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COMPREHENSIVE E-CIGARETTE FLAVOR BANS AND TOBACCO USE AMONG YOUTH AND ADULTS

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After this paper was completed, we learned of a closely related paper by Charles Courtemanche, Chad Cotti, Catherine Maclean, Erik Nesson, Joseph Sabia, and Yang Liang. Their paper is entitled "The Effect of E-Cigarette Flavor Bans on Tobacco Use" and reaches similar conclusions to our study. We are grateful to the National Institute of Drug Abuse (5 R01 DA055976), which provided funding support for this research. We thank Ege Aksu for excellent research assistance and comments on an earlier draft of this study. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Comprehensive E-cigarette Flavor Bans and Tobacco Use among Youth and Adults
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ABSTRACT

The vast majority of youth e-cigarette users consume flavored e-cigarettes, raising concerns from public health advocates that flavors may drive youth initiation into and continued use of e-cigarettes. Flavors drew further notice from the public health community following the sudden outbreak of lung injury among vapers in 2019, prompting several states to enact sweeping bans on flavored e-cigarettes. In this study, we examine the effects of these comprehensive bans on e-cigarette use and potential spillovers into other tobacco use by youth, young adults, and adults. We utilize both standard difference-in-differences (DID) and synthetic DID methods, in conjunction with four national data sets. We find evidence that young adults decrease their use of the banned flavored e-cigarettes as well as their overall e-cigarette use, by about two percentage points, while increasing cigarette use. For youth, there is some suggestive evidence of increasing cigarette use, though these results are contaminated by pre-trend differences between treatment and control units. The bans have no effect on e-cigarette and smoking participation among older adults (ages 25+). Our findings suggest that statewide comprehensive flavor bans may have generated an unintended consequence by encouraging substitution towards traditional smoking in some populations.

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A data appendix is available at http://www.nber.org/data-appendix/w32534

1. Introduction

The past decade has seen a major disruption to the tobacco market with the advent of electronic cigarettes (e-cigarettes) or more broadly electronic nicotine delivery systems (ENDS). Entering the U.S. market in 2007, e-cigarettes have surged in popularity among youth, surpassing cigarettes in 2014 and becoming the most widely used form of tobacco among adolescents. After witnessing an almost doubling in the prevalence of e-cigarette use among high school students (from 11.7% to 20.8% over 2017-2018) and about a 50 percent increase among middle school students (from 3.3% to 4.9%) in a single year (over 2017-2018), the U.S. Surgeon General declared youth vaping a national epidemic (U.S. Department of Health and Human Services – DHHS 2018).[1]

No form of tobacco is deemed safe especially for youth and young adults for whom nicotine exposure can present adverse developmental consequences. Adolescence, in particular, is a key period for brain development, and the prefrontal cortex, which regulates executive function, rational decision making, and higher order cognitive abilities, continues to develop until about the age of 24 (Lopes-Ojeda and Hurley 2024; Arain et al. 2013). E-cigarette use among young adults has also been linked to respiratory symptoms (Tackett et al. 2024). While not completely safe, e-cigarettes are considered to be a safer alternative to combustible cigarette use, though there exists a degree of uncertainty with respect to the relative risk of these tobacco products. The Office of Health Improvement and Disparities in the U.K. (McNeill et al. 2022) recently reiterated its prior conclusion that nicotine vaping poses only a small fraction of the risk relative to smoking (about 5%), whereas a recent survey of 137 tobacco

[1] Based on the National Youth Tobacco Surveys, prevalence of past 30-day e-cigarette use among high school students increased further to 27.5% in 2019 before declining over the pandemic period (19.6% in 2020 and 11.3% in 2021). Among youth and young adults who reduced their use of e-cigarettes over the pandemic, the most commonly cited reasons related to fewer social interactions, health concerns, and reduced access (Bennett et al. 2023).

control experts reported a 37% relative health risk, on average, for e-cigarette use compared to smoking (Alcott and Rafkin 2022).

The heavy toll of smoking, responsible for over 480,000 deaths annually (U.S. DHHS 2014), in conjunction with the significantly lower relative risk profile of e-cigarettes, have presented a key regulatory challenge. Policymakers at the federal, state, and local levels have grappled with how best to regulate access to e-cigarette products such that their harm reduction potential is maximized (i.e. for adults who want to use these smoking alternatives to quit the habit or reduce their combustible cigarette consumption) while constraining uptake and use among youth. This uncertainty surrounding the optimal regulatory approach is reflected in the variance in the policy landscape across the country. For instance, e-cigarette taxes – an increasingly popular policy lever deployed by states and localities to curb e-cigarette use – are currently levied in only 32 states and in D.C., along with a handful of local jurisdictions; there is no federal tax.[2] And, even among states and localities that have adopted these taxes, they vary widely in their structure (i.e. ad valorem vs. excise tax vs. specific sales tax) and in the amount of the tax (Dave et al. 2022). Moreover, several studies have shown that while higher e-cigarette taxes are effective in reducing vaping, especially among youth and young adults, they generate an unintended consequence in the form of increasing cigarette sales and smoking participation and deterring smoking cessation (Abouk et al. 2023; Cotti et al. 2022; Saffer et al. 2020).

In pronouncing youth e-cigarette use a public health epidemic, the U.S. Surgeon General further placed a spotlight on the popularity of flavored e-cigarettes among youth and the importance of reducing access to flavored tobacco products for young people (U.S. DHHS

[2] In 2019, Senator Ron Wyden (Oregon) introduced a bill (E-cigarette Tax Parity Act) that would have expanded the definition of federally taxable tobacco products to include ENDS, and which would establish an excise tax on these alternative nicotine products at a rate per-milligram of nicotine content that would be commensurate with the current federal excise tax of $1.01 per pack of cigarettes.

2018).[3] Advocates contended that flavored e-cigarettes were very appealing to youth and that restrictions on flavors could decrease tobacco use by youth (Chen et al. 2017). Among high school students who currently use e-cigarettes, the vast majority (~85%) use flavored ones (Wang 2020). Flavors have been linked to youth initiation of e-cigarette use (Zare et al. 2018; Villanti et al. 2017), and drew further notice from the public health community following the sudden outbreak of lung injury and deaths among vapers in 2019. This "vaping associated pulmonary injury" was later linked to vapers using their vaping devices to consume THC e-liquids that had contained harmful additives. The 2009 Family Smoking and Tobacco Prevention Act had banned the sale of flavored cigarettes, though menthol and tobacco flavors were exempted, and other flavored tobacco products – notably flavored e-cigarettes – remained on the market. This was partially remedied when the Food and Drug Administration (FDA) extended the ban to cover cartridge-based e-cigarettes in February of 2020. However, menthol and tobacco-flavored cartridge-based e-cigarettes were allowed to remain on the market, and the FDA ban also permitted all flavors to continue to be sold in disposable e-cigarettes and in tank-based vaping devices.[4] Because of these exemptions and substitution possibilities, the federal ban could be easily circumvented rendering its potential impact on flavored e-cigarette use and overall e-cigarette use to be minimal (Romm et al., 2022).

