment and post-treatment trends (2003-2019). 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 (panel (a)) and stacked difference-in-differences (panel (b)) regressions.[43] 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. An examination of event study analyses using the stacked difference-in-differences estimator continues to, in the main, support the parallel trends assumption.

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 2.4 percentage-point (20.8 percent) reduction in the probability of ENDS use *and* marijuana use 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

coefficient estimate and standard error are -0.02340 and 0.0080 (-0.0326 and 0.0055) which implies an 11.4 percent (15.8 percent) decline in any marijuana use in the past 30 days among teens following a one-dollar increase in the ENDS tax. Second, we control for the state general sales tax (Tax Policy Center, 2023). Again, our results are not sensitive to including this control variable. Using the sample and specification just described, we find that the coefficient estimate and standard error are -0.02367 and 0.0083, which implies an 11.5 percent decline in teen marijuana use. All coefficient estimates from these sensitivity checks are statistically significant at the five percent level or better.

[43] 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 parallel trends assumption across all treated units with different treatment intensity as well as the non-treated units, which is difficult to test.

reducing their consumption of marijuana following ENDS tax increases. Interestingly, while there is a small (~5 percent relative to the baseline mean; Panel II, column 3), though not statistically significant, reduction in co-participation in lighter ENDS use and marijuana use, almost all of the decline appears to be driven by co-use of marijuana with heavier ENDS use (Panel III). This 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.

In prior work using data from the YRBS and the Monitoring the Future (MTF), we uncover robust evidence that a one-dollar increase in ENDS taxes lead some youth to substitute into smoking, thereby raising youth smoking by about one to 1.3 percentage-points (Abouk, Courtemanche, et al., 2023). As described in Section 2.5, most of the causal evidence (relying on tobacco policy variation) 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 (5.4 to 7.6 percentage-points; see Table 1) than the second-order effects of these taxes on smoking (about one percentage-point), the dominant channel would expectedly operate through the link from reduced vaping through its relations with marijuana.[44]

We can also assess this relationship more directly, by assessing how ENDS taxation is impacting co-use of cigarettes and marijuana (Panels IV and V). Estimates in Panel IV suggest a small 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 tax-induced changes in cigarette smoking. While excluding vapers leads to a selected sample, we find no significant or meaningful effects on

[44] 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 lead to approximately a 0.25 to 0.57 percentage-point increase in marijuana use, in which case our estimated effects (2.0 to 2.4 percentage points) are net of this pathway.

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. 2022), thus secondary effects on marijuana use may potentially operate through these tax-induced decreases in alcohol consumption. 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.[45]

Figure 3 reports heterogeneity in ENDS tax effects on any marijuana use among youth of different demographic groups based on the State YRBS. In particular, we estimate separate regressions for boys and girls; Whites, Blacks, and Hispanics; and younger (less than 18 years) and older (18 years and older) youth. Coefficient estimates from the full sample are reported for comparison. Overall, our analyses suggest that the probability of using marijuana declines in all groups post-tax. 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.[46]

Taken together, our YRBS-based findings provide strong evidence of spillover effects of ENDS taxes on marijuana use for most youths.

5.2 BRFSS Results on Adult ENDS Use

Next in Table 6, 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). First, we again establish a first stage, indicating a strong relationship between ENDS taxes and nicotine vaping behavior among younger adults. For individuals ages 18-to-20 (panel I), we find that a one-dollar increase in ENDS taxes leads to a 2.2 to 3.1 percentage-point decline in prior-month ENDS use, which translates to a 16 to 23 percent decline relative to the pre-treatment mean. Similarly, among adults

[45] The marginal positive coefficients on co-participation in binge drinking and marijuana use (excluding vapers), if anything, is consistent with a small induced substitution response across these two behaviors, in which case our main effects on marijuana use can be interpreted as net of any such response.

[46] 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.

ages 21-to-30 (panel II), we find that a one-dollar increase in ENDS taxes leads to an albeit smaller and much less precisely estimated 0.8 to 1.1 percentage point (9 to 13 percent) reduction in ENDS use. However, we find no statistically significant evidence that ENDS taxes are effective at reducing ENDS use among those over age 30 in our preferred specifications, as we more carefully control for policy confounders (i.e., columns (3) to (6)). Overall, these findings align with the conclusions drawn by Pesko et al. (2020), and suggest that any spillover effects of ENDS taxes on marijuana are likely to be concentrated among teens and young adults.[47]

5.3 NSDUH Results on Marijuana Use and Harder Drug Use

We next turn to the NSDUH to explore the effects of ENDS taxes on marijuana use among both teenagers ages 12-to-17 and adults ages 18-and-older. In our preferred specification, we find little evidence that ENDS taxes are related to marijuana use among youths (column 1 of panel I in Table 7). One explanation for this finding may be that marijuana use in the NSDUH – due to differences in the sampling and how information on current use is captured (see footnote 31) – is more reflective of intensive use. In later analyses, we confirm that this margin of heavy/intense marijuana use is not responsive to ENDS taxation, but rather much of the reduction in marijuana use appears to be driven by light and moderate users.

For adults (ages 18+), the effect on marijuana use is more pronounced. In panel II, column 1 shows that an increase in the ENDS tax by one-dollar reduces their marijuana use by 0.77 percentage points (10.5 percent).[48] While we suspect that the declines in adult marijuana use are expectedly driven by those ages 18-30 (and not older adults) since we observe declines in ENDS use only within this younger adult population (Table 6), we are not able to explicitly assess this hypothesized pattern since finer age groups are not observed in the state-level NSDUH data.

Figure 4 reports event study analyses utilizing our fully saturated TWFE estimator for both youths and adults. Two key observations are worth noting. First, pre-treatment disparities in marijuana use between ENDS states and control states are comparable and well-balanced

[47] Appendix Table 8 reports BRFSS analysis using survey weights provided by the CDC.
[48] These estimates from the NSDUH analyses are smaller in magnitude. If the reports from the NSDUH are more reflective of relatively more frequent or chronic users of marijuana (see footnote 31), then these effects would capture a somewhat different margin of use and suggest that ENDS taxation may be largely impacting light or infrequent users rather than heavy users when interpreted in conjunction with the YRBS estimates. We more directly assess effects on various margins of marijuana use below in Table 9.

throughout the pre-policy period.[49] Second, we observe a noticeable divergence in marijuana use between ENDS states and control states for adults ages 18 and older, which becomes evident after the law is implemented. This pattern is in line with a causal relationship between the ENDS tax implementation and the observed changes in adult marijuana use.[50,51]

In the additional columns of Table 7, we examine whether ENDS taxes had any spillover effects on other harder substance use, specifically cocaine (column 2), and heroin (column 3), methamphetamines (column 4) using the NSDUH data, and (for youths in the State YRBS) we examine whether the respondent had ever used cocaine or ever used heroin (column 6). However, our analysis does not reveal any evidence suggesting a relationship between ENDS taxes and other substance use, including the use of harder drugs.[52]

5.4 Income Effect

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 the potential influence of indirect effects on marijuana reduction 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 first examine how ENDS taxes affect the demand for other products that constitute a relatively large portion of daily spending among teens and young adults (18 to 20) in the BRFSS data, with the

[49] While there appears to be a small uptick in marijuana use among youths two or more years post-ENDS tax adoption, comparable upticks are also evident in the lead effects; thus, overall, we interpret trends in marijuana use to have remained flat among teens from pre- to post-tax adoption, consistent with the point estimate in Table 7.

[50] In order to account for potential biases arising from heterogeneous and dynamic treatment effects, we conduct an additional analysis using a stacked difference-in-differences approach. The event study figure, presented in Appendix Figure 4, aligns with the estimates obtained from the TWFE event study regression, though lagged effects for youth and adults are no longer statistically significant for two years post-implementation.

[51] We examine 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. This metric varies within states and over time (e.g., states that adopt one of these two policies are coded zero pre-policy and one post-policy). 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. We consider past-month marijuana use in the State YRBS (12-18 years) and NSDUH (12-17 years and ages 18+). Results are reported in Appendix Table 9A. We do not observe statistically different effects for states that both restrict access to ENDS through taxation and expand access to marijuana through legalization. However, the sign and magnitude of the interaction – while imprecisely estimated – is suggestive that the decrease in marijuana use which follows higher ENDS taxes is moderated in states where access to marijuana, for recreational or medical purposes, is more liberalized.

[52] In Appendix Table 9B we disaggregate the analyses for adults, reporting separate analyses for younger (ages 18-25) and older (ages 26+) adults. Here we observe some evidence that ENDS taxes reduce marijuana use among younger adults: among those NSDUH respondents ages 18-25 years, a one-dollar increase in the ENDS tax rate leads to a roughly one percentage point (2.8 percent) reduction in marijuana use.

estimates reported in Table 8. If we observe similar declines in use of other goods, then that pattern of results would support the hypothesis that our findings potentially, and at least partially, reflect income effects rather than more direct pathways underlying economic complementarity.

While the availability of questionnaire items on many of these consumption measures is limited to the nutrition supplement of the BRFSS, our analysis reveals little evidence of a significant relationship between ENDS taxes and prior-month consumption of various items which would be sensitive to an income shock. Specifically, we find that ENDS taxes are not significantly associated with the consumption of French fries (often purchased at fast food locations), sugar/sweetened beverages, juices, soda, or fruits. We conduct a similar analysis in the State YRBS dataset (Table 8). Again, we do not observe any significant impact of ENDS taxes on consumption of soda, milk, or vegetables, or the use of condoms during sexual intercourse for youth. These may be items affected by teens' or young adults' discretionary spending, and if higher ENDS taxes were producing a substantial income effect, we would expect to observe some impact on their consumption.

Next, 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).[53] 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 three to four percent (0.08 percentage point) of the estimated decline in marijuana use (2.0 to 2.4 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 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.

[53] 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).

