The Effects of Tobacco 21 Policies on Smoking and Vaping: Evidence from Panel Data and Biomarkers

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Abstract

In December 2019, the United States adopted a national Tobacco 21 (T21) law, raising the federal minimum age of sale of all tobacco products to 21 years. This followed earlier T21 laws in 16 states and the District of Columbia. We use data from the Population Assessment of Tobacco Use and Health (PATH), a longitudinal data set including self-reported and biomarker measures of smoking and vaping, to connect the enactment of state-level T21 laws with changes in smoking and vaping. We find that T21 laws lead to reductions in self-reported cigarette smoking among young adults 18-to-20 years old, particularly among those who were males and non-users when T21 laws were implemented. Further, we observe that formerly treated individuals who have "aged-out" of treatment are less likely to subsequently initiate self-reported smoking or vaping. Smokers ages 18-20 are less likely to buy their own cigarettes and also more likely to buy cigarettes in a different state after the enactment of T21 laws. Finally, we find a misalignment between self-reported and corresponding biomarker measures of cigarette smoking. Investigation suggests that T21 laws induce likely cigarette smokers to under-report their smoking behavior, which may increase the magnitude of the apparent effect of T21 policies on cigarette smoking as measured by self-reports.

Keywords: Tobacco T21, Smoking, Vaping, Biomarkers

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1 Introduction

In 2019, over 30% of high school students reported using tobacco products in the last 30 days, and nearly 28% reported using electronic cigarettes (e-cigarettes) (Wang et al., 2019). Compared to 2015, overall tobacco use increased by 20% and e-cigarette use doubled (Singh et al., 2016). This rapid growth in tobacco use, driven by e-cigarette use, has alarmed public health officials (CDC, 2018; FDA, 2019). The response of governments and public health officials to the large increase in e-cigarette usage has been to implement a series of restrictions on access to both e-cigarettes and traditional cigarettes (CDC, 2019a).

In particular, in December 2019, the United States enacted a national Tobacco 21 (T21) law, which raised the minimum age of sale of all tobacco and nicotine products from 18 to 21 years across the United States (FDA, 2020). The national T21 law followed state and local-level T21 laws and other minimum legal age of sale laws for e-cigarettes. Hawaii became the first state to enact a T21 law in January 2016, followed by California in June 2016, Washington DC in February 2017, and 14 additional states before the national T21 law. Taken together, these T21 laws represent some of the most significant tobacco control policies since the Master Settlement Agreement in 1998. Thus, understanding the effects of these T21 laws is critical to having well-formulated tobacco product regulations by the FDA, CDC, and other public health authorities.

The general concept of T21 laws is that restricting the legal purchasing age for *all tobacco products* to 21 years old will reduce access to all tobacco products by minors during the critical youth initiation phase and, subsequently, reduce downstream adult smoking and vaping. This is particularly salient among adolescents and young adults, as most adult smokers initiate tobacco use as minors (Everett et al., 1999; Gilliland et al., 2006), with a mean age of smoking initiation of under 13 years old (Sharapova et al., 2020). Further, given the complexities of youth smoker access to tobacco-related products, for example, obtaining tobacco products via social networks (Hansen, Rees, and Sabia, 2013) and having time-inconsistent preferences (Crettez and Deloche, 2020), investigating how adolescents and young adults respond to new policies and with regard to new products is needed to improve population health.

In this paper, we investigate the effects of T21 laws enacted at the state level on a set of tobacco outcomes. We use data from the Population Assessment of Tobacco Use and Health (PATH) data set, a longitudinal data set of tobacco use and health outcomes which includes both self-reported measures of tobacco use and, importantly, biomarkers of recent nicotine and tobacco exposure for individuals ranging from 12 to 90 years old. We connect state-level tobacco controls to individuals in the PATH data set to examine how T21 laws change both self-reported measures of tobacco use and two biomarkers, urinary cotinine levels, a measure of overall nicotine exposure, and urinary NNAL levels, a measure of tobacco exposure, across a range of age groups.