Largely in response to the sudden outbreak of severe lung injury among vapers in 2019/2020 and in recognition of the federal exemptions, several states enacted more sweeping restrictions aimed at flavored e-cigarettes by banning all flavors and/or extending the federal ban to all e-cigarette devices. The key regulatory dilemma of balancing harm reduction while constraining youth access also applies to these more stringent statewide restrictions on the sale of flavored e-cigarettes. Even if these bans are effective in reducing flavored and overall e-

[3] Evidence from a discrete choice experiment of adults also indicated that participants exhibited the strongest preference for non-tobacco and non-menthol flavors (Yang et al. 2023b).
[4] In April 2021 the FDA announced that it will issue product standards within the next year to ban menthol in cigarettes and ban all flavors including menthol in cigars.

cigarette use among youth and young adults – though it is not at all certain that they are since the restrictions could still be circumvented through cross-border purchases, online purchases, purchases at exempted retailers, or users adding their own flavors – they could generate unintended consequences in the form of substitution to cigarettes. These possibilities were encapsulated in a survey of young adult e-cigarette users just following the 2020 federal ban, who reported how they would respond to comprehensive flavor restrictions; subsets of participants reported they would quit vaping or have ways to circumvent the restrictions and not be impacted, or substitute to cigarettes (Romm et al. 2022).

This study directly informs each of these scenarios across youth as well as adults, and presents some of the most comprehensive evidence to date on how the statewide flavor restrictions have impacted e-cigarette use and smoking. We separately explore impacts for adolescents, young adults, and adults, leveraging information from four national datasets: pooled state Youth Risk Behavior Surveys (YRBS), Monitoring the Future (MTF), Behavioral Risk Factor Surveillance System (BRFSS), and Population Assessment of Tobacco and Health (PATH). The main analyses rely on a generalized difference-in-differences approach in conjunction with the synthetic difference-in-differences estimator (Arkhangelsky et al. 2021; Clarke et al. 2023), and we draw conclusions from the weight of the evidence across multiple data sources in combination with the validity of the counterfactual assumptions.

We document several key findings in support of each of the three scenarios noted above – albeit operating differentially across the different age groups. First, for adolescents, while there is some indication of a small decrease in their use of the banned flavored e-cigarettes, we find little evidence to suggest that the statewide flavor bans reduced their overall e-cigarette participation. Models which support parallel trends also do not indicate any meaningful spillovers into smoking participation for youth. Second, for young adults (ages 18-24), we find some evidence that the comprehensive restrictions on flavored e-cigarettes lowered their use of the banned flavored e-cigarettes and reduced their overall e-cigarette participation, by about one to two percentage points. For young adults, the bans appear to have generated an unintended consequence by raising their smoking participation. Finally, for older adults (ages 25+), the statewide bans have no discernible impact on either their e-cigarette or cigarette use.

The remainder of the paper proceeds as follows. Section 2 provides background on the statewide restrictions on e-cigarette flavors, and discusses some of the relevant literature. The multiple data sets are outlined in Section 3, and Section 4 describes our methods. Our main results, robustness checks, and extensions are reported in Section 5. Finally, Section 6 concludes by offering further context for our findings with respect to limitations and policy implications.

2. Background

2a. Statewide e-cigarette flavor bans

Between October 2019 and July 2020, eight states had enacted far more sweeping restrictions on flavored e-cigarettes in relation to the federal ban. Table 1 presents a timeline of the enactment of these restrictions. In addition to these statewide bans, some localities in states without more comprehensive statewide restrictions enacted their own localized e-cigarette flavor bans. We do not include these local bans as they are fairly easily circumvented through cross-border purchases or other means (Yang et al. 2022; Rich 2022; Dove et al. 2023). Local bans also created confusion for retailers on what is legal to sell in their location, and places the burden of enforcement on local authorities who may not have the requisite resources.

The enactment of more comprehensive restrictions on e-cigarette flavors was largely driven by concerns regarding the health effects of vaping as they unfolded over 2019-2020 in conjunction with the outbreak of lung injury among vapers. Most of the states that enacted permanent bans on flavors also enacted, or attempted to enact, emergency flavor bans as a result of this nation-wide outbreak of severe lung disease linked to e-cigarettes and other vaping devices in 2019.[5]

Eight states (Table 1) issued emergency rules to temporarily ban the sale of flavored e-cigarettes. As a result of legal challenges, these orders were blocked in four states. Temporary bans adopted in Rhode Island (RI) and Massachusetts (MA) became permanent in March and June of 2020, respectively. New York (NY) and Utah (UT), where bans were initially blocked by legal challenges, were able to enact permanent bans. New Jersey (NJ) and Maryland (MD) also enacted permanent bans. Montana (MT) and Washington state (WA) implemented temporary restrictions on flavored e-cigarette sales in October 2019 which expired in January of 2020. We exclude these states from the analysis since the bans were very short-lived; we also exclude these states from the control group given they have been previously treated, albeit for a short period of time.

2b. Use of flavored e-cigarettes

Table 2 presents descriptive information, based on the PATH, on the percent of nicotine vapers who use banned flavors across the three age groups. In all treatment states other than MA, all flavors were banned in all e-cigarette devices except for tobacco and menthol flavors. MA further banned menthol flavors in e-cigarette products as well. These estimates underscore two key points. First, banned flavors were most popular among youth, with the majority of adolescents who currently use e-cigarettes reporting use of the (banned) flavored e-cigarettes, both before and after the bans. There is a steep age gradient in the use of the banned flavors among current users, with the popularity of these flavors waning for younger and older adults. This gradient appears to flatten post-treatment, particularly between youth and young adults. Second, interestingly, post-treatment, conditional on e-cigarette use, consumption of the banned

[5] The first case of vaping-related lung injury was reported to the Centers for Disease Control and Prevention (CDC) in August 2019. Cases quickly rose and peaked in September. By February 2020, over 2800 cases and 68 related deaths were recorded. See: Krishnasamy et al. (2020) and Lancet Respiratory Medicine (2020).

flavors increases for all age groups, for treatment states as well as the control states. The last column presents the unconditional difference-in-differences estimates, which indicate that the largest decline in the use of flavors out of all age groups occurred for young adults (by 5.2 percentage points) in the ban states relative to the never adopters. Declines in the use of the banned flavors for youth and older adults are minimal.

The relatively high use of flavors in the treatment states, even after the bans go into effect, may be in part due to exemptions for certain store types. MA exempts stores that primarily sell tobacco, e-cigarette establishments, tobacco/smoking bars, adult-only retailers, and liquor stores from all flavor bans. UT also exempts tobacco retail specialty businesses from flavor bans (Public Health Law Center, 2023). Users are also able to add their own flavors to the e-liquid mix by opening the e-cigarette cartridge or tank device. As it is not difficult to make these modifications, a flavor ban could also result in a black market for flavored e-cigarettes. This essentially is what happened during the 2019 outbreak of lung injuries, which were linked to vape devices that had been modified and sold by black market operators. Hence, users still be able to obtain flavored e-cigarettes through online purchases or illegally on the black market or through establishments due to lack of enforcement.[6]

2c. Prior studies

Restrictions on flavored e-cigarettes have been motivated by the popularity of flavors among youth users, and with the stated rationale of preventing youth initiation and continued use of these products. Given the recency of the more comprehensive sub-national flavor bans, the literature on the direct and broader impacts of these restrictions is still emerging.

Ali et al. (2022) study the effects of flavor restrictions on e-cigarette sales in three states with a permanent ban (MA, NY, RI) and one state with a short-lived ban (WA) using early data

[6] Anecdotal evidence on seizures from the MA Department of Revenue points to a thriving illicit market in the state. There was a substantial increase in seizures of untaxed ENDS and other tobacco products entering the state from surrounding states, and unlicensed distributors continuing to operate and sell banned flavored tobacco products within MA (Grier 2023).

through 2020, and thus essentially identifying very short-term effects for up to a year post-treatment. They find substantial reductions in sales (on the order of 25-31%), largely driven by a reduction in the sale of non-tobacco flavored e-cigarettes. Xu et al. (2022), using a similar post-ban window extending through early 2020, widen the lens to study effects on cigarette sales. They focus on bans in three states (MA, RI, and WA) and find significant increases in cigarette sales in the short term on the order of 5-8%. Expanding on the number of treated localities (to include seven ban states as well as various sub-state local bans) and extending the post-treatment window through early 2023, Friedman et al. (2023) also find a significant reduction in ENDS sales, driven by a decrease in the sale of flavored products, and a substitution into cigarette sales, both overall and for brands disproportionately preferred by youth.