5.5 Heavier Marijuana Use and Substance Use Disorder Treatment Admissions

In Table 9, 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, for both younger and older teens, is due to a transition from 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 (-0.016) is largely similar to our corresponding main coefficient estimate for any participation (-0.020; column 6, panel II in Table 3). There is also a meaningful decline in ever-use of marijuana, which is more reflective of the initiation margin.[54] Coefficient estimates in columns 3 and 4 become smaller in absolute magnitude and turn positive and statistically indistinguishable from zero when we reach marijuana use 10 or more times in the last month (column 4), suggesting no statistically or economically significant effects on heavier or chronic marijuana use. Together, these results provide less evidence that ENDS taxes significantly reduce heavier marijuana use among younger teens (under age 18, panel I), or ages 18-and-older (panel II), suggesting that the margin most affected by ENDS taxation is the "experimental" or light 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.[55] 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 do not provide significant evidence of any causal effects on marijuana-related treatment admissions for either youths or adults. We also present the stacked difference-in-differences event study in Appendix Figure 5B, and the

[54] 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. (2019) for a discussion of these metrics).

[55] In Table 9, we use log transformed admissions variables. In Appendix Table 10 we use the non-logged admission rate variable in level. 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 second or third substance of use.

results are consistently null. The corresponding event study figures for illicit drug use not related to marijuana are presented in Appendix Figure 6. Consistently, we find that the coefficient estimates from these event study analyses are statistically indistinguishable from zero.

Downstream or gateway effects on the use of harder drugs may possibly take time to unfold given the relative recency of ENDS taxation.[56] While a more definitive assessment of longer-term dynamics is not possible at this stage with the available data, in supplementary analyses we focus on the early adopting states for whom we are able to observe effects over a relatively longer post-treatment period. Synthetic control analyses for these states reveal no meaningful or statistically significant impacts on illicit drug use other than marijuana based on the NSDUH and the TEDS.[57]

6. Conclusion

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 has grown dramatically since the entrance of these products in U.S. tobacco markets in 2006, with 32.1 percent of 12th grade students consuming these products in the past year in 2022 (Miech et al., 2023). According to the Centers for Disease Control and Prevention's latest survey of U.S. high school students, 10.1 percent of teenagers are dual users of ENDS and marijuana. 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 the first evaluation of raising ENDS taxes, one of the most recent and prominent policies adopted by states and local governments to curb vaping, on marijuana and harder drug consumption among youth and adults. We leverage five

[56] We also note here that, if there are downstream effects on harder drugs, these are more likely to reflect secondary pathways through the reduction in marijuana use (rather than a direct pathway linking vaping with harder drug use). The implication here is that these effects – if present – would then take further time to unfold and, being an order of magnitude smaller, may require more statistical power to detect.

[57] Specifically, we focus on the five states and localities (the District of Columbia, Louisiana, Minnesota, North Carolina, and Montgomery County in Maryland) which had adopted ENDS taxes prior to the end of 2015, permitting a post-treatment window of at least four years. States which had not yet adopted a tax by the end of our sample period (2019) comprised the donor pool. Results are not reported and available upon request.

large-scale national datasets, with complementary strengths, in conjunction with generalized difference-in-differences methods to carefully assess the impact of ENDS taxes on marijuana and other substance use. We find robust evidence that a one-dollar increase in the ENDS tax leads to a 10 to 12 percent decline in marijuana use among youth and about a 11 percent decline among adults 18 years and older. Our results do not appear to be driven by differential pre-trends between states that do and do not adopt ENDS taxes or bias from dynamic and heterogeneous treatment effects when applying TWFE methods to policies that follow a staggered rollout. Furthermore, the relative magnitude of our "second stage" effects for marijuana (less than one third the size of the "first stage" effects for vaping) appear reasonable. This result is consistent with the hypothesis that e-cigarettes and marijuana are economic complements. In addition, we note that our finding that marijuana use declines post-ENDS tax appears to be driven by light or experimental marijuana users, and not heavy consumers, and that ENDS taxes do not result in any change in non-marijuana drug use or drug treatment admissions. Our estimates represent average treatment effects on the treated over the post-treatment windows available for the tax-adopting states. On average, these windows are approximately two years. If gateway effects on harder drugs 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); 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. 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. (2022) document that ENDS taxes reduce heavier drinking (e.g., binge drinking) 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.

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Figure 1. Geographic and Temporal Variation in ENDS Taxes

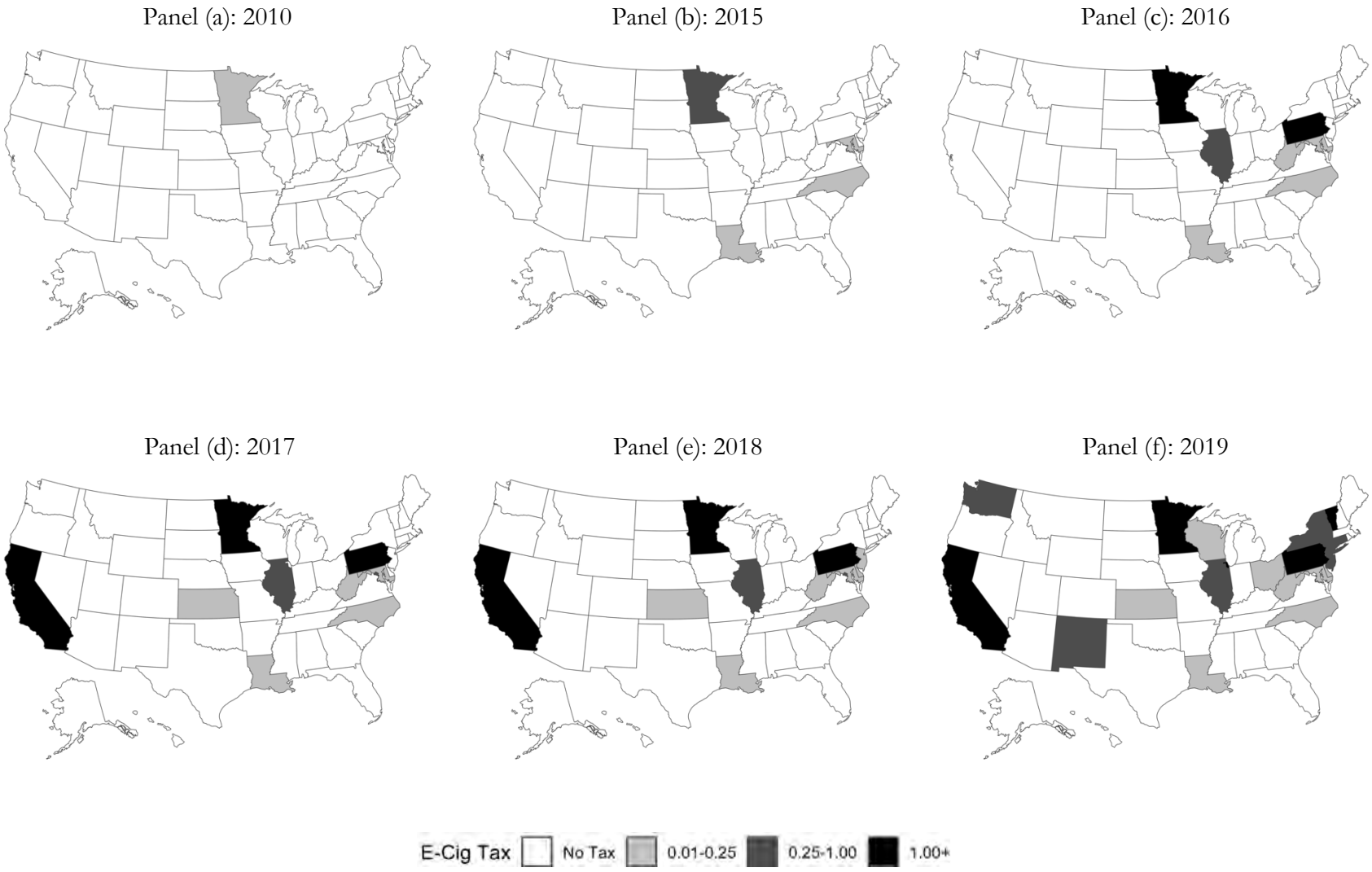
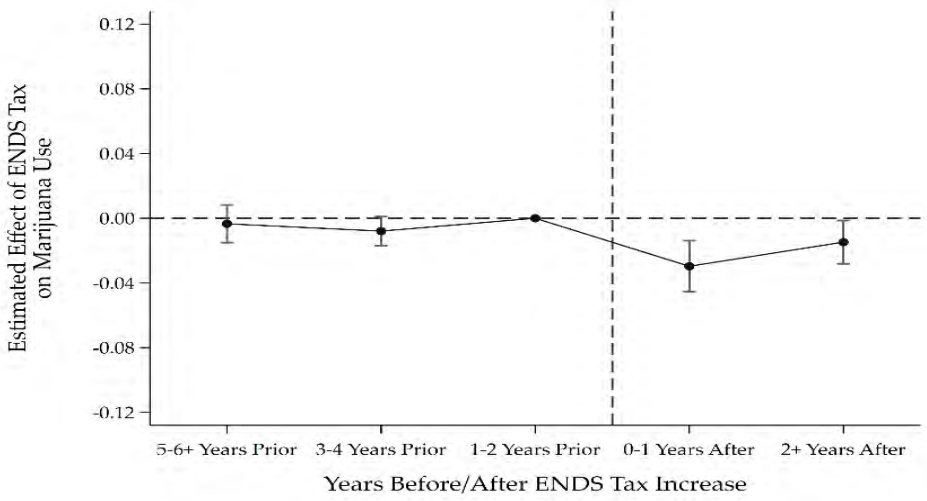
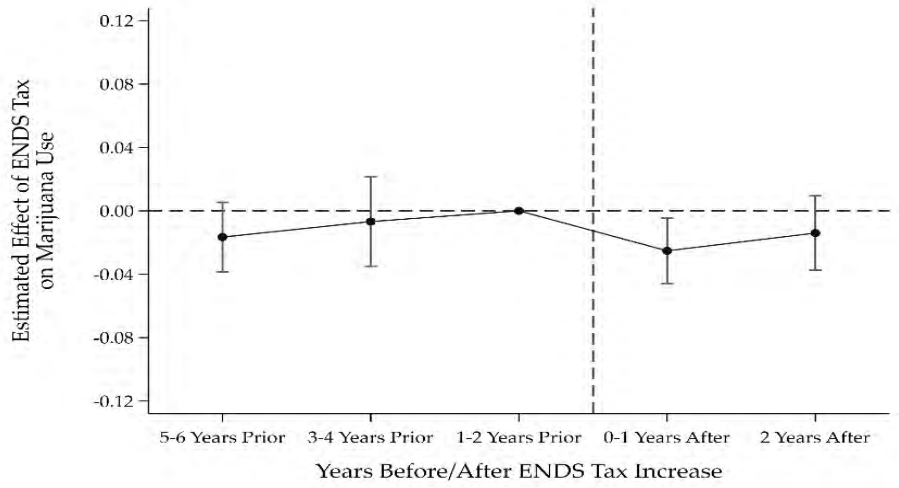