We find that T21 laws lead to notable reductions in the self-reported probability that young adults (18-to-20 years old) initiate smoking cigarettes, which is driven by males. While we do not observe statistically significant effects of T21 laws on self-reported vaping in the whole sample, we find evidence for a reduction among those 18-to-20 years old in certain sub-samples. We also observe longer-run effects of T21 laws on smoking or vaping initiation among adults (21-to-25 years old) who were formerly treated by T21 laws. We also find evidence that 18-to-20 year olds evade the T21 laws by having other people buy their cigarettes or cross-border shopping. Finally, we investigate how T21 laws impact clinically measured biomarker outcomes. This analysis yields evidence of a reduction in urinary cotinine levels, which could indicate a reduction in use of any products that contain nicotine, including cigarettes and e-cigarettes. However, despite the large reductions in self-reported cigarette smoking, we do not find any statistically significant changes in urinary NNAL levels (e.g., tobacco consumption). Further investigation reveals T21 laws reduce the probability that likely smokers, as determined by NNAL levels, self-report as smokers. This raises concerns that estimates of the effects of T21 laws on smoking based on self-reported data may be overstated. While we do not find evidence that T21 laws change the propensity of likely vapers to report their status, we do find evidence that the inconsistency between the self-reported and biomarkers measures for this behavior is a function of changing sample composition.

Our paper helps fill gaps in a growing literature examining the effects of these T21 policies both in empirical approach and in the particular questions that can be addressed. Some of the best existing papers use individual-level health survey data (e.g., BRFSS, YRBS, MTF, etc.) to estimate the effects of T21 laws on the self-reported youth and adult consumption of cigarettes, e-cigarettes, and other potentially related goods. However, while papers such as Bryan et al. (2021) and Abouk, De, and Pesko (2021) are exceedingly well done, they nevertheless face constraints imposed by the nature of the data available. For example, the use of cross-sectional data structures prevents prior studies in this space from explicitly gauging how T21 laws impact within-person behaviors. Moreover, geographic controls may not completely account for unobservable factors that drive the adoption of T21 policies and changes in smoking/vaping behaviors. As such, individual fixed effects models may provide a higher degree of control and more reliable estimates. Second, repeated cross-sectional data are unable to rule out that estimated behavioral changes are an artifact of sample composition brought on by changes in tobacco policies and may bias results or cloud interpretation. Third, cross-sectional data is unable to reliably investigate the effects of T21 policies on formerly treated individuals after they "aged-out" of treatment, relative to their never treated peers. This study leverages panel data to try to build upon the prior cross-sectional studies and address some of these issues.

Further, our data allow us to investigate how individuals' purchasing behaviors (e.g., own-purchase versus surrogate purchase, and cross-border shopping tendencies) are affected by T21 laws and, perhaps most importantly, to understand "net behavioral" effects across all tobacco/nicotine products and the accuracy/reliability of estimates when dealing with exclusively self-reported outcomes. Self-reported outcomes may provide an incomplete measure of changes in tobacco use for a number of reasons. First, tobacco users may compensate for more stringent tobacco control policies by smoking each cigarette or vaping each e-cigarette more intensely to ingest more nicotine from each cigarette or e-cigarette. Second, tobacco control policies, especially ones that make use for certain age groups illegal, may affect the propensity of individuals to accurately report their tobacco use. This is related to concerns raised by DeCicca et al. (2008) that "anti-smoking sentiment" may drive the adoption of tobacco control policies and also reduce cigarette use. If T21 laws affect the propensity of individuals to accurately report tobacco use, any reduction in self-reported tobacco use in response to T21 laws may represent an increase in misreported tobacco use rather than an actual reduction in smoking or vaping.