All of these studies rely on commercial sales data from IRI, which cover sales from national chain convenience stores, large food stores, drug stores, mass merchandiser outlets, and military sales. This this work identifies compelling effects on e-cigarette sales and potential substitution into cigarettes, but the use of these commercial sales introduces three main limitations to any analysis. First, sales from online retailers, independent convenience stores, independent food stores, other independent stores (excluding drug stores), and tobacco specialty stores such as vape shops are excluded. These exclusions omit a large share of tobacco sales. For instance, Selya et al. (2023) conclude that about 50% of the e-cigarette market is not recorded by IRI. Analyses with the PATH data, in terms of where users purchase their e-cigarette products, show that about 60% of youth purchases of vaping products occur through tobacco specialty stores; the corresponding shares for young adults and adults are 70.24% and 67.26%, respectively. In addition to capturing only a limited fraction of tobacco sales, estimates using the IRI data may further present a distorted picture of the impact of bans since many of the retailers not represented in the data (i.e. vape dispensaries, specialty tobacco retailers) were also exempted by the flavor bans in certain states. If the bans shifted sales away from traditional retailers to these specialty retailers, either because they were exempted or less vigorously enforced, then the identified treatment effects in studies using the IRI data may be overstated. Second, sales do not equate to use. A reduction in sales in the banned states could be offset by an increase in cross-border sales or through illicit purchases. Indeed, recent work with the IRI data (Chen et al. 2023), even over a short post-treatment window (through February 2020) uncovered strong evidence of spatial spillovers; bans implemented in four states (MA, WA, RI, and MT) resulted in significant increases in ENDS sales in neighboring counties. Third, relatedly, use of these aggregate sales data cannot uncover separate effects on use across youth vs. adults or across other sub-populations of interest.

Quasi-experimental studies of comprehensive flavor bans that have gone beyond effects on sales are few, and have largely focused on a single state or locality prior to the 2020 federal ban. Several studies have explored the effects of restrictions on flavored tobacco that were adopted in the San Francisco Bay Area over 2018-2019. In their analysis of the impact of these bans among high school students, using the California Healthy Kids Survey, Dove et al. (2023) find no effects on current or ever use of e-cigarettes over a post-policy window of one year.[7] They attribute this finding to potential substitution from the banned to the non-banned flavors and/or cross-border purchases. Friedman (2021), utilizing data on high-school students from the district YRBS, finds robust evidence that San Francisco's ban also resulted in adolescents substituting into cigarette use, even over the study's short post-policy window.[8] Hawkins et al. (2022) study how local restrictions on flavored tobacco products in Massachusetts counties, which predated the federal flavor ban, affect youth use of e-cigarettes and cigarettes. Using biennial data from the 2011-2017 Massachusetts Health Surveys, they find significant

[7] Similarly, evidence from outside the U.S. context – based on a pre-post comparison surrounding the Finnish Tobacco Act, which in 2016 banned flavors in tobacco products excluding tobacco flavor – found essentially no change in e-cigarette use (Ruokolainen et al. 2022).

[8] A descriptive study (Yang et al. 2020), presenting pre-post comparisons among a small sample of previous tobacco users in San Francisco, finds a similar pattern of result as
finds significant reduction in flavored tobacco and e-cigarette use among adults (ages 18-34). These decreases, however, are counteracted by increases in cigarette use, with this substitution being particularly pronounced among younger adults (ages 18-24).

reductions in both e-cigarette and cigarette use among adolescents in the treated counties after the adoption of the ban relative to counties that did not enact these restrictions.

Based on an online survey of 1624 adult e-cigarette users, a recent study (Yang et al. 2023a) explores pre-post changes in e-cigarette use and flavored e-cigarette use associated with flavor restrictions in three states (WA, NJ, and NY). Following the ban, 8.1% of e-cigarette users stopped using e-cigarettes, and overall, the use of non-flavored e-cigarettes increased from 5.4% to 25.4%. Descriptive evidence indicated that e-cigarette users were able to obtain the banned flavors, post-restrictions, through various means: in-state retailers, cross-state purchases, online purchases, black market, mixing the flavors themselves, and stocking up on e-cigarettes prior to the ban. Their finding that 45% of e-cigarette users continued to be able to purchase the banned flavors from in-state retailers suggests that compliance and enforcement were not high.

2d. Contributions

Our study makes several key contributions to this nascent literature. First, we focus on reported use (as opposed to aggregates sales) and provide some of the first and most comprehensive evidence to date on the impact of major statewide restrictions on flavors on both e-cigarette use and cigarette use. Second, we provide effects of these restrictions on three age groups, including youth, young adults, and adults, thereby informing some of the key issues that present a challenge for policymakers – how to regulate e-cigarettes so as to reduce uptake and use among youth without generating unintended consequences across the life-course (i.e. increasing the update of smoking or deterring smoking cessation). Third, we draw on information from four national individual-level data sets – with three of these data sets containing information on youth, and two containing information on adults – allowing us to cross-validate findings across independent surveys and settings. Fourth, we utilize the most recent data available, thereby extending the post-policy window beyond the very short-term to encompass effects up to three years following the bans. Other than studies utilizing sales data, most of the prior work on reported use, which also has been confined to only a single state or locality, has peered into very short-term windows (up to one year post-treatment). Finally, we also bring to bear recent innovations in the two-way fixed effects (TWFE) difference-in-differences (DID) literature in our analyses, paying careful attention to the validity of counterfactual assumptions and drawing conclusions from the weight of the evidence across the multiple datasets and estimation methods.

3. Data

To obtain a comprehensive view on the effects of flavor ban policies on smoking and e-cigarette use, we capitalize on information from several different datasets for both youth and adults, each offering complementary strengths. Specifically, we use the pooled state Youth Risk Behavior Survey (YRBS), Monitoring the Future (MTF), Population Assessment of Tobacco and Health (PATH), and the Behavior Risk Factor Surveillance Survey (BRFSS). The outcomes we assess in each dataset are past 30-day use of cigarettes or e-cigarettes.[9] A summary of these datasets with descriptive statistics on key variables is presented in Appendix Tables A10-A14. Figure 1 documents trends in e-cigarette and cigarette use separately for youth, young adults (ages 18-24), and older adults (ages 25+) across the four datasets. [10]

3a. Youth Risk Behavior Survey

The state YRBS is a biennial representative sample of youth for each state that participates and collects information on a set of topics that the CDC has determined is of critical importance for mortality and morbidity. It is a self-administered survey that takes place in schools for grades 9-12. The YRBS is opt-in, and not every state samples in every sample period. For models that require a balanced panel, we drop states that are not available in all waves of the survey. Cigarette use is measured from 2011-2021. Information on e-cigarette use

[9] In supplementary analyses, we also assess spillover effects on other tobacco products (smokeless tobacco, cigars) when available.
[10] While there are some differences in the prevalence rates across data sources, likely driven by differences in the underlying sampling, the trends largely track similarly across the datasets.

is available from 2015 onwards. The YRBS offers several important advantages. With approximately 150,000 students surveyed in a given year, pooling the states yields very large sample sizes for assessing heterogeneity and improving precision of the estimates. The YRBS is also one of the few national datasets that is state-representative, which helps to minimize bias in identifying the effects of a statewide intervention (such as the ones we study here) that may arise due to potential shifts in the composition of state-specific samples.[11] The YRBS is conducted every other year on an odd-year basis. Hence, there are no data for the pandemic year of 2020.