Figure 2. Dynamic Effects of ENDS Taxes on Marijuana Use Among Youths, State YRBS 2003-2019

Panel (a): TWFE Estimates

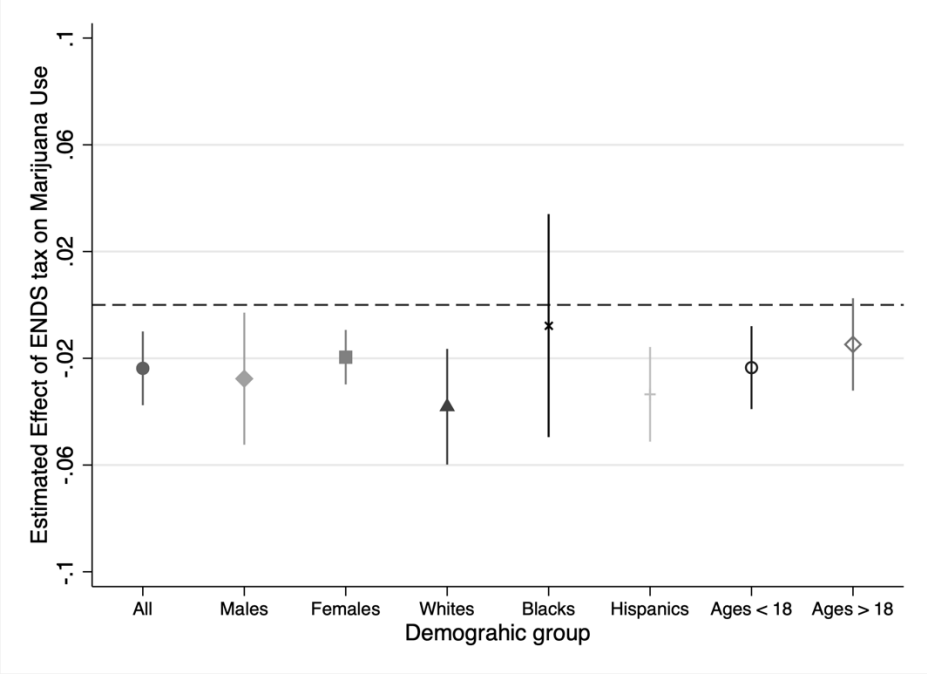


Panel (b): Stacked DD Estimates



Notes: Estimates in Panel (a) are generated using weighted OLS estimates from a TWFE event study regression using the 2003-2019 waves of the State YBRS. Estimates in Panel (b) are generated with a stacked event study regression using the 2003-2019 waves of the State YBRS. 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. 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.

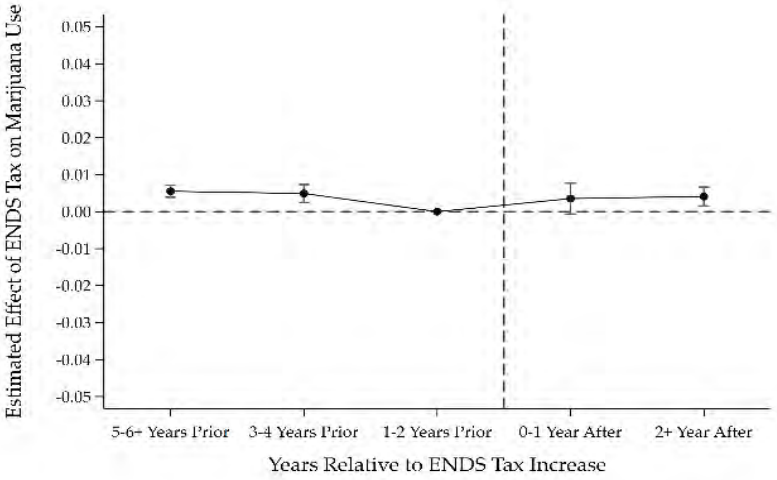
Figure 3. Heterogeneity in the Effects of ENDS Taxes on Marijuana Use Among Youths, State YRBS 2003-2019



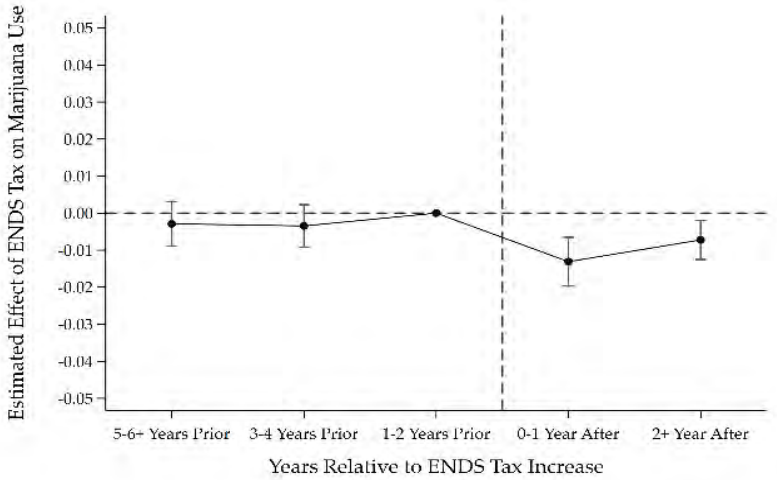
Notes: Weighted OLS estimates from a TWFE difference-in-differences regression for each sample noted on the x-axis are shown using the 2003-2019 waves of the State YBRS. The regressions control for state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, and non-marijuana drug policy controls. 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. Dynamic Effects of ENDS Taxes on Marijuana Use Among Youths and Adults, NSDUH 2002-2019

Panel (a): Youths Ages 12-17



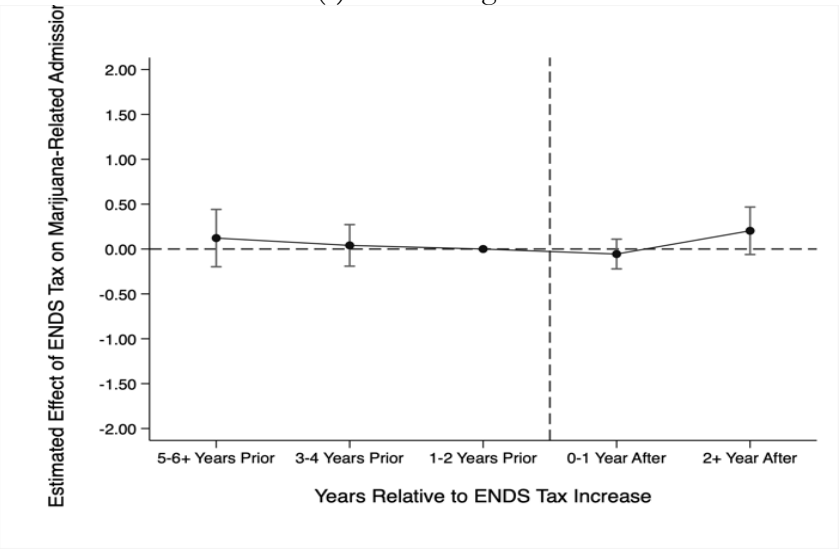
Panel (b): Adults Ages 18+



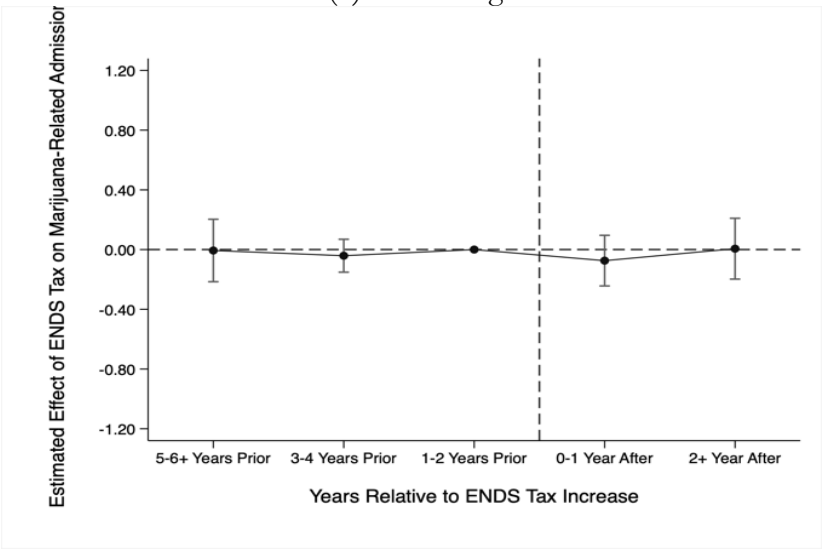
Notes: Weighted OLS estimates from the TWFE event study regression are shown using the 2002-2019 waves of the NSDUH. The sample used in Panel (a) includes all individuals aged 12-to-17 and the sample used in Panel (b) includes all individuals aged 18 and older. The event-time window ranges from six years 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. 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. All the right-hand side variables merged with the NSDUH data (which are based on two-year averages) are merged according to the initial year of the two-wave average.