Our paper also contributes to a broader literature examining policies aimed at addressing e-cigarette use and estimating the economic relationship between e-cigarettes and traditional cigarettes. Many studies suggest that these two goods are economic substitutes (Pesko, Courtemanche, and Maclean, 2020; Cotti et al., 2020; Saffer et al., 2018, 2019; Dave et al., 2019; Pesko and Warman, 2019; Friedman, 2015), while others suggest they are complements (Abouk and Adams, 2017; Cotti, Nesson, and Tefft, 2018). However, the nature of the economic relationship between cigarettes and e-cigarettes may vary across age groups, which has important implications for policy effectiveness.

2 Data

2.1 The Population Assessment of Tobacco Use and Health

Our main data source is the Population Assessment of Tobacco Use and Health (PATH) data set. PATH is a longitudinal study of tobacco use and health including adults aged 18 - 90 and youths aged 12-17 that is matched over time. Wave 1 spans 2013-2014, Wave 2 spans 2014-2015, Wave 3 spans 2015-2016, Wave 4 spans late 2016-2017, there is a Wave 4.5 for the youth sample (12-to-17 years old) only during 2018, and Wave 5 (again for all participants) during 2018-2019. Collectively, PATH provides over 234,000 observations of roughly 65,000 unique individuals from across all 50 states and the District of Columbia, although coverage in some states is low. The average participant appears in the data set 4.3 times and approximately 60% of participants appear five times or more.[1]

The PATH data contains a rich set of self-reported information about tobacco use, including measures of whether individuals currently use cigarettes and e-cigarettes. We create two self-reported measures of whether people report using cigarettes or e-cigarettes in the past 30 days, which is asked of respondents 12 years and older. Unfortunately, while PATH asks adult respondents about the number of cigarettes they smoke per day, they do not ask this question of adolescents. Thus, we focus mainly on the extensive margin of smoking and vaping for self-reports.

We also use self-reported information from PATH regarding how adolescents and adults get their cigarettes. First, PATH asks about how individuals usually buy their cigarettes, in-person, from the internet, over the phone, or they did not buy their own cigarettes. From this, we create an indicator for whether a smoker purchased their own cigarettes. PATH also asks both adults and adolescents about the location of their cigarette purchases. Specifically, PATH asks respondents, "Do you usually buy your cigarettes inside your own state or in another state." From this, we create a second indicator variable for individuals purchasing cigarettes in another state. Finally, we combine these two measures together to form an indicator variable for what we might call "legitimate" cigarette purchases: cigarette purchases made by the individual in their own state.

Importantly, PATH also collects urine samples from a subset of individuals and measures a wide variety of biomarker compounds. One of the compounds measured is urinary cotinine levels, a major metabolite of nicotine. When nicotine is ingested, it is fairly quickly metabolized into cotinine, which has a much longer half-life in the body of 16-20 hours (Benowitz and Jacob III, 1994; Benowitz et al., 1994). Any product containing nicotine, including traditional cigarettes, e-cigarettes, smokeless tobacco, or many anti-smoking products containing nicotine, will increase an individual's cotinine levels. Cotinine levels, whether sampled from the blood or urine, are a popular and accurate biomarker for levels of recent nicotine exposure (e.g., Adda and Cornaglia, 2006, 2010; Nesson, 2017a,b).

PATH also contains urinary levels of 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol (NNAL). NNAL is a metabolite of 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK), which belongs to a family of tobacco-specific nitrosamines (TSNA). As suggested by their name, TSNAs are found only in tobacco products, and are not found in meaningful levels in e-cigarettes or nicotine-replacement therapies.[2] NNK is a po-

[1] In Wave 4 additional newly sampled people were added to replenish attrition that had occurred between Waves 1 and 4.
[2] www.cdc.gov/biomonitoring/NNAL_BiomonitoringSummary.html

tent carcinogen, and is strongly linked to lung cancers (Hecht, 1998). Importantly, about 95% of NNK is metabolized into NNAL. NNAL has a longer half-life in the body than cotinine, with a half-life of 18-45 days (Goniewicz et al., 2009; Hecht et al., 1999). However, unlike cotinine, NNK is not found in electronic cigarettes, and urinary levels of NNAL among exclusive vapers and non-smokers are similar (Bustamante et al., 2018). Thus, measuring NNAL in people's urine is a reliable way to determine exposure to tobacco products, although it is not easy to differentiate between cigarettes or other tobacco products. Additionally, exposure to environmental tobacco smoke from cigarettes or hookah may increase NNAL levels, but this exposure is usually very light compared to own-tobacco use.