3b. Monitoring the Future

As with the YRBS, the MTF is also a school-based survey; it is nationally representative of middle school and high school students in the 8^{th}, 10^{th}, and 12^{th} grades. We utilize the restricted version of the MTF with geographic identifiers. Approximately 45,000 students are sampled each year. We measure e-cigarette and cigarette use in the MTF from 2014-2022. Due to the difficulty with in-school sampling during the school closures and lockdowns during the pandemic, data for 2020 are excluded from the analyses.

3c. Population Assessment of Tobacco and Health

The PATH is a panel study that longitudinally resamples youth ages 12-17 and adults of all ages in multiple waves. It is a household sample and takes place in-home, and therefore provides an alternate sample to the school-based MTF and YRBS – a differentiation which may prove important over the post-pandemic periods. The included waves cover 2014-2021 where both cigarette and e-cigarette use are measured throughout. We again drop 2020 from the analyses due to challenges with in-home sampling during this year. An advantage of the PATH is its detailed information on the use of flavored ENDS products, which is important for

[11] Pooling the state YRBS data and generating national estimates requires standardized person-specific sampling weights, which we generate by following the literature (see for instance: Dave et al. 2024; Abouk et al. 2023).

assessing the popularity of these flavors among youth and adults and how e-cigarette users shifted their consumption across banned and non-banned flavors following the restrictions (Table 2). Another advantage of the PATH is its sampling of both youth as well as adults. There are approximately 13,000 youth, 8,000 young adults (ages 18-24), and 16,900 older adults (ages 25+). If there is attrition, then samples are refreshed from a shadow sample to maintain sample sizes and representativeness. They also include new sets of youth as they age into the sample, and youth who age out are then included in the adult sample. To be consistent with the other datasets, our analyses treat the PATH as repeated cross-sections.

3d. Behavioral Risk Factor Surveillance System

The BRFSS is a state representative phone survey of adults conducted on a yearly basis. It covers approximately 24,000 younger adults (ages 18-24) and 410,000 older adults (ages 25+) sampled independently each year. One disadvantage of the BRFSS is that e-cigarette use was only included in an optional module that each state could opt into or out of in 2018, and it was not measured at all in 2019, and included again as an optional module in 2020. This limits the consistency of this measure across time and so we include only the years 2016, 2017, 2021, and 2022 in our analyses of e-cigarette use in the BRFSS. Past 30-day cigarette use is measured consistently from 2014-2022.

3e. Additional policy measures and control variables

We account for various additional confounding tobacco control measures, including cigarette taxes, indicators for the adoption of an e-cigarette tax and the type of tax, and indicators for the adoption of internet sales bans. We match these to the survey data based on residential state and survey year. All analyses further control for socio-demographics (age, gender, race, and ethnicity).

4. Methods

We leverage the quasi-natural experiment provided by the enactment of comprehensive flavor bans in six states to provide plausibly causal estimates of the effects of these bans.

We start with the following standard difference-in-differences (DID) model:

$$E_{ist} = \beta * FBAN_{st} + X_{ist} * \theta + \gamma_s + \tau_t + \varepsilon_{ist} \quad (1)$$

Here, E_{ist} denotes various tobacco use outcomes for person (i) in state (s) at time (t), and $FBAN_{st}$ is an indicator for when, and which states, enacted the comprehensive e-cigarette flavor ban. The six states with permanent e-cigarette flavor bans adopted these bans between late 2019 and mid-2020. These adoption dates are reasonably proximate and minimally staggered such that 2020 can be defined as the treatment initiation year. The issues associated with potential biases due to staggered adoption periods are thus not empirically relevant. The vector X_{ist} includes tobacco policy measures, and individual characteristics including age, gender, race, and Hispanic ethnicity. All models include fixed effects for each state (γ_s), which accounts for any stable unmeasured heterogeneity across these areas (for instance, differences resulting from unmeasured cultural factors or sentiment towards tobacco use) and fixed effects for each period (τ_t), which captures unobserved secular trends in tobacco use outcomes impacting the full sample. The parameter of interest, β, summarizes the average causal effect of the flavor bans on tobacco use realized over the post-treatment period. We estimate the effects of flavor bans for the three age groups, and for e-cigarette use, cigarette use, in the past month. As noted above, the three age groups studied are youth aged 14-17, young adults ages 18-24, and adults ages 25+. We estimate equation 1 at the individual level but obtain standard errors by state-cluster bootstrap methods.

To draw a more explicit focus on the validity of the control states and the counterfactual design, we apply the synthetic difference-in-differences (SDID) estimator (Arkhanglesky et al. 2021; Clarke et al. 2023). The SDID estimation bridges strengths from both panel data DID and synthetic control (SC) methods, while providing various additional strengths and modeling flexibility.

Specifically, in its basic form, a consistent causal effect of the flavor restrictions on a given tobacco use outcome (Y_{st}, in a given state *s* at time period *t*) can be derived by estimating:

$$\left(\hat{\beta}^{SDID}, \hat{\mu}, \hat{\gamma}, \hat{\tau}\right) = \underset{\beta, \mu, \gamma, \tau}{arg\ min} \left\{\sum_{s=1}^{n} \sum_{t=1}^{t} (Y_{st} - \mu - \gamma_s - \tau_t - FBAN_{st}\beta)^2 \hat{\omega}_i^{SDID} \hat{\lambda}_t^{SDID}\right\}. \quad (2)$$

In the above equation, the causal effect of the treatment, that is the average treatment effect on the treated (ATT; represented above by $\hat{\beta}^{SDID}$), is estimated from a two-way fixed effects (TWFE) model with optimally-chosen weights $\hat{\omega}_i^{SDID}$ and $\hat{\lambda}_t^{SDID}$. In contrast to the standard TWFE DID estimation, however, which relies on the "parallel trends" assumption, SDID more flexibly reweights and matches pre-treatment *trends* by selecting a weighted set of control units that minimizes the trend differences in the pre-exposure periods. Specifically, optimal unit-specific weights $\hat{\omega}_i^{SDID}$ are chosen to align pre-treatment trends across outcomes in the untreated vs. treated states, subject to a regularization parameter which prevents overfitting while increasing the variance and uniqueness of the weights. SDID also introduces, and optimally chooses, time-specific weights $\hat{\lambda}_t^{SDID}$ to further remove bias from unobserved shocks and improve precision. These considerations serve to improve the robustness and precision of the SDID estimator, in addition to making the model more flexible in generating credible counterfactual comparisons (Arkhangelsky et al. 2021). As is the case in the standard DID models, we obtain standard errors by state-cluster bootstrap methods.

SDID estimation requires a balanced panel which, given the data we are using, requires aggregation to the state and year level. This necessitates dropping some states in datasets for which those states do not appear in every year. SDID has been shown in some contexts to outperform two-way fixed effects models based on having superior power and insensitivity in power to selection of the pre-treatment period by the analyst (Dench et al., 2024). In this case this advantage may be balanced against the need to drop some states from the some analytic samples.

In order to assess pre-policy parallel trends between the treatment and control states, we generate event studies which in this circumstance are the average conditional difference between the treatment and control group in each year relative to some reference period. In the context of DID analysis, we use the reference period included in that dataset that is closest to the treatment, and control groups are all weighted equally. The SDID event studies are time series plots of the difference between the treatment group and the control group. The average pre-period differential between the treatment group and control group is subtracted from each period's differential. All confidence intervals are based on state-level cluster bootstrap inference and reported at the 95% confidence level.