Figure 5. Dynamic Effects of ENDS Taxes on Marijuana-Related Drug Treatment Admissions, TEDS 2000-2019

Panel (a): Youths Ages 12-17



Panel (b): Adults Ages 18+



Notes: Weighted OLS estimates from the TWFE event study regression are shown using the 2000-2019 TEDS. The sample used in Panel (a) includes all individuals aged 12-to-17 and the sample used in Panel (b) includes all individuals aged 18 and older. The dependent variable is the natural log of the marijuana-related drug treatment admissions rate. 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 proxies 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 2015-2019

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel I: State YRBS			
ENDS Tax ($)	-0.0345***	-0.0363***	-0.0675***	-0.0659***	-0.0642***	-0.0761***
	(0.0054)	(0.0073)	(0.0144)	(0.0138)	(0.0165)	(0.0175)
N	499,839	499,839	499,839	499,839	499,839	499,839
Pre-Treatment Mean of Dep Variable	0.2269	0.2269	0.2269	0.2269	0.2269	0.2269
			Panel II: National YRBS			
ENDS Tax ($)	-0.0701***	-0.0689***	-0.0846***	-0.0612***	-0.0712***	-0.0535**
	(0.0158)	(0.0172)	(0.0205)	(0.0196)	(0.0254)	(0.0256)
N	39,153	39,153	39,153	39,153	39,153	39,153
Pre-Treatment Mean of Dep Variable	0.2628	0.2628	0.2628	0.2628	0.2628	0.2628
State and Year FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic Control?	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 2015-2019 waves of the State (Panel I) and National (Panel II) YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate and state poverty rate. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. State alcohol policy control is the beer tax (2019$). 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.

Table 2. Lead Effects of ENDS Taxes on ENDS Use, State and National YRBS 2015-2019

	(1)	(2)	(3)
	Panel I: State YRBS		
Lead ENDS Tax (0/1)	-0.0213	-0.0024	0.0090
	(0.0226)	(0.0155)	(0.0145)
ENDS Tax ($)	-0.0449***	-0.0654***	-0.0721***
	(0.0081)	(0.0169)	(0.0162)
N	499,839	499,839	499,839
Pre-Treatment Mean of Dep Variable	0.2269	0.2269	0.2269
	Panel II: National YRBS		
1 Wave Prior	0.0424	0.0101	-0.0184
	(0.0290)	(0.0289)	(0.0318)
ENDS Tax ($)	-0.0460**	-0.0654**	-0.0621*
	(0.0184)	(0.0307)	(0.0321)
N	39,153	39,153	39,153
Pre-Treatment Mean of Dep Variable	0.2628	0.2628	0.2628
State and Year FE?	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes
Macroeconomic 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 2015-2019 waves of the State (Panel I) and National (Panel II) YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate and state poverty rate. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. State alcohol policy control is the beer tax (2019$). 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.

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, 2015-2019[a]			
ENDS Tax ($)	-0.0359***	-0.0388***	-0.0648***	-0.0608***	-0.0596***	-0.0702***
	(0.0057)	(0.0075)	(0.0142)	(0.0137)	(0.0164)	(0.0177)
N	483959	483959	483959	483959	483959	483959
Pre-Treatment Mean of Dep Variable	0.2234	0.2234	0.2234	0.2234	0.2234	0.2234
			Panel II: Marijuana Use, 2015-2019[a]			
ENDS Tax ($)	-0.0225***	-0.0206***	-0.0115	-0.0139**	-0.0154**	-0.0200***
	(0.0039)	(0.0037)	(0.0071)	(0.0068)	(0.0075)	(0.0067)
N	483959	483959	483959	483959	483959	483959
Pre-Treatment Mean of Dep Variable	0.2092	0.2092	0.2092	0.2092	0.2092	0.2092
			Panel III: Marijuana Use, 2003-2019			
ENDS Tax ($)	-0.0216**	-0.0212**	-0.0241***	-0.0243***	-0.0239***	-0.0238***
	(0.0094)	(0.0081)	(0.0081)	(0.0080)	(0.0083)	(0.0082)
N	1194048	1194048	1194048	1194048	1194048	1194048
Pre-Treatment Mean of Dep Variable	0.2059	0.2059	0.2059	0.2059	0.2059	0.2059
State and Year FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic 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 2015-2019 waves of the State YRBS in Panel I and II and the 2003-2019 waves of the State YRBS in Panel III. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate and state poverty rate. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. State alcohol policy control is the beer tax (2019$). 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 2003-2019

	(1)	(2)	(3)	(4)	(5)	(6)
ENDS Tax ($)	-0.0223***	-0.0215***	-0.0190**	-0.0191**	-0.0185*	-0.0194**
	(0.0071)	(0.0069)	(0.0082)	(0.0082)	(0.0096)	(0.0092)
N	5,465,178	5,465,178	5,465,178	5,465,178	5,465,178	5,465,178
Pre-Treatment Mean of Dep Variable	0.1945	0.1945	0.1945	0.1945	0.1945	0.1945
State and Year FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic 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 2003-2019 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 and state poverty rate. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. State alcohol policy control is the beer tax (2019$). 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 5. TWFE Estimates of the Effects of ENDS Taxes on Dual ENDS and Marijuana Use Among Youths, State YRBS 2015-2019

	(1)	(2)	(3)
	Panel I: Any ENDS Use and Any MJ Use		
ENDS Tax ($)	-0.0219***	-0.0183**	-0.0242***
	(0.0024)	(0.0078)	(0.0064)
N	483,959	483,959	483,959
Pre-Treatment Mean of Dep Variable	0.1166	0.1166	0.1166
	Panel II: Lighter ENDS Use (< 20 Days) vs No ENDS Use and Any MJ Use		
ENDS Tax ($)	-0.0054	-0.0005	-0.0049
	(0.0037)	(0.0063)	(0.0060)
N	462,106	462,106	462,106
Pre-Treatment Mean of Dep Variable	0.1004	0.1004	0.1004
	Panel III: Heavier ENDS Use (≥ 20 Days) and Any MJ Use		
ENDS Tax ($)	-0.0184***	-0.0200***	-0.0221***
	(0.0034)	(0.0062)	(0.0063)
N	483,959	483,959	483,959
Pre-Treatment Mean of Dep Variable	0.0190	0.0190	0.0190
	Panel IV: Any Cigarette Use and Any MJ Use		
ENDS Tax ($)	-0.0120***	-0.0092**	-0.0093*
	(0.0034)	(0.0043)	(0.0051)
N	522,744	522,744	522,744
Pre-Treatment Mean of Dep Variable	0.0646	0.0646	0.0646
	Panel V: Any Cigarette Use (excluding ENDS Users) and Any MJ Use		
ENDS Tax ($)	-0.0028	0.0012	0.0010
	(0.0064)	(0.0023)	(0.0028)
N	473,279	473,279	473,279
Pre-Treatment Mean of Dep Variable	0.0176	0.0176	0.0176
	Panel VI: Any Binge Drinking (excluding ENDS Users) and Any MJ Use		
ENDS Tax ($)	0.00645*	0.00673*	0.00806**
	(0.00359)	(0.00386)	(0.00363)
N	410,687	410,687	410,687
Pre-Treatment Mean of Dep Variable	0.021	0.021	0.021
	Panel VII: Any Alcohol (excluding ENDS Users) and Any MJ Use		
ENDS Tax ($)	0.00329	0.00262	0.00633
	(0.00754)	(0.00401)	(0.00424)
N	447,605	447,605	447,605
Pre-Treatment Mean of Dep Variable	0.040	0.040	0.040
State and Year FE?	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes
Macroeconomic 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 2015-2019 waves of the State YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate and state poverty rate. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. State alcohol policy control is the beer tax (2019$). 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 2016-2018

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel I: Ages 18-20			
ENDS Tax ($)	-0.0281***	-0.0281***	-0.0221	-0.0305**	-0.0312**	-0.0312**
	(0.0041)	(0.0044)	(0.0164)	(0.0133)	(0.0136)	(0.0136)
N	25,653	25,653	25,653	25,653	25,653	25,653
Pre-Treatment Mean of Dep Variable	0.137	0.137	0.137	0.137	0.137	0.137
			Panel II: Ages 21-30			
ENDS Tax ($)	-0.0085***	-0.0093***	-0.0077	-0.0090	-0.0108	-0.0108
	(0.0016)	(0.0014)	(0.0119)	(0.0125)	(0.0122)	(0.0122)
N	104,943	104,943	104,943	104,943	104,943	104,943
Pre-Treatment Mean of Dep Variable	0.083	0.083	0.083	0.083	0.083	0.083
			Panel III: Ages > 30			
ENDS Tax ($)	0.0022**	0.0021**	0.0000	-0.0002	-0.0006	-0.0006
	(0.0009)	(0.0009)	(0.0027)	(0.0029)	(0.0031)	(0.0031)
N	1,011,642	1,011,642	1,011,642	1,011,642	1,011,642	1,011,642
Pre-Treatment Mean of Dep Variable	0.027	0.027	0.027	0.027	0.027	0.027
State and Year FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic 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 2016-2018 waves of the BRFSS dataset. Demographic controls include 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 and state poverty rate. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. State alcohol policy control is the beer tax (2019$). 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 standard errors are clustered at the state level and are reported in parentheses.

Table 7. Effects of ENDS Taxes on Prevalence of Youth and Adult Substance Use, NSDUH 2002-2019 and State YRBS 2015-2019

	(1)	(2)	(3)	(4)	(5)
	Marijuana	Cocaine	Heroin	Meth	Ever Harder Drug Use (Cocaine or Heroin)
Data Source	NSDUH	NSDUH	NSDUH	NSDUH	YRBS
			Panel I: Ages 12-17		
ENDS Tax ($)	-0.0002	-0.00006	-0.00005	-0.0004	0.0016
	(0.0016)	(0.0004)	(0.0001)	(0.0004)	(0.0056)
N	867	867	306	204	842,133
Pre-Treatment Mean of Dep Variable	0.0714	0.0107	0.000742	0.00168	0.0599
			Panel II: Ages 18+		
ENDS Tax ($)	-0.0077***	0.0007	-0.00001	0.00002	-0.0311
	(0.0020)	(0.0005)	(0.00068)	(0.00099)	(0.0186)
N	867	867	306	204	194,297
Pre-Treatment Mean of Dep Variable	0.0732	0.0211	0.00340	0.00663	0.1011

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

Notes: Estimates in columns 1 to 4 are generated with a TWFE difference-in-differences regression using the 2002-2019 waves of the NSDUH, and columns 5 utilizes data from the 2003-2019 State YRBS. 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. NSUDH data are weighted by the age-specific state population and 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. All the right-hand side variables merged with the NSDUH data (which are based on two-year averages) are merged according to the initial year of the two-wave average.