PATH also includes detailed demographic data. From this data, we could create indicators for each individual's sex, racial categories (white, black, Asian, other and multi-racial, and missing), Hispanic ethnicity, ten household income categories, educational attainment categories (less than high school, high school or GED, some college or associates degree, bachelor's degree, and advanced degree), as well the individual's age. However, since our models include individual fixed effects, we only include age in our specifications due to collinearity.

2.2 Tobacco-related Policy and State Measures

We obtain the dates that states enacted T21 laws from the Preventing Tobacco Addiction Foundation (`https://tobacco21.org/`). A list of states that enact T21 laws, along with the effective date and whether that state contributes variation in PATH and has pre-existing sub-state T21 laws can be found in Appendix Table A.1.

We also merge information on a series of tobacco-related policy measures to account for the potential effect these related policies may have on smoking and vaping utilization. In particular, we add data on per pack excise tax on cigarettes at the quarterly level, calculated as the real ($2020) federal plus state cigarette excise tax in each state (DeCicca, Kenkel, and Lovenheim, 2020; Cotti, Nesson, and Tefft, 2016), and indicator for whether a state had a minimum legal purchasing age for e-cigarettes lower than 21 (Friedman, 2015), an indicator for the presence of an e-cigarette tax (Cotti et al., 2021), and an indicator for the legalization of recreational marijuana. This information was accessed via the CDC's State Tobacco Activities Tracking and Evaluation System (CDC STATE (CDC, 2019b), various state agencies, or investigation by the authors. Lastly, we add state-level unemployment rates to control for variation in economic activity, obtained from the Bureau of Labor Statistics.

2.3 Analytical Sample

In constructing our analytical sample, we begin by restricting the data to those 12-to-25 years of age. This reduces the sample to 131,455 observations of 39,211 individuals of interest. PATH has limitations, however, that further reduce the size of the overall analytical sample available in this study.

First, while the mean number of observations across states in the 12-to-25-year-old sample is 5,980 (median = 4,358), with California having the highest number of observations at 15,287, some states have very low representation in the survey. Specifically, seven very rural and/or low-population states (i.e., AK, DE, ND, RI, SD, VT, and WY) had collectively only 99 total observations, and, as a result, we drop the 99 observations from these seven states.

Second, PATH does not provide sub-state geographical identifiers. This presents an issue because some cities and counties enacted T21 laws before state-level T21 laws. As such, we drop survey participants residing in states with any populations covered by sub-state T21 laws prior to a state-level T21 policy adoption (i.e., IL, KS, MA, MO, NJ, NY, and OH). This leaves us with a baseline analytical sample of approximately 107,000 observations across 36 states (plus D.C.), where 10 implemented state-level T21 laws by the end of our sample time period in 2019.

Table 1 shows summary statistics for key PATH variables by age group. Both self-reported smoking participation and vaping participation jump considerably for the age 18-20 group, and while smoking participation increases further for the age 21-25 age group, vaping participation falls slightly. Biomarkers of nicotine and tobacco exposure also suggest that use of cigarettes or e-cigarettes is higher in the 21-25 age group. Other characteristics are relatively constant across the sections, including exposure to T21 laws, demographic characteristics, and other state-level variables.

3 Methods

Our primary statistical framework connects changes in an individual's exposure to a T21 law to within-person variation in tobacco product usage or related biomarker outcomes for those 12-to-25 years of age. Notably, 18-to-20-year-old young adults are the age group explicitly "treated" by T21 laws, as the younger population is bound by pre-existing minimum purchase age laws. Yet, there may be spillover effects onto the adolescent population, so we investigate both age groups in this analysis.