Because we rely on a set of studies and alternate samples, we further construct and report an aggregate of the separately estimated treatment effects using a fixed effects method of aggregation (Hedges 1998). We do so in order to provide a convenient summary of our estimates and to draw out patterns across alternate data sets. This "meta-analysis" involves taking a weighted average of the estimates across the alternate data sets, where the weights are the inverse of the squared standard error (SE) of each estimate, normalized to add up to one. The standard error of this estimate is the inverse of the square root of the sum of all these weights. In this aggregation method, we assume that each dataset is estimating the same target parameter from an underlying population (i.e. youth, young adults, adults) but with different samples. Assuming homogeneity of effects across samples and time-periods is required for this assumption to be met.

5. Results

5a. Main analyses of e-cigarette use and cigarette use

We report our main findings from DID and SDID regressions in Tables 3 and 4. We show SDID event history studies in Figures 2 through 4 and the corresponding DID event history studies in the figures in the Appendix. Supplemental analyses and robustness checks also may be found in the Appendix. Table 3 presents estimated treatment effects of the statewide flavor bans on our key outcomes – e-cigarette and cigarette use – across the three age-defined sub-populations, across the four datasets, for both the DID and SDID estimation. We emphasize and discuss results based on our preferred SDID estimation, though our conclusions and overall pattern of findings are not materially changed with the standard TWFE DID estimates. We summarize the average treatment effect on the treated (ATT) across the alternate datasets for each age group in Table 4 through the meta-analytic aggregation method.

Turning to youth (Table 3, Panel A), we do not find any statistically significant effects of the bans on e-cigarette participation, for any of our datasets, using either the DID or SDID estimator. Estimated effects based on the MTF are somewhat more suggestive of a potentially meaningful decline in overall e-cigarette use, between 1.3 to 2.3 percentage points (9.4 ~ 16.5% relative to the mean). While these estimates in the MTF are credibly supported by parallel trends in the SDID event study analyses (Figure 2), they are imprecise and do not reach statistical significance. Moreover, the aggregated treatment effect (Table 4, Panel A) of the bans on youth e-cigarette use across all datasets is very small and not statistically distinguishable from zero.

Interestingly, the aggregated average treatment effect on youth in the treated states (Table 4, Panel A) indicates evidence of spillovers into the cigarette market – a statistically significant increase in cigarette use at the extensive margin (on the order of 1.7 to 2.6 percentage points). Prima facie, this is suggestive of the flavor bans generating an unintended consequence by raising smoking participation among youth. Given that there are essentially no discernible effects on e-cigarette participation, one interpretation is that any such potential substitution effects into cigarette use may operate through shifts at the intensive margins of e-cigarette use and/or the composition of e-cigarette use (types of devices and flavors uses). However, on closer scrutiny, it is notable that the significant and positive aggregated ATT (for the SDID estimation) on cigarette use among youth (Table 4, Panel A) is driven by positive and significant effects in the YRBS and the PATH (Table 3, Panel A). SDID event study analyses (Figure 2) show that the apparent increase in cigarette use in the YRBS, and the PATH is a continuation of a pre-existing trend differential and therefore not supportive of a causal interpretation. For the MTF analyses, where there is stronger evidence of parallel pre-treatment trends between the treated and control states, and thus more supportive of causal inference, there is no indication of any statistically significant or meaningful change in cigarette use. We interpret the sum of these results for youth to suggest that the state flavor bans had little to no impact on their use of e-cigarettes or cigarettes at the extensive margin.

Next, we explore effects for younger adults (ages 18-24) using data from the BRFSS and the PATH. Estimates of the ATT presented separately across the two datasets (Table 3, Panel B) show a significant decrease in e-cigarette use and substitution into cigarette use, based on analyses with the BRFSS. The SDID estimates indicates effect magnitudes on the order of about two percentage points (16.9% decrease in e-cigarette use; 20% increase in cigarette use; relative to the mean). A causal interpretation of these estimates is strongly supported by the balanced trends in both the SDID (Figure 3) and DID (Appendix) event study analyses. Estimated SDID effects, based on the PATH, are largely similar (suggesting a 2-3 percentage point decrease in e-cigarette use and consequent increase in cigarette use) but not statistically significant. Combining the treatment effects across both samples (Table 4, Panel B), summarizes our key findings for young adults. Comprehensive flavor bans were effective in reducing overall e-cigarette use among 18-24 year olds by about two percentage points, though this decrease was just about fully counteracted by a corresponding increase in their smoking participation. In contrast to these shifts for younger adults, we do not find any discernible extensive margin effects of the bans on either e-cigarette or cigarette use for older adults (ages 25 and up) (Tables 3 and 4, Panel C). While the event study analyses for older adults (Figure 4 and Appendix) are somewhat noisier, they also do not uncover any consistent or meaningful effects over a post-policy window of two to three years.

5b. Extensions

In supplementary analyses (results reported in the Appendix), we address specific issues and sensitivity of our main estimates. First, we explore if the bans had any impacts on other forms of tobacco (other than e-cigarettes and cigarettes) or at the margin of co-use of both e-cigarettes and cigarettes (Appendix Tables A1 and A2). We do find a suggestive increase in cigar use among youth, though in the SDID analyses – which exhibit stronger parallel trends and are more supportive of a causal interpretation – the estimated effect is highly imprecise and not statistically significant. Among young adults, for whom we found a significant decrease in their e-cigarette use and increase in cigarette use, we also find some evidence of substitution into smokeless tobacco (Appendix Table A2; SDID event study in the Appendix). And, for older adults, we continue to find no impacts on other forms or margins of tobacco use that are supported by parallel trends and a credible causal interpretation from the event study analyses.

Second, we present estimates without controlling for any covariates in Appendix Table A3 (for youth) and Appendix Table A4 (for younger and older adults). Our findings for adults are not sensitive to models that exclude the additional policy controls and covariates. For youth, in models that do not include any covariates, we find some evidence across datasets of a decrease in e-cigarette use and an increase in cigarette use. However, that these estimates are sensitive to the inclusion of tobacco policy controls gives some pause to a causal interpretation, and we therefore cannot rule out that the smoking bans had little to no effect among youth after accounting for these other confounding shifts.

Finally, we assess heterogeneity in the estimated treatment effects across gender and race/ethnicity (Appendix Tables A5-A9). Among youth, it is difficult to discern heterogeneity that is consistent or credibly supported across datasets. For young adults, there is more consistent evidence of stronger effects on e-cigarette use and substitution effects into smoking among males and among whites and Hispanics. Among older adults, while we had overall found no impact on their use of e-cigarettes or cigarettes in relation to the flavor bans, there is some suggestive evidence from the SDID estimation based on the BRFSS (Appendix Table A6) of possible decreases in e-cigarette use and substation into cigarette use among males. Estimating heterogeneous treatment effects across these sub-populations is a noisy endeavor, and we view these patterns as suggestive.

6. Discussion

A key regulatory challenge facing tobacco control policymakers surrounds how best to regulate access in the e-cigarette market to maximize the product's harm reduction potential while minimizing access for youth. The U.S. Surgeon General, FDA, and various public health groups have expressed concerns relating to the popularity of flavored e-cigarettes among youth, in light of evidence linking the use of flavored e-cigarettes in the initiation of nicotine vaping (Chen et al. 2017; Zare et al. 2018; Villanti et al. 2017; U.S. DHHS 2018). The FDA responded by banning certain flavors in e-cigarette devices in 2020, albeit with various exemptions (i.e. menthol flavors and flavored disposable and tank-based vaping devices could continue to be sold). Unfolding over a period that witnessed a sudden outbreak of lung injuries and deaths among vapers, several states, guided by the precautionary principle, enacted sweeping statewide restrictions on the sale of flavored e-cigarettes which fixed many of the loopholes in the federal ban.