Table 8. Exploring an Income Effect of ENDS Taxes on Non-Alcoholic Drinks, Food, and Condom Use, BRFSS 2011-2019 and State YRBS 2003-2019

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Data Source	BRFSS					State YRBS				
	Any Fries	Any Sodas	Any Sugar/Sweetened Beverages	Any Pure Juices	Any Fruit	Drank Soda Everyday	Drank Milk Everyday	Ate Veggies Everyday	No Condom Use (Unconditional)	Condom Use | Sex
ENDS Tax ($)	-0.0148	-0.1082	-0.0134	0.0242	0.0088	0.00889	0.01161	0.01151	0.00649	-0.02105
	(0.0126)	(0.0769)	(0.0519)	(0.0187)	(0.0064)	(0.01180)	(0.00959)	(0.00741)	(0.00666)	(0.01517)
N	17,507	7,033	6,982	43,447	44,344	940,058	709,694	978,088	1034573	411,423
Pre-Treat Mean of DV	0.924	0.798	0.782	0.697	0.962	0.244	0.368	0.213	0.155	0.645

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

Notes: TWFE difference-in-differences regression. Columns 1 to 5 are based on data from the BRFSS for adults 18-20, and columns 6 to 10 utilize data from the State Estimates are generated with a YRBS. All regressions control for state, year, and month fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, non-marijuana drug policy controls. BRFSS-based regressions are unweighted and include month fixed effects. 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.

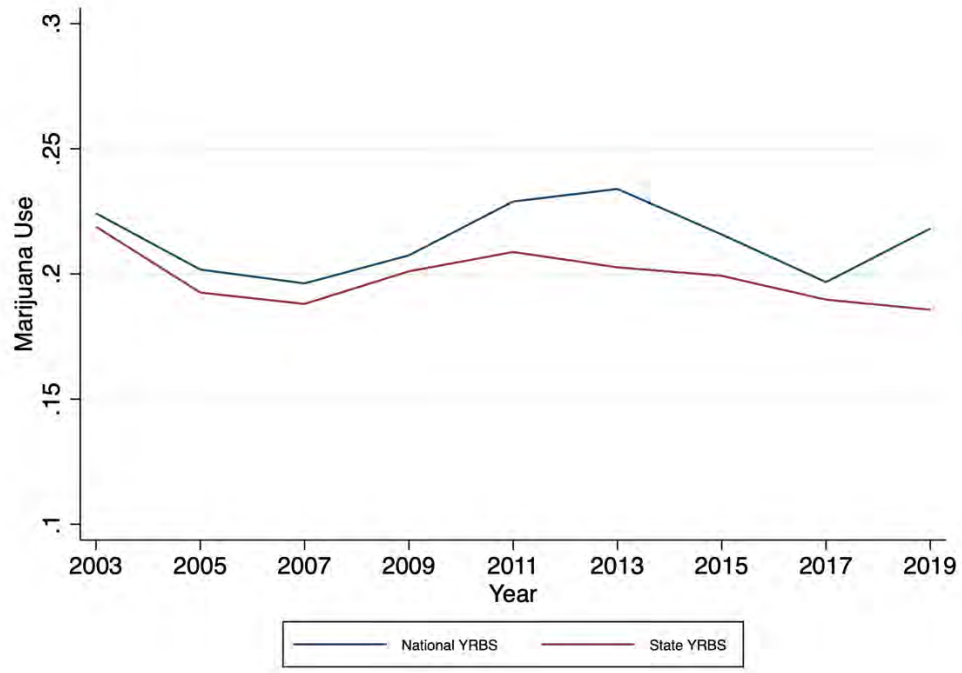
Table 9. Effects of ENDS Taxes on Drug Treatment Admissions and Heavier Marijuana Use, State YRBS 2003-2019 and TEDS 2000-2019

	(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: Ages 12-17				
ENDS Tax ($)	-0.0160***	-0.1023**	-0.0101*	0.0014	0.0149	-0.00361	-0.141	-0.124	-0.165
	(0.0048)	(0.0512)	(0.0059)	(0.0028)	(0.112)	(0.114)	(0.161)	(0.320)	(0.244)
N	939,937	864,649	1,072,980	1,072,980	996	996	996	996	996
Pre-Treat Mean DV	0.124	0.353	0.073	0.080	3.996	4.865	0.800	0.0724	0.352
					Panel II: Ages 18+				
ENDS Tax ($)	-0.0191*	-0.0884**	0.0007	0.0151	-0.0159	-0.0531	-0.0712	-0.0568	0.0317
	(0.0097)	(0.0439)	(0.0071)	(0.0136)	(0.0555)	(0.0681)	(0.0542)	(0.112)	(0.135)
N	98,799	104,452	121,068	121,068	996	996	996	996	996
Pre-Treat. Mean DV	0.185	0.509	0.126	0.113	0.818	2.080	4.722	1.55	1.65

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

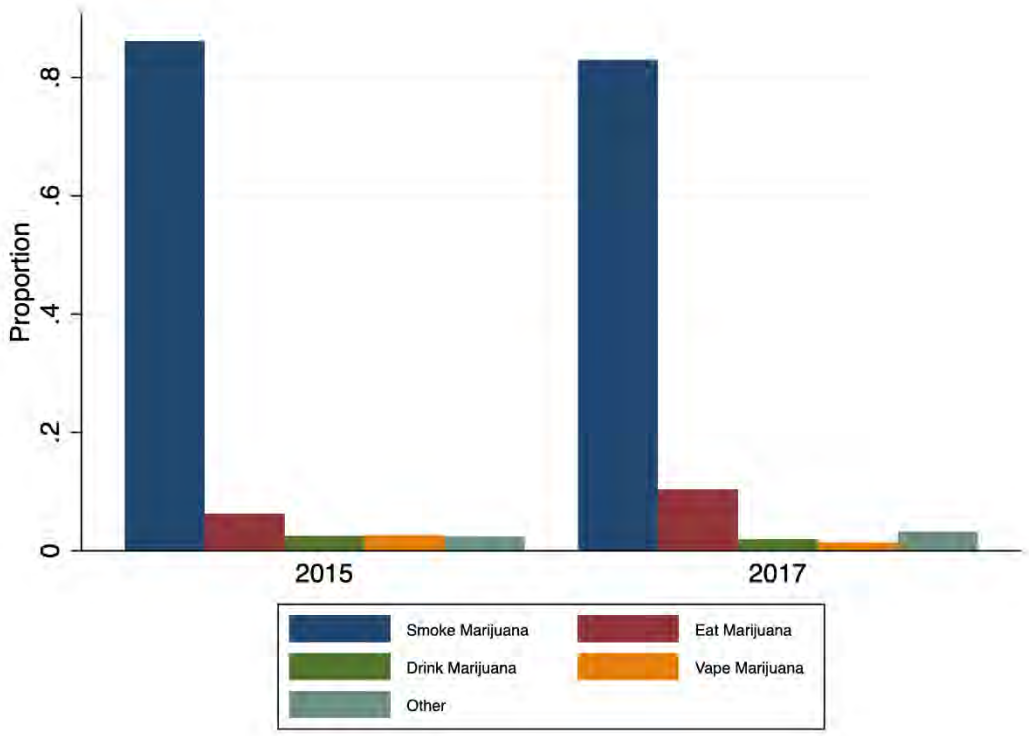
Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2003-2019 waves of the State YRBS and the 2001-2019 TEDS. In columns 1 through 4, the dependent variable is a State YRBS respondent outcome. In columns 5 to 9, the dependent variables are the log of indicated drug 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. TEDS regressions also control for proxies 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 2003-2019



Notes: Time trends in marijuana consumption. Data are from the 2003-2019 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.

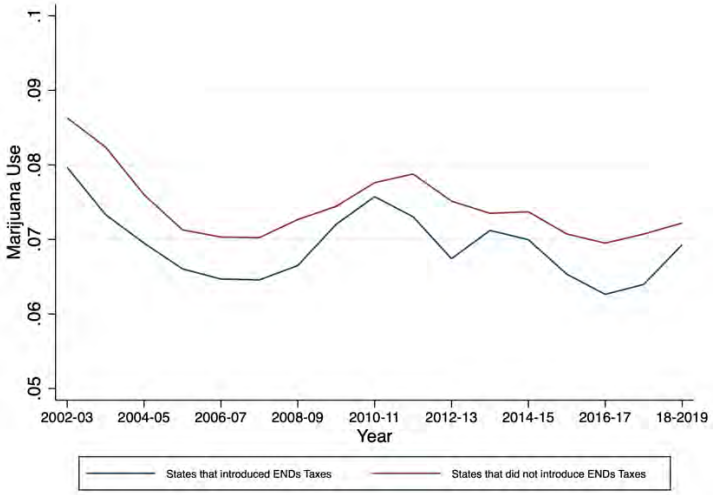
Appendix Figure 2. Prevalence Rate in Ways of Consuming Marijuana, State YRBS 2015-2019



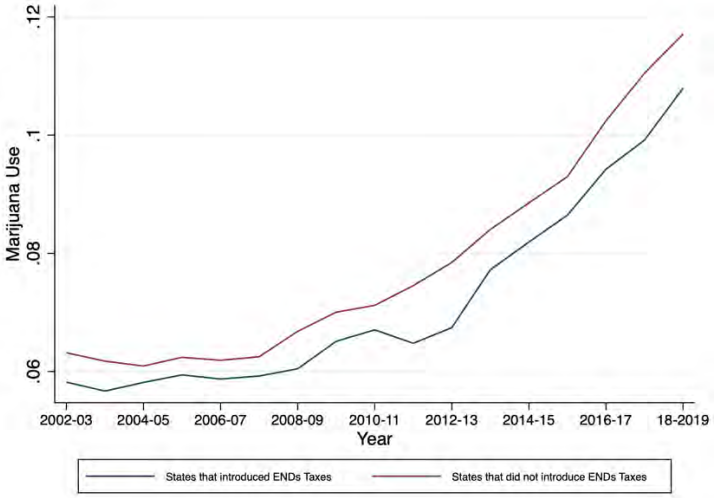
Notes: Proportion of respondents in the 2015-2017 waves of the State YRBS that smoke, eat, drink, and vape marijuana. The sample includes Alaska, Hawaii, Nebraska, and Nevada. Data are weighted to be representative of each state's 14-to-18-year-old population (see footnote 24 for details).