While using a standard difference-in-differences (DiD) two-way fixed effects approach is a potential strategy, one concern may be whether smoking or vaping trends in the control group are notably different from those in the treatment group. Specifically, a DiD regression design assumes that confounders varying across groups are time-invariant, and time-varying confounders are group invariant; the classic common trend assumption (see Wing, Simon, and Bello-Gomez, 2018). To address this potential problem and leverage the panel nature of the data more completely, we focus on using a triple difference design (DDD), similar in approach to recent work on T21 laws by Bryan et al. (2021). Hence, we utilize a second comparison group that is not exposed to treatment but is exposed to the potentially problematic time-varying confounders. In this case, we use the individuals 21-to-25 years old, who are not bound by the T21 laws, but reside in locations with T21 laws as well as control locations without T21 laws during the sample period.

As such, our main specifications estimate individual-level fixed effects linear probability models, similar to a triple-difference model, for individual i living in state s at year y and quarter q, as follows:

$$\begin{aligned} Y_{i,s,yq} = \alpha + \delta \mathrm{T21}_{s,yq} + \sigma_{i,yq} + \delta_{t,u18} \mathrm{T21}_{s,yq} \times \mathrm{ageu18}_{i,yq} + \\ \delta_{t,1820} \mathrm{T21}_{s,yq} \times \mathrm{age1820}_{i,yq} + \gamma \mathrm{FT}_{i,yq} + \beta X_{s,yq} + \mu_i + \tau_{yq} + \epsilon_{i,s,yq}. \end{aligned} \tag{1}$$

In equation (1), the dependent variable is a smoking or vaping-related outcome. We first examine self-reported measures of smoking or vaping within the last 30 days, and then cigarette purchase methods. After that we examine levels of urinary cotinine and NNAL to estimate the relationship between T21 laws and *overall* nicotine and tobacco consumption.

All models include an indicator, $\mathrm{T21}_{s,yq}$, for whether an individual resides in a state after the implementation of a T21 law and indicators ($\sigma_{i,yq}$) for an individual's age in years at the time of each survey. Our independent variables of interest are the interactions between T21 and indicators for being under age 18 or between 18 and 20 years old ($\mathrm{ageu18}_{i,yq}$ and $\mathrm{age1820}_{i,yq}$). Thus, identification comes from comparing persons who are affected by the T21 law (those under 21 in each group) with their peers in other states before and after T21 treatment (standard difference-in-difference), and then against the similar difference with those who are 21 or older in treated and non-treated locations before and after T21 implementation. Notably, some survey participants were treated by T21 laws and later "aged into" the older 21-to-25-year-old control population in treated states. As such, we add an indicator variable, $\mathrm{FT}_{i,yq}$, which identifies if an individual was formerly constrained by a T21 law when they were under 21. This both allows us to control for these individuals contaminating our control group, but also investigate if the behaviors of those formerly treated by T21 policy are different in a measurable way relative to their never treated peers.

All models also include individual fixed effects and time period (year and quarter) fixed effects, given by μ and τ, respectively. The inclusion of individual fixed effects washes out time-invariant individual characteristics such as gender, race, or ethnicity. We control for a vector of public policies and state controls discussed above that may affect smoking or vaping behavior in the vector X (cigarette excise taxes, an indicator for the presence of a minimum legal purchasing age for e-cigarettes, an indicator for the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and the state unemployment rate). All standard errors are clustered at the state level.

4 Results

4.1 Self-Reported Smoking and Vaping Participation

In Table 2, we begin by presenting estimates of the relationship between Tobacco 21 laws and self-reported cigarette or vaping use among adolescents (12-to-17 years old) and young adults (18-to-20 years old) from various samples of PATH participants. First, in columns (1) and (2) we present estimates of the relationship between T21 laws and smoking and vaping participation for the entire analytical sample. We observe a notable 2.8 percentage-point (14.6%) reduction in the likelihood of smoking after a T21 law among the 18-to-20 years old, but no corresponding change among adolescents. No statistically significant relationship is observed when looking at the likelihood of vaping among either age group, although the point estimates for the 18-to-20-year-old sample are similar to the point estimate for cigarette smoking.