When a sample of current e-cigarette users were asked how they may respond to comprehensive flavor restrictions in nicotine vaping products (Romm et al. 2022), three modal responses emerged: 1) quit e-cigarette use; 2) not change their use of e-cigarettes; 3) substitute into cigarette use. Each of these scenarios has important implications for public health. We provide some of the first and most comprehensive evidence to date, informing these scenarios and assessing how the statewide flavor bans affected youth, young adults, and adults with respect to their actual use of e-cigarettes and cigarettes.

We find evidence of a relatively small but meaningful decline in e-cigarette participation, on the order of about two percentage points, among young adults ages 18-24; however, this decrease was almost fully offset by substitution into smoking. For youth, some of our analyses especially with the MTF data seem to suggest a similar pattern, though pre-existing trends and sensitivity of these estimates across data sets and samples make us cautious in attributing a causal interpretation; we therefore cannot rule out that the bans had little to no effect on adolescents' cigarette or e-cigarette use. Turning to older adults ages 25+, we do not find any discernible impacts associated with the bans.

One implication of these results, including the relatively small effect sizes for young adults, is that the statewide restrictions – even if more comprehensive in scope compared to the federal ban – are still being circumvented. Support for this interpretation of the findings comes from the PATH, which shows that a substantial fraction of youth and young adult e-cigarette users continue to report using banned flavors even after the bans. Survey and anecdotal evidence point to various ways that e-cigarette users are able to bypass the restrictions, through online purchases, purchases from illicit sources, cross-border purchases, purchases from non-compliant retailers in the state, and users adding their own flavors to the e-liquid in vaping devices (Romm et al. 2023; Chen 2023; Yang et al. 2023a; Rich 2022). A more comprehensive federal ban on flavored e-cigarettes could be more effective in reducing flavored and overall e-cigarette use by shutting down some of these circumvention channels, for instance by deterring cross-border purchases or by enforcing retailer compliance. However, other sources of flavored e-cigarettes may remain (black market, self-made flavorings) and may continue to moderate the effectiveness of further nationwide restrictions unless directly addressed.

A key challenge for any analysis of the recent statewide flavor bans, adopted over late 2019-mid 2020, is that these bans coincided with the advent of the COVID-19 pandemic. While we were cautious in drawing causal interpretations in conjunction with evidence of balanced trends pre-policy adoption or pre-pandemic, we cannot rule out potential confounding bias arising from more complex interactions between the bans and the pandemic and from any heterogenous impact of the pandemic related shocks (economic, health, social distancing, school and business closures) across the various treated and control states. Given the recency of the statewide bans, the treatment effects we estimate capture changes over a post-policy window of two to three years. Observing effects as additional years of data become available would be fruitful for assessing behavioral changes in tobacco use that may take further time to materialize; extending the post-policy window can also help further disentangle the confounding effects of the pandemic (which would be expected to fade over time) from any persistent direct effects of the bans.

These caveats notwithstanding, we note that even the moderately sized substitution effects into smoking, which we find among the young adult population, can generate substantial costs. Our finding that the comprehensive flavor bans increased smoking participation by about 2.4 percentage points among young adults would add about $5.1 billion total lifetime societal costs for the average treatment state.[12] Such unintended consequences serve to moderate the public health benefits of sub-national restrictions on flavored e-cigarettes. They underscore the need to account for not only outcomes directly targeted by such restrictions but also potential spillovers into non-targeted outcomes for a more complete calculus of the potential costs and benefits of such policies.

[12] We monetize the increase in smoking participation using the population for the average treated state (7.76 million in 2022), the share of the population that is ages 18-24 (~ 9.4%), and estimates for the total social cost of smoking over one's lifetime from Sloan et al. (2006). The study reports total costs in the amount of $106,000 for a female smoker and $220,000 for a male smoker. We take the average and deflate to 2022 dollars, resulting in a lifetime cost estimate of $292,700 per average smoker.

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Table 1
Timeline of State E-cigarette Flavor Bans

Date			10/19	11/19	12/19	1/20	2/20*	3/20	4/20	5/20	6/20	7/20
State	FIPS	EVALI										
MA	25	17.86		T	T	T	T	T	T	T	P	P
RI	44	5.00	T	T	T	T	T	P	P	P	P	P
NY**	36	8.75								P	P	P
UT**	49	39.06										P
NJ	34	13.59							P	P	P	P
MD	24	12.10				P	P	P	P	P	P	P
WA	53	3.25	T	T	T	T						
MT	30	5.00	T	T	T	T						

EVALI are the approximate number of EVALI hospitalizations or deaths reported to the CDC, as of 2/2020, per million population. The US average was about 6.67. No state bans tobacco flavor. Only MA bans menthol in all tobacco products. MD prohibits only the sale of cartridge-based and disposable e-cigarettes with flavors. T = Temporary ban based on EVALI concerns. P = permanent ban on flavored vapes. WA and MT are excluded from the data used in this paper because their bans were only in effect for four months which makes them different from both the treatment states and the control states. *Federal ban on cartridge based flavored e-cigarettes goes into effect. ** Temporary bans block by legal challenges. The state flavor bans are for e-cigarettes only. Ban data from Tobacco Free Kids, https://www.tobaccofreekids.org/assets/factsheets/0398.pdf

Table 2
Weighted Descriptive Data on the Percent of E-Cigarette Users that Report Using a Banned Flavor

Treated States Pre-Treatment	Treated States Post-Treatment	Difference in Percentage Points	Other States Pre-Treatment	Other States Post-Treatment	Difference in Percentage Points	Difference-in-Difference in Percentage Points
Age 14-17						
58.41%	74.42%	16.01	50.26%	68.78%	18.52	-2.51
Age 18-24						
38.14%	61.53%	23.38	35.11%	63.72%	28.61	-5.23
Age 25+						
22.69%	45.19%	22.50	23.47%	47.73%	24.26	-1.76

Treatment states are NY NJ MD UT RI MA. Banned flavors are candy, fruit, chocolate, clove/spice, alcoholic drink, non-alcoholic drink, or other flavors. Unbanned flavors are tobacco and menthol, except for MA where tobacco is the only unbanned flavor. Data are the percent of e-cigarette users that reported using banned flavors. Difference = post-period minus pre-period. Difference-in-Difference = treatment difference minus control difference. Data from the PATH.