Appendix Figure 3. Time Trends in Marijuana Use Among Youths, NSDUH 2002-2019

Panel (a): Ages 12-17



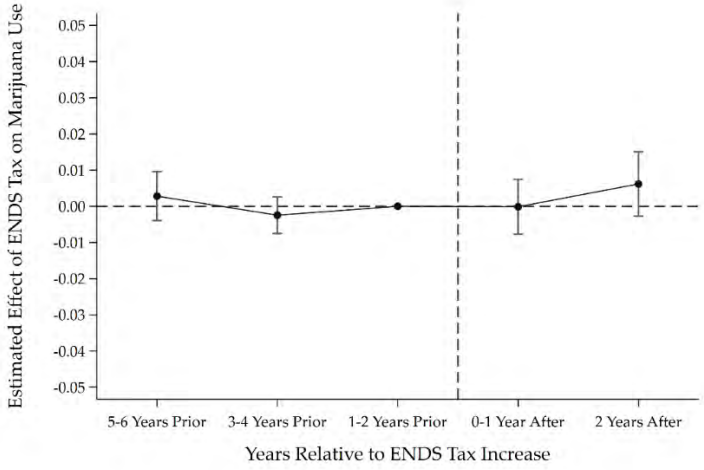
Panel (b) Ages 18+



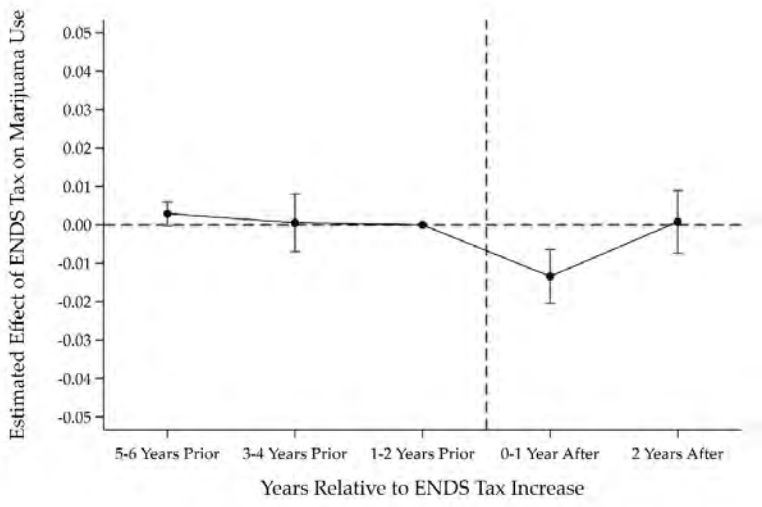
Notes: Time trends in marijuana consumption. Data are from the 2002-2019 waves of the NSDUH. Data are weighted by the age-specific state population.

Appendix Figure 4. Dynamic Effects of ENDS Taxes on Marijuana Use, NSDUH 2002-2019, Using Stacked Difference-in-differences Estimates

Panel (a): Ages 12-17



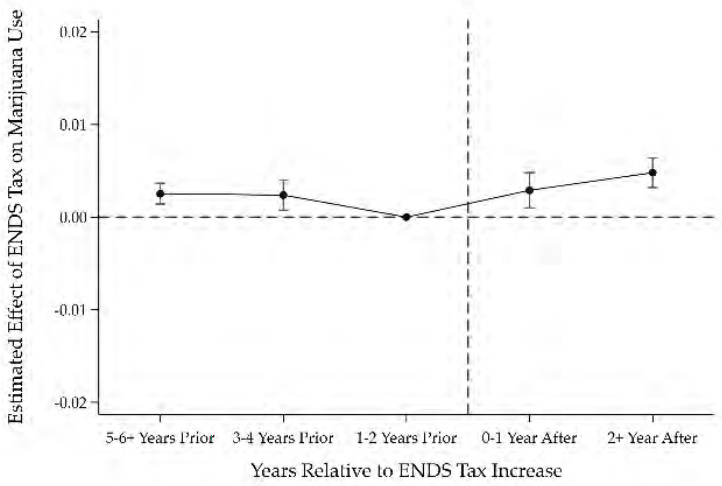
Panel (b): Ages 18+



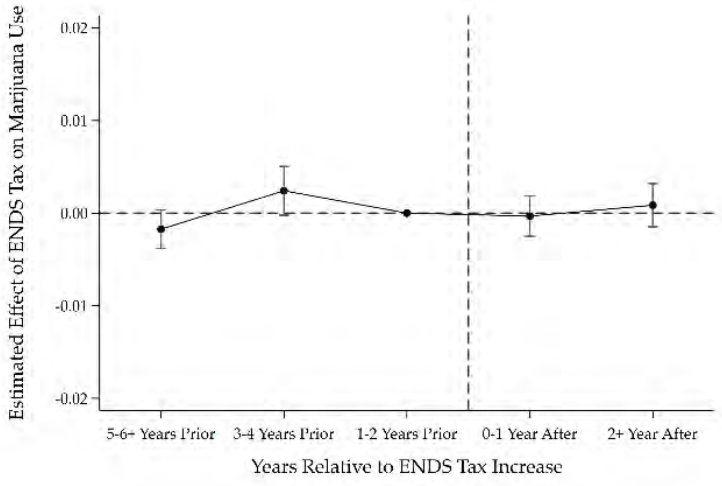
Notes: Estimates are generated with a stacked event study regression using the 2002-2019 waves of the NSDUH. The regression controls state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, and non-marijuana drug policy controls. 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. 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. The reference period is 1-2 years prior to tax adoption. All the right-hand side variables merged with the NSDUH data (which are based on two-year averages) are merged according to the initial year of the two-wave average.

Appendix Figure 5A. Dynamic Effects of ENDS Taxes on Illicit Drug Use Other than Marijuana Among Youths and Adults, NSDUH 2002-2019

Panel (a): Ages 12-17

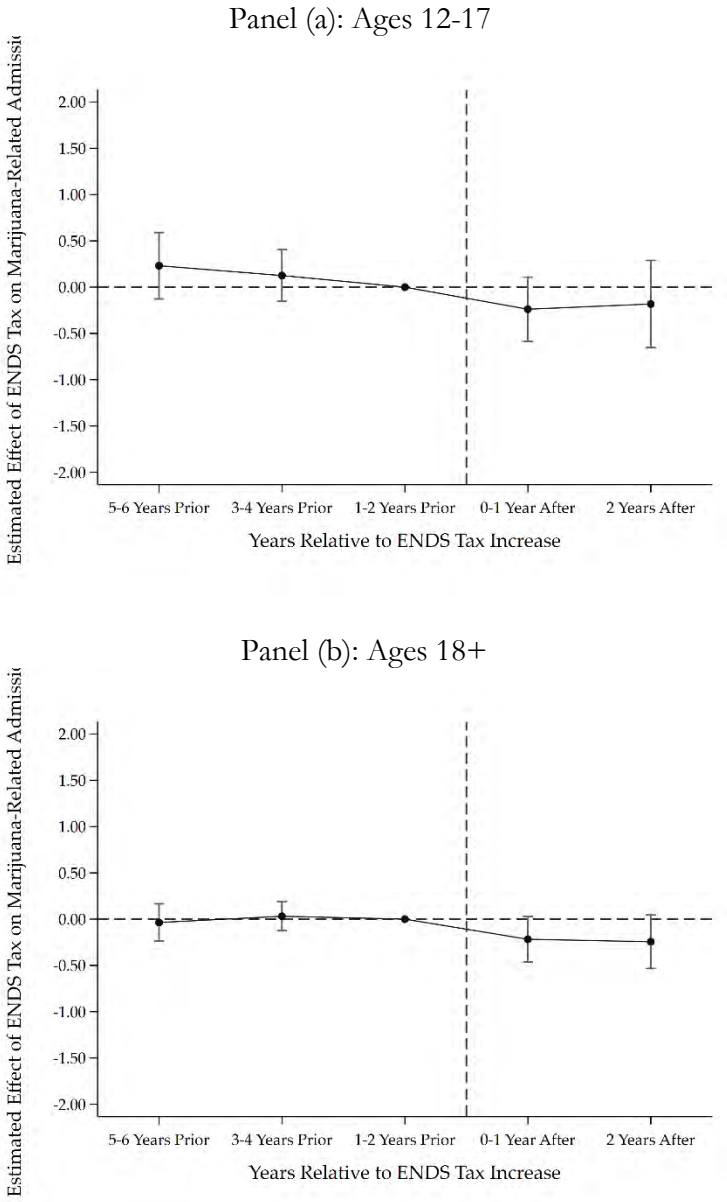


Panel (b): Ages 18+



Notes: Weighted OLS estimates from the TWFE event study regression are shown using the 2002-2019 waves of the NSDUH. The event-time window ranges from six years prior to tax adoption to two years following adoption. The regressions control state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy controls, and non-marijuana drug policy controls. 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. The reference period is 1-2 years prior to tax adoption. All the right-hand side variables merged with the NSDUH data (which are based on two-year averages) are merged according to the initial year of the two-wave average.