Next, we investigate how estimates vary between individuals who were non-smokers and non-vapers at survey onset (columns (3) and (4)) as compared to those who were identified as a smoker or vaper at survey onset (columns (5) and (6)). Columns (3) and (4) show a statistically significant 1.8 percentage-point (20.6%) reduction in the likelihood of smoking among initial non-smokers/non-vapers in the 18-to-20 years old group. As with the full sample, the coefficient for vaping participation is negative, but not statistically significant. There is no statistially significant effect of the T21 laws on self-reported smoking or vaping among participants under the age of 18. Further, columns (5) and (6) do not show statistically significant changes in smoking or vaping, although here again some coefficients are notably large, for example smoking participation among 18-to-20-year-olds and vaping participation among 12-to-17-year-olds.

Lastly, in the final row of Table 2 we also investigate how being formerly treated by a T21 law (i.e., "aging out" of being treated) is related to smoking and vaping choices when an individual is over 21 years old and no longer bound by T21 laws, relative to otherwise similar non-treated peers (even who may reside in the same state but slightly older). Estimated effects of being "formerly treated" by T21 laws are negative for both vaping and smoking use among those survey participants who were non-smokers/non-vapers at survey onset (columns (3) and (4)). This is again consistent with T21 laws working mostly by preventing initiation rather than increasing cessation. Further, the effects are of non-trivial size, with the estimated effects of a 3.2 percentage point reduction in the likelihood of smoking initiation and a 3.9 percentage point reduction in the likelihood of vaping initiation relative to their non-treated peers (aged 21-to-25).

Overall, the longitudinal estimates presented in Table 2 only provide evidence of the effects of T21 laws on self-reported smoking behavior among those explicitly impacted by the laws (18-to-20-year-olds). The estimates seem to largely be driven by those who were initially not cigarette or e-cigarette users, suggesting that the effect of T21 laws manifest most through reducing smoking initiation. Further, the size of the effects is non-trivial, with a greater than 20% reduction in the likelihood of smoking participation observed for the initially non-user sample. Importantly, the "formerly treated" relationship indicates that the effects of T21 laws persist beyond the explicit treatment age groups, suggesting the impact of T21 laws may be quite significant and provides further evidence about the importance of limiting access of risky products to the youngest adults.

In Figure 1 we show event study estimates for the results in Table 2. We track the coefficients for four years and earlier before a T21 law and up to two years after a T21 policy for the two age groups of interest, 12-to-17-year-olds and 18-to-20-year-olds. Figure 1 generally shows no evidence of trends in self-reported smoking or vaping before the enactment of a T21 law. Self-reported smoking prevalence declines after the imposition of the T21 laws among both under-21 age groups, but the decline takes a few years to appear. As we saw before, this drop appears to be driven by the non-users in Wave 1. There is also an immediate drop in smoking prevalence among 18-20-year-olds who were smokers in Wave I, but this drop is not sustained in future waves. For vaping, trends after the enactment of T21 policies are not as clear. Non-users in Wave I show some evidence of a decrease in vaping prevalence after a T21 law enactment, while Wave I vapers who are ages 12-17 show some evidence of an increase in vaping after a T21 law enactment.