Table 3
Results by dataset
Dichotomous Nicotine Use in the Past 30 Days
DID and SDID Models with Covariates

	DID				SDID				
	β_{DD}	SE	p-value	N	β_{DD}	SE	p-value	N	Mean Y*
Panel A: Youth									
YRBS Age 14+									
E-cigarette	-0.0055	0.0241	0.8185	606,405	0.0000	0.032	0.9989	100	0.202
Cigarette	0.0147	0.0108	0.1739	902,482	**0.0354****	**0.0142**	**0.0127**	**132**	**0.092**
MTF Age 14+ Grades 8, 10 and 12									
E-cigarette	-0.0132	0.016	0.4116	127,394	-0.0233	0.0221	0.2916	296	0.139
Cigarette	**0.0199****	**0.0082**	**0.0157**	**234,656**	-0.0095	0.0249	0.7033	296	0.0493
PATH Age 14-17									
E-cigarette	-0.0045	0.0145	0.7589	50,082	0.0043	0.0162	0.7901	266	0.0668
Cigarette	**0.0168****	**0.0076**	**0.0271**	**50,189**	**0.0269****	**0.0111**	**0.0149**	**266**	**0.0395**
Panel B: Young Adults 18-24									
BRFSS									
E-cigarette	**-0.0321****	**0.0132**	**0.0148**	**89,650**	**-0.0247***	**0.0144**	**0.0852**	**192**	**0.1463**
Cigarette	**0.0205*****	**0.0049**	**0.0000**	**201,385**	**0.0235*****	**0.0045**	**0.0000**	**441**	**0.1171**
PATH									
E-cigarette	0.001	0.0135	0.9408	54,504	-0.0232	0.0265	0.3826	304	0.1902
Cigarette	0.0264	0.027	0.3288	54,691	0.032	0.042	0.447	304	0.2469
Panel B: Older Adults Age 25+									
BRFSS									
E-cigarette	-0.0014	0.0038	0.7186	1,463,124	0.0006	0.004	0.8723	192	0.0345
Cigarette	-0.0054	0.0049	0.2731	3,299,134	-0.0032	0.0035	0.3513	441	0.1443
PATH									
E-cigarette	0.0132	0.0169	0.4348	118,001	0.0114	0.0175	0.5156	304	0.1145
Cigarette	-0.0042	0.0076	0.5821	118,703	0.004	0.0154	0.7943	304	0.4023

* Mean for all the individual level data for each use variable. DID models use microdata and all treatment states. SDID uses aggregate data. YRBS SDID models include NY MD RI as treatment states. MTF SDID models include MA, MD, NJ, NY as treatment states. DID models use microdata and all treatment states, except YRBS does not have data from MA. PATH SDID models include NY NJ MD UT MA as treatment states. BRFSS SDID includes all treatment states. Covariates are age, white, black, Asian, Hispanic, male, e-cigarette tax, cigarette tax, and internet sales ban. Mean for all the individual level data for each use variable.. SDID uses aggregate data. Covariates are age, white, black, Asian, Hispanic, male, e-cigarette tax, cigarette tax and internet sales bans. *** =P <.01, ** =P <.05, * =P <.1
*** =P <.01, ** =P <.05, * =P <.1

Table 4 **Meta-analysis estimates of effects of Flavor Bans on E-cigarette Use and Cigarette Use across youth, young adults and adults**				
	DID		SDID	
Panel A: Youth				
	β	SE_{FE}	**β**	SE_{FE}
E-cigarette	-0.008	0.010	-0.005	0.012
Cigarette	**0.017*** **	**0.005**	**0.026*** **	**0.008**
Panel B: Young Adults (Ages 18-24)				
E-cigarette	**-0.016***	**0.009**	**-0.024***	**0.013**
Cigarette	**0.021*** **	**0.005**	**0.024*** **	**0.004**
Panel C: Adults (Age 25+)				
E-cigarette	-0.002	0.002	-0.002	0.002
Cigarette	-0.003	0.003	-0.001	0.003
The outcome is use in the last 30 days of cigarettes or e-cigarettes. We used the fixed effect method of meta-analysis to combine estimates from Table 3. We take the weighted average of estimates for each population for each product where the weights are equal to the inverse of the standard errors squared, normalized to add up to one. The standard errors for each estimate are computed as the inverse of the square root of the sum of the weights. *** =P <.01, ** =P <.05, * =P <.1 *** =P <.01, ** =P <.05, * =P <.1				

Figure 1
Trends in E-cigarette and Cigarette Use

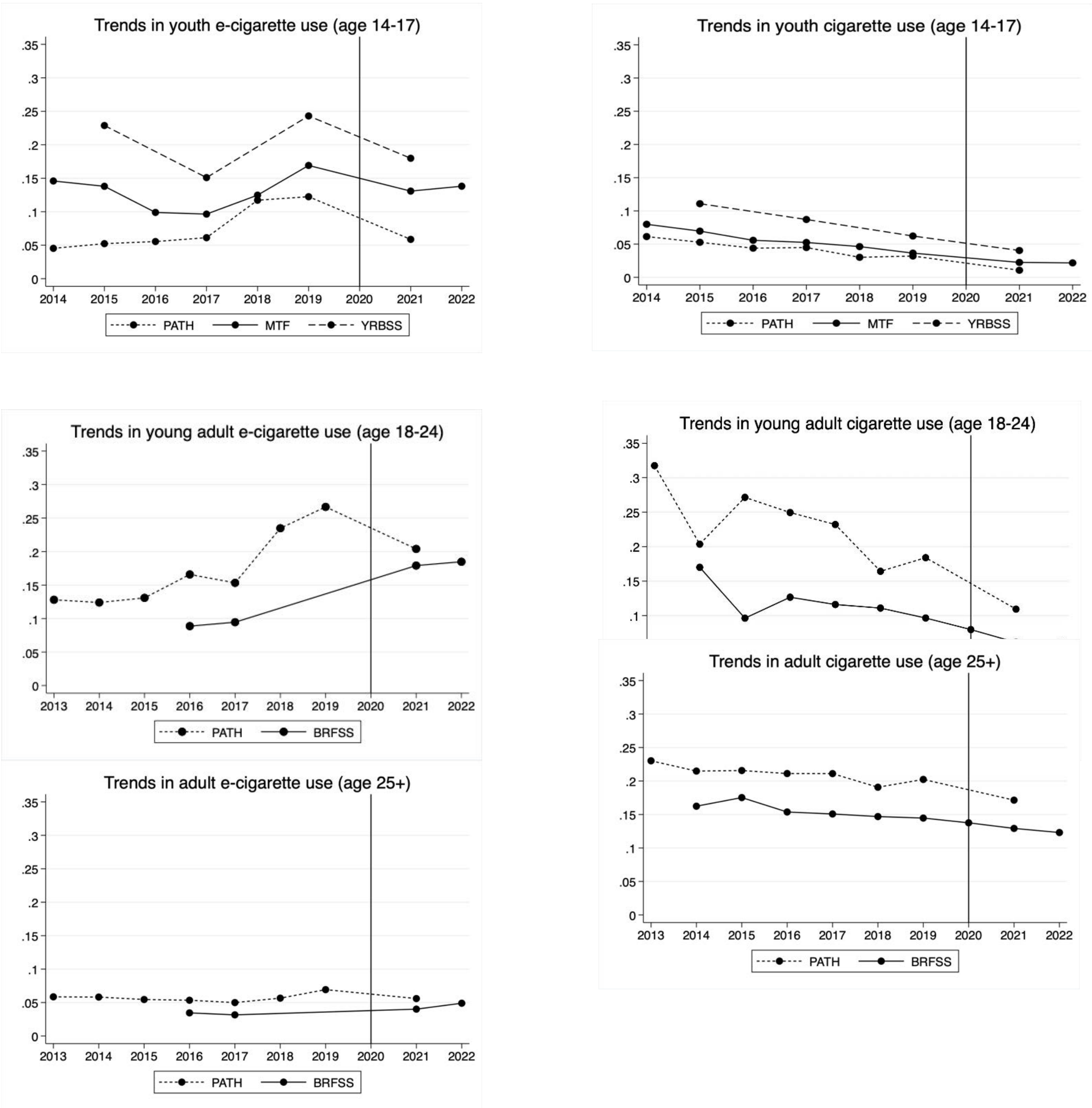

Figure 2.