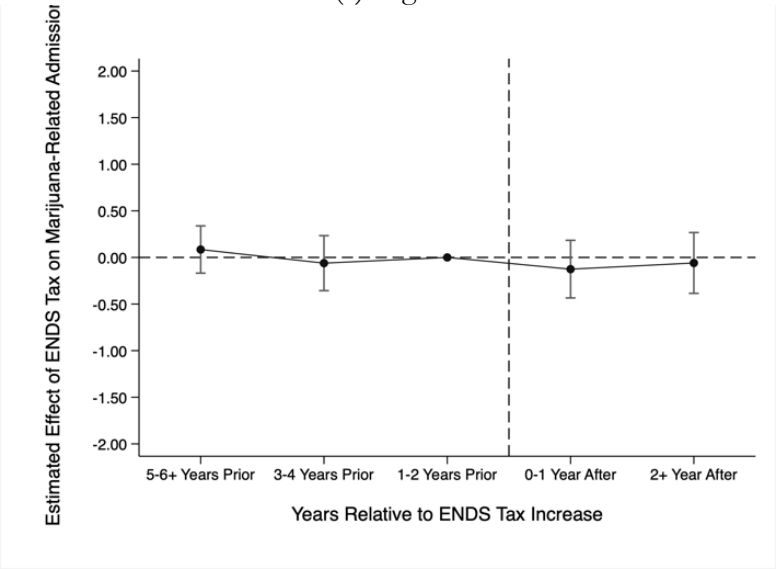
Appendix Figure 5B. Dynamic Effects of ENDS Taxes on Marijuana-Related Admissions TEDS 2000-2019, Using Stacked Difference-in-differences Estimates



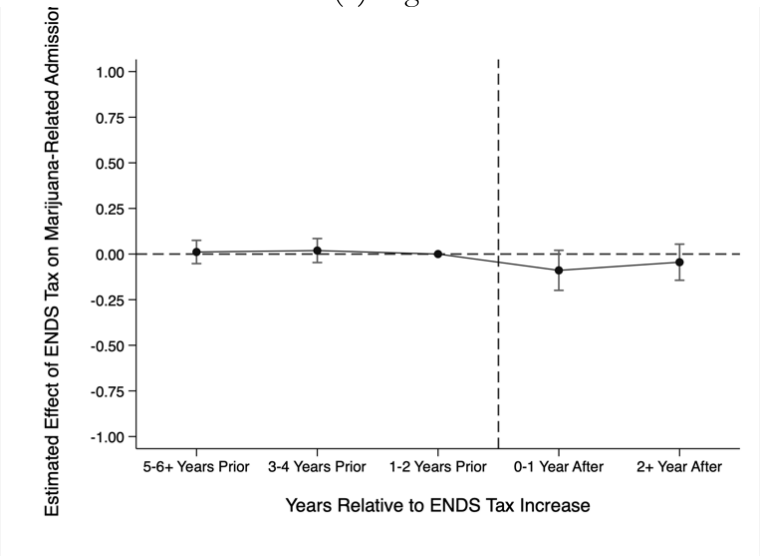
Notes: Estimates are generated with a stacked event study regression using the 2000-2019 TEDS. The sample used in Panel (a) includes all individuals aged 12-to-17 and the sample used in Panel (b) includes all individuals aged 18 and older. The dependent variable is the natural log of the marijuana-related 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 proxies 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 6. Dynamic Effects of ENDS Taxes on Non-Marijuana Drug Admissions, TEDS, 2000-2019

Panel (a): Ages 12-17



Panel (b): Ages 18+



Notes: Estimates are generated using a TWFE event study regression using the 2000-2019 TEDS. Dependent variables are logged. The event-time window ranges from six years prior to tax adoption to two years following adoption. All regressions include controls for state and year fixed effects, demographic controls, macroeconomic controls, tobacco policy controls, marijuana policy controls, alcohol policy control, non-marijuana drug policy controls, and proxies for treatment delivery capacity and reporting. 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. The reference period is 1-2 years prior to tax adoption.

Appendix Table 1. ENDS Tax Adoption

Jurisdiction	Effective Date	Contributes to Identifying Variation?			Tax per mL Fluid, Q1-4 Average (2019 $)					
District/State		*State YRBS*	*National YRBS*	*BRFSS, NSDUH, FARS*	*2010*	*2015*	*2016*	*2017*	*2018*	*2019*
California	4/2017, 7/2017, 7/2018, 7/2019	Yes	Yes	Yes	$0	$0	$0	$1.08	$1.71	$1.61
Connecticut	10/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.10
Delaware	1/2018	Yes	Yes	Yes	$0	$0	$0	$0	$0.05	$0.05
Illinois	7/2019	Yes	Yes	Yes	$0	$0	$0	$0	$0	$0.20
Kansas	1/2017, 7/2017	Yes	No	Yes	$0	$0	$0	$0.13	$0.05	$0.05
Louisiana	7/2015	Yes	Yes	Yes	$0	$0.03	$0.05	$0.05	$0.05	$0.05
Minnesota	8/2010, 7/2013	No	Yes	Yes	$0.45	$2.70	$2.66	$2.61	$2.55	$2.50
North Carolina	6/2015	Yes	Yes	Yes	$0	$0.03	$0.05	$0.05	$0.05	$0.05
New Jersey	10/2018, 11/2019	Yes	Yes	Yes	$0	$0	$0	$0	$0.03	$0.15
New Mexico	12/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.25
New York	7/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.07
Ohio	10/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.03
Pennsylvania	7/2016	Yes	Yes	Yes	$0	$0	$0.56	$1.10	$1.07	$1.05
Vermont	7/2019	No	No	Yes	$0	$0	$0	$0	$0	$1.21
District of Columbia	10/2015, 10/2016, 10/2017, 10/2018	No	No	Yes	$0	$0.47	$1.86	$1.75	$1.85	$2.53
Washington	10/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.07
West Virginia	7/2016	Yes	Yes	Yes	$0	$0	$0.04	$0.08	$0.08	$0.08
Wisconsin	10/2019	No	No	Yes	$0	$0	$0	$0	$0	$0.01
County/City										
Chicago Illinois	1/2016, 1/2019	Yes	Yes	Yes						
Cook County, IL	5/2016	Yes	Yes	Yes	$0	$0	$0.89	$0.92	$0.92	$1.64
Montgomery County, MD	8/2015	Yes	Yes	Yes	$0	$0.78	$0.84	$0.80	$0.80	$0.79

Note: Standardized ENDS taxes are from Cotti et al (2022). Reprinted from Dave et al. (2024).

Appendix Table 2. Descriptive Statistics, State and National YRBS, 2003-2019

Survey	State	National
Dependent Variables		
E-cigarette Use[a]	0.211	0.236
	(0.408)	(0.424)
	[N=499,839]	[N=39,153]
Marijuana Use[b]	0.199	0.220
	(0.399)	(0.414)
	[N=1,194,048]	[N=125,280]
Use Marijuana Less Than 3 Times[b]	0.079	0.088
	(0.027)	(0.284)
	[N=1,038,736]	[N=107,153]
Use Marijuana More Than 3 Times[b]	0.130	0.145
	(0.336)	(0.352)
	[N=1,194,048]	[N=125,280]
Use Marijuana More Than 10 Times[b]	0.082	0.092
	(0.274)	(0.289)
	[N=1,194,048]	[N=125,280]
Ever Use Cocaine[b]	0.065	0.062
	(0.247)	(0.015)
	[N= 1,073,077]	[N=125,280]
Ever Use Heroin[b]	0.030	0.024
	(0.170)	(0.005)
	[N=1,079,685]	[N=125,280]
Individual Controls		
Male	0.489	0.494
	(0.500)	(0.50)
Age	15.857	16.101
	(1.233)	(1.234)
Non-Hispanic White	0.568	0.437
	(0.495)	(0.496)
Non-Hispanic Black	0.133	0.192
	(0.339)	(0.394)
Latino/Hispanic	0.172	0.198
	(0.377)	(0.398)
Grade	10.365	10.49
	(1.096)	(1.116)
Independent Variables		
ENDS Tax (2019 $)	0.021	0.065
	(0.105)	(0.297)
Cigarette Tax (2019 $)	1.865	1.414
	(1.063)	(0.928)
Beer Tax (2019 $)	0.301	0.335
	(0.268)	(0.311)
Tobacco 21 Law	0.021	0.034
	(0.139)	(0.179)
ENDS MLSA	0.479	0.337
	(0.479)	(0.472)
Indoor Smoking Restrictions	0.723	0.493

	(0.447)	(0.498)
Indoor ENDS Smoking Restrictions	0.090	0.057
	(0.283)	(0.231)
Recreational Marijuana Law	0.045	0.051
	(0.207)	(0.22)
Medical Marijuana Law	0.496	0.386
	(0.499)	(0.484)
Unemployment Rate	5.571	6.428
	(2.036)	(2.225)
Poverty Rate	11.971	13.336
	(3.406)	(3.056)
Naloxone Access Laws	0.443	0.383
	(0.492)	(0.483)
Prescription Drug Monitoring Programs	0.234	0.143
	(0.419)	(0.35)
N	1,236,118	128,210

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 2015-2019 YRBS.