4.1.1 California Treatment Sample

Owing to the fact that California has the second oldest state-level T21 law in the US (effective since June of 2016, five months after Hawaii) and that California is the most populous state in the US, we find that approximately 82 percent of all treated observations (e.g., individuals under 21 years of age who were sampled while residing in a state with an effective T21 law) lived in California while surveyed. This is an unfortunate artifact of California's tremendous population and that six of the other nine remaining treatment states (i.e., AR, CT, DC, MD, TX, and VA) implemented T21 laws during the second half of 2019, which is at the very end of the survey window. Hence, California dominates the treated observations. As such, in Appendix Table A.2 we reproduce the estimates found in Table 2 where California is the only treated state. As we only have one treatment state, we show p-values at the bottom of the table calculated from a Wild bootstrap procedure.

Most notably, the estimated effects of T21 laws on self-reported outcomes are now statistically more identifiable when participants treated by the California T21 law are the only treatment group considered (but some of these inferences are sensitive to bootstrapping). In particular, we now observe statistically significant reductions in vaping participation among all participants (significant at the 10% level), which is driven by Wave I non-users. A statically significant reduction in vaping among Wave I non-users also appears for 12-to-17-year-olds. Given the adolescent age group is already impacted by pre-existing minimum legal age laws, these estimates may point to a social network mechanism. While not something we can test formally in this setting, the results are consistent with T21 laws potentially breaking down social networks and research into how youths obtain tobacco products (Hansen, Rees, and Sabia, 2013).[3]

4.1.2 Effects by Sex and Race

Smoking behaviors vary considerably between males and females. For example, the smoking rate among females is notably lower than their male counterparts, and we observe similar patterns in the PATH data. Among 18-to-20-year-olds treated by a T21 law, 23% of males and 16% of females report smoking in the last 30 days. Recognizing that differences in the likelihood of smoking or vaping exist across sexes, in Table 3 we return to the main analytical sample and break the overall sample estimates down by these subpopulations to investigate for heterogeneous effects of T21 laws. Three general findings emerge.

First, the reductions in smoking participation related to the passage of T21 laws estimated in Table 2 are largely driven by behavioral changes among males (column (1)). Second, we observe an estimated decline in vaping participation among the male-only sample (column (3)). Third, we observe heterogeneity among those "formerly treated" 21-to-25-year-olds, as effects are only observed for males and only among vapers. We do see sizable decreases in vaping participation among females for both age groups, however, these effects are not statistically significant.

4.1.3 Analysis of Shopping Behaviors

Next, we examine the effects of T21 laws on how affected individuals acquire cigarettes. Table 4 shows results from these models, which use the same general specifications as equation (1). However, PATH only

[3] Why estimated effects appear more apparent for California is unclear. When conducting a "leave out" analysis of each treatment state in the overall sample, we observe estimates for 18-to-20-year-olds similar to those observed with the CA-only treatment sample if the state of Oregon is excluded. Hence, it may not be something specific to the sample residing in California that drives the results, rather, it could be something about the behavior or reporting of those residing in Oregon that masks some of the effects of T21 laws on young adults in the broader sample.

asks self-reported smokers about whether they purchase their own cigarettes, and only asks people who purchase their own cigarettes about where they are purchased. We first create an indicator measuring what we call "legitimate" cigarette purchases: those made by individuals in their own state. We then show results for each part of the indicator: individuals buying their own cigarettes and, if so, whether individuals buy cigarettes in their own state. We find that T21 laws affect purchase methods mainly for individuals between 18-to-20-years-old. Specifically, T21 laws reduce the probability that 18-to-20-year-olds purchase their own cigarettes in their state of residence by 44 percentage points. Within this, 18-to-20-year-olds decrease purchasing their own cigarettes anywhere by about 33 percentage points, a large decrease off the pre-treatment mean of 84 percent. Simultaneously, T21 laws decrease the probability that 18-20-year-olds who continue to purchase their own cigarettes purchase them in their own state by 26 percentage points, again representing very large increases off pre-treatment mean of 97 percent. Hence, indicating a notable amount of cross-border shopping in response to the state-level T21 laws.