Synthetic difference-in-differences Event Study Plots - Youth

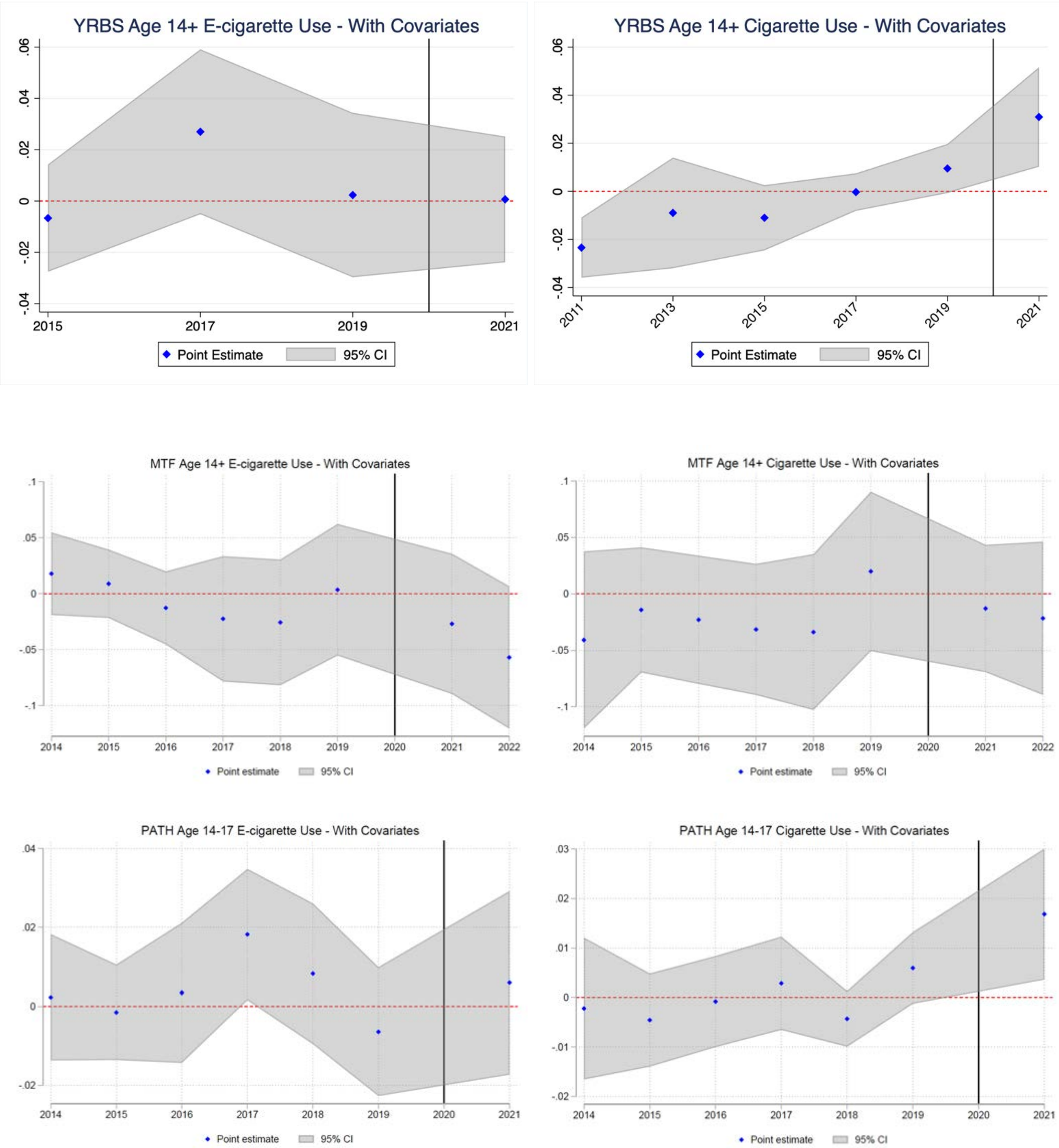

Figure 3.

Synthetic difference-in-differences Event Study Plots – Young Adults (Ages 18-24)

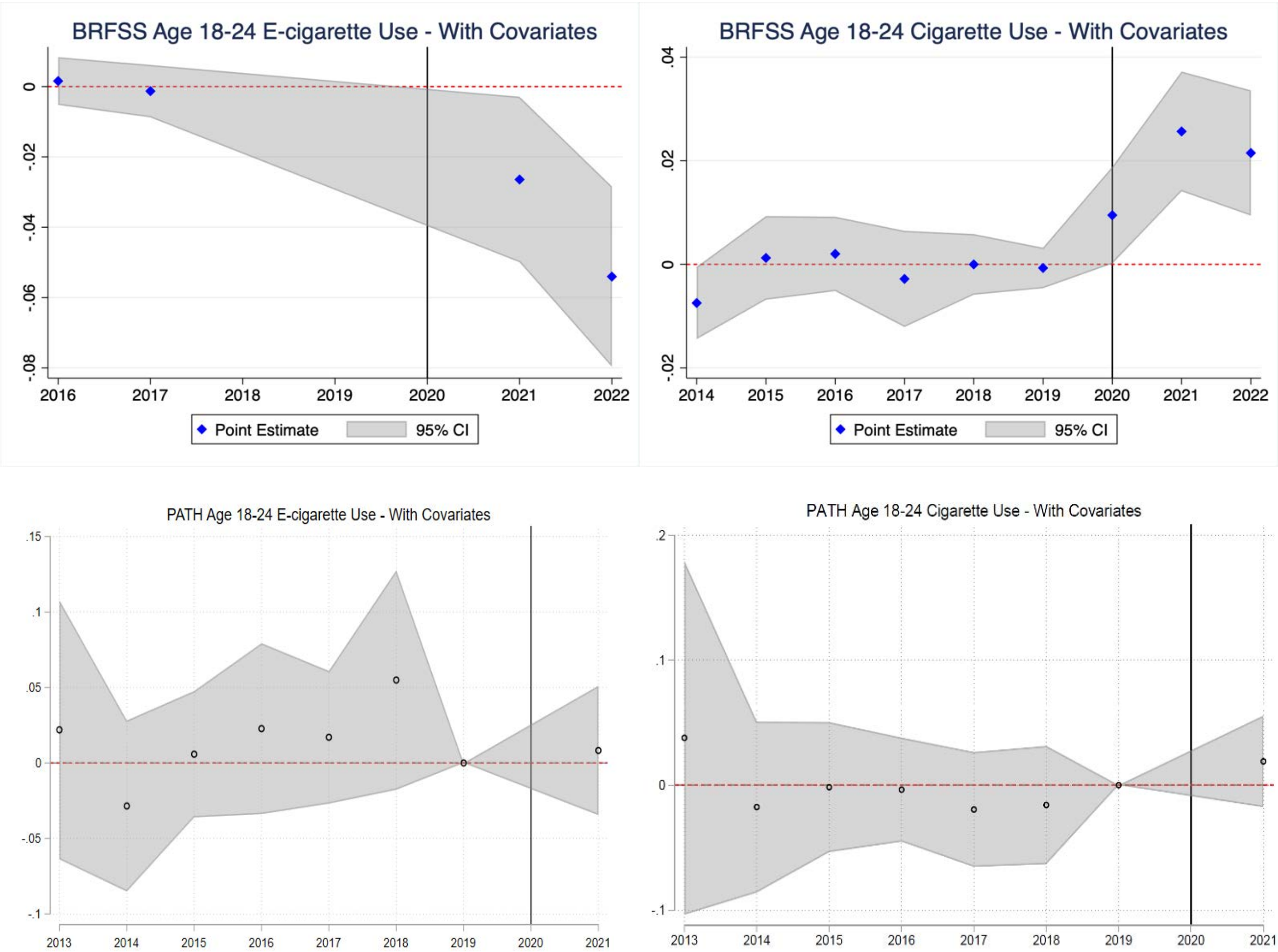

Figure 4.

Synthetic difference-in-difference Event Study Plots – Older Adults (Ages 25+)