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

Appendix Table 3. Descriptive Statistics, BRFSS 2015-2019

	Ages 18-to-20	Ages 21-to-30	Ages 31-and-older
Dependent Variables			
ENDS Use	0.135	0.081	0.027
	(0.342)	(0.272)	(0.161)
Individual Control Variables			
Age	18.991	25.750	59.384
	(0.819)	(2.865)	(13.872)
Female	0.443	0.492	0.569
	(0.497)	(0.500)	(0.495)
Married	0.030	0.281	0.562
	(0.171)	(0.450)	(0.496)
No High School	0.102	0.061	0.073
	(0.302)	(0.239)	(0.261)
High School	0.509	0.266	0.271
	(0.500)	(0.442)	(0.444)
Some College	0.371	0.315	0.271
	(0.483)	(0.465)	(0.444)
College Degree	0.016	0.356	0.383
	(0.126)	(0.479)	(0.486)
Non-Hispanic White	0.606	0.636	0.788
	(0.489)	(0.481)	(0.409)
Non-Hispanic Black	0.100	0.094	0.077
	(0.299)	(0.292)	(0.266)
Latino/Hispanic	0.164	0.146	0.060
	(0.370)	(0.353)	(0.237)
N	25,653	104,943	1,011,642

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

Appendix Table 4. Descriptive Statistics, NSDUH 2002-2019

Dependent Variables		Mean	SD	N
Prior-Month Marijuana Use	Age 12-to-17	0.0712	0.0129	867
Prior-Month Marijuana Use	Age 18-and-older	0.0749	0.0255	867
Prior-Year Cocaine Use	Age 12-to-17	0.0104	0.0054	867
Prior-Year Cocaine Use	Age 18-and-older	0.0212	0.0052	867
Prior-Year Heroin Use	Age 12-to-17	0.0007	0.0004	306
Prior-Year Heroin Use	Age 18-and-older	0.0034	0.0014	306
Prior-Year Methamphetamine Use	Age 12-to-17	0.0016	0.0006	204
Prior-Year Methamphetamine Use	Age 18-and-older	0.0067	0.003	204
Prior-Month Illicit Drugs Use	Age 12-to-17	0.0403	0.0118	816
Prior-Month Illicit Drugs Use	Age 18-and-older	0.0343	0.0047	816
Prior-Month Marijuana Use	Age 18-to-25	0.1869	0.0424	867
Prior-Month Marijuana Use	Age 26-and-older	0.0558	0.024	867
Prior-Year Cocaine Use	Age 18-to-25	0.0563	0.015	867
Prior-Year Cocaine Use	Age 26-and-older	0.0153	0.004	867
Prior-Year Methamphetamine Use	Age 18-to-25	0.0089	0.0043	204
Prior-Year Methamphetamine Use	Age 26-and-older	0.0063	0.003	204
Perceptions of Great Risk from Marijuana	Age 12-to-17	0.295	0.0569	816
Perceptions of Great Risk from Marijuana	Age 18-and-older	0.3315	0.0722	816
Perceptions of Great Risk from Cigarette	Age 12-to-17	0.6671	0.0296	816
Perceptions of Great Risk from Cigarette	Age 18-and-older	0.7287	0.0372	816
Perceptions of Great Risk from Alcohol	Age 12-to-17	0.4042	0.0353	816
Perceptions of Great Risk from Alcohol	Age 18-and-older	0.4281	0.0387	816

Notes: Means are weighted by the age-specific state population.

Appendix Table 5. Descriptive Statistics, TEDS 2000-2019

Dependent Variables	
Primary Marijuana-Related Admissions, Ages 12-to-17	3.335
	(0.092)
Primary Marijuana-Related Admissions, Ages 18-and-older	0.897
	(0.029)
Any Marijuana-Related Admissions, Ages 12-to-17	4.085
	(0.113)
Any Marijuana-Related Admissions, Ages 18-and-older	2.439
	(0.083)
Any No-Marijuana-Related Admissions, Ages 12-to-17	0.757
	(0.033)
Any No-Marijuana-Related Admissions, Ages 18-and-older	5.147
	(0.170)
Primary Heroin-Related Admissions, Ages 12-to-17	0.0542
	(0.003)
Primary Heroin-Related Admissions, Ages 18-and-older	1.436
	(0.076)
Primary Cocaine and Meth-Related Admissions, Ages 12-to-17	0.237
	(0.014)
Primary Cocaine and Meth-Related Admissions, Ages 18-and-older	1.389
	(0.44)
N	996

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

Appendix Table 6. Effects of ENDS Taxes on Perceptions of Great Risk of Harm from Substance Use, NSDUH 2002-2019

	(1)	(2)	(3)	(4)	(5)	(6)
	Marijuana	Marijuana	Cigarette	Cigarette	Alcohol	Alcohol
Age Group	12-17	18+	12-17	18+	12-17	18+
ENDS Tax ($)	-0.00902***	-0.00567	-0.00630***	-0.00172	-0.00704	-0.00453
	(0.00256)	(0.00444)	(0.00194)	(0.00188)	(0.00408)	(0.00290)
N	816	816	816	816	816	816
Pre-Treatment Mean of DV	0.299	0.337	0.667	0.729	0.403	0.427
Full Controls?	Yes	Yes	Yes	Yes	Yes	Yes

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

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2002-2019 waves of the NSDUH. All regressions include controls 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. The data are weighted by the age-specific state population. Standard errors are clustered at the state level and are reported in parentheses. All the right-hand side variables merged with the NSDUH data (which are based on two-year averages) are merged according to the initial year of the two-wave average.

Appendix Table 7. TWFE Estimates of the Effects of ENDS Taxes on Marijuana Use Among Youths, National YRBS 2015-2019

	(1)	(2)	(3)	(4)
ENDS Tax ($)	-0.0244**	-0.0280**	-0.0076	-0.0062
	(0.0121)	(0.0114)	(0.0213)	(0.0265)
N	41,067	41,067	41,067	41,067
Pre-Treatment Mean of Dep Var	0.2275	0.2275	0.2275	0.2275
State and Year FE?	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes
Macroeconomic 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

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

[a] The sample for these regressions is 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 2015-2019 waves of the National YRBS. Demographic controls include age, gender, grade, and race/ethnicity. Macroeconomic controls include state unemployment rate and state poverty rate. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. State alcohol policy control is the beer tax (2019$). 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. National YRBS data are weighted by YRBS-provided weights. Standard errors are clustered at the state level and are reported in parentheses.

Appendix Table 8. Weighted TWFE Estimates of Effect of ENDS Taxes on ENDS Use Among Young Adults, BRFSS 2016-2018

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel I: Ages 18-20			
ENDS Tax ($)	-0.0325***	-0.0319***	-0.0125	-0.0122	-0.0114	-0.0114
	(0.0036)	(0.0045)	(0.0087)	(0.0084)	(0.0075)	(0.0075)
N	25,653	25,653	25,653	25,653	25,653	25,653
Pre-Treat Mean of Dep Var	0.124	0.124	0.124	0.124	0.124	0.124
			Panel II: Ages 21-30			
ENDS Tax ($)	-0.0043*	-0.0062***	-0.0098*	-0.0092	-0.0090	-0.0090
	(0.0024)	(0.0023)	(0.0058)	(0.0056)	(0.0054)	(0.0054)
N	104,943	104,943	104,943	104,943	104,943	104,943
Pre-Treat Mean of Dep Var	0.087	0.087	0.087	0.087	0.087	0.087
State and Year FE?	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic 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 TWFE difference-in-differences regression using the 2016-2018 waves of the BRFSS dataset. Demographic controls include 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 and state poverty rate. State tobacco policy controls include T-21 laws, ENDS MLSA laws, cigarette taxes, an index for indoor smoking restrictions, and an index for indoor ENDS restrictions. State alcohol policy control is the beer tax (2019$). 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 using BRFSS provided sample weights. Standard errors are clustered at the state level and are reported in parentheses.

Appendix Table 9A. Interactive Effects of Marijuana Policy Environment with ENDS Taxes, State YRBS 2003-2019 and NSDUH 2002-2019

	(1)	(2)	(3)
	Marijuana use 12-18 years	Marijuana use 12-17 years	Marijuana use 18+ years
Data Source	State YRBS	NSDUH	NSDUH
ENDS Tax ($)	-0.0449	-0.00194	-0.00883***
	(0.0561)	(0.00162)	(0.00266)
ENDS Tax * Marijuana Liberalized	0.0210	0.00180	0.00118
	(0.0572)	(0.00187)	(0.00183)
Recreational Marijuana Law	-0.0035	0.0108***	0.0397***
	(0.0066)	(0.00215)	(0.00529)
Medical Marijuana Law	-0.0012	-0.000268	0.00651***
	(0.0043)	(0.00140)	(0.00204)
N	1,187,907	867	867
Pre-Treatment Mean of Dep Variable	0.2059	0.0714	0.0732
State and Year FE?	Yes	Yes	Yes
Full Controls?	Yes	Yes	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 2003-2019 State YRBS and the 2002-2009 NSDUH. All regressions control for state and year 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) and NSDUH data are weighted by the age-specific state population. Standard errors are clustered at the state level and are reported in parentheses. All the right-hand side variables merged with the NSDUH data (which are based on two-year averages) are merged according to the initial year of the two-wave average.

Appendix Table 9B. Effects of ENDS Taxes on Prevalence of Adult Substance Use by Age, NSDUH 2002-2019

	(1)	(2)	(3)	(4)	(5)	(6)
	Marijuana Ages 18-25	Marijuana Ages 26+	Cocaine Ages 18-25	Cocaine Ages 26+	Meth Ages 18-25	Meth Ages 26+
ENDS Tax ($)	-0.0052*	-0.0078***	0.0027	0.00054	0.0012	-0.0002
	(0.0026)	(0.0026)	(0.0015)	(0.0004)	(0.0015)	(0.0011)
N	867	867	867	867	204	204
Pre-Treat Mean of Dep Var	0.185	0.0541	0.0562	0.0151	0.00920	0.00621

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

Notes: Estimates are generated with TWFE difference-in-differences regressions using the 2002-2019 waves of the NSDUH. All regressions include controls 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. The data are weighted by the age-specific state population. Standard errors are clustered at the state level and are reported in parentheses. All the right-hand side variables merged with the NSDUH data (which are based on two-year averages) are merged according to the initial year of the two-wave average.

Appendix Table 10. Effects of ENDS Taxes on Drug Treatment Admission (Level Per Population), TEDS 2000-2019

	(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 ($)	0.0266	-0.0204	-0.154	0.00897	-0.131***
	(0.185)	(0.220)	(0.0952)	(0.0206)	(0.0175)
N	996	996	996	996	996
Pre-Treat Mean DV	3.996	4.865	0.800	0.0724	0.352
			Panel II: Ages 18 and older		
ENDS Tax ($)	-0.0309	0.00695	-0.00695	-0.265**	0.208
	(0.0498)	(0.164)	(0.164)	(0.124)	(0.201)
N	996	996	996	996	996
Pre-Treat. Mean DV	0.818	2.080	4.722	1.55	1.65

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

Notes: Estimates are generated with a TWFE difference-in-differences regression using the 2001-2019 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 proxies 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.