Figure 2 shows event studies from the analysis of cigarette cross-border purchases. We show event study estimates for the 12-to-17-year-old and 18-to-20-year-old coefficients. Here again, we do not see evidence of pre-trends in the propensity of smokers to purchase their own cigarettes. However, after the enactment of a T21 policy, the probability of 18-to-20-year-old smokers buying their own cigarettes drops by close to 50 percentage points (bottom panel). Shifting to purchases made in other states, again we see no pre-trends in individuals making purchases out of state. However, after a T21 law, 18-to-20-year-olds who buy their own cigarettes are about 35 percentage points more likely to buy cigarettes in a different state (top panel).

4.2 Biomarkers

In addition to collecting individual-level longitudinal data on self-reported tobacco-related behaviors, PATH also collects urine samples from a sub-sample of survey participants and calculates the levels of a number of biomarkers from these samples. Included in this are individual measures of several tobacco and nicotine-derived metabolites. We focus on two biomarkers: cotinine, a biomarker of recent nicotine exposure, and NNAL, a biomarker of recent exposure to tobacco. Unfortunately, the PATH biomarker data sample has certain data constraints that are not present in the self-reported data. First, PATH only collected biomarker data on youth (12-to-17) during Wave 1, so the youth sample is not included in the biomarker estimates. Second, PATH only collected biomarker data from a sub-sample of approximately 11,500 adults, of which only about 4,000 are 18 to 25 years old.[4] Lastly, owning to sub-state implementation of T21 laws,

[4] These adults were selected from a diverse mix of six tobacco product use groups representing never, current, and recent former (within 12 months) users of tobacco products. This group constitutes the Wave 1 Biomarker Core, whose urine was collected during each subsequent survey wave.

survey participants residing in these states once again are excluded. This leaves us with a relatively small analytical sample of approximately 3,200 unique individuals with whom to study overtime.

In investigating the relationship between T21 laws and cotinine or NNAL, we replicate the methods described in equation (1) except we replace smoking or vaping participation with measured levels of urine cotinine or NNAL as the dependent variable, both measured in ng/ml, and use the PATH provided biomarker urine weights. The results of this analysis are presented in Table 5 and provide an interesting set of results. Specifically, we observe a statistically significant negative effect of T21 laws on measured cotinine for the entire sample and Wave 1 non-users (columns (1) and (2)), which is completely consistent with the self-reported smoking estimates reported in Table 2. Conversely, we observe no effect of T21 laws on measured NNAL levels overall or for either sub-set based on initial user status.

These estimates are derived from a notably smaller sample, so should be viewed with some caution. Nevertheless, given that NNAL measures an individual's exposure to tobacco specifically, while cotinine more broadly measures nicotine, biomarker estimates that are isolated to finding reductions in *only* cotinine measures would suggest effects are driven by reductions in the likelihood of e-cigarette use (i.e., vaping) or smoking cessation products, such as nicotine gum or patches. However, self-reported measures shown in Table 2 consistently point to reductions in the likelihood of cigarette use (or both cigarette and e-cigarette use in the case of those estimates presented in Table 3 or Appendix Table A.2). So, the lack of an NNAL (tobacco) effect is puzzling.

In Figure 3 we show event study estimates for the results in Table 5. Figure 3 shows a sharp drop in cotinine levels after the enactment of a T21 law, driven by Wave I non-users. NNAL levels show some evidence of a decrease after a T21 policy, but no coefficients are statistically significant.[5]

Next, we investigate a few possible causes of the lack of direct reconciliation between the self-reported measures and the biomarker outcomes.

4.2.1 Investigation: Confounding from Other Related Products

The results presented in Table 5 may be inconsistent with those in Table 2 because we have not accounted for use of other related products that can also impact NNAL and cotinine levels besides cigarettes and e-cigarettes. In particular, NNAL levels are a function of using cigarettes, smokeless tobacco, cigars, pipes, etc., while cotinine levels are also impacted by vaping as well as nicotine-replacement therapies (e.g., gum,

[5]In Appendix Table A.3, we show these results for the California-only treatment sample, similar to Appendix Table A.2. The results follow a similar pattern as Table 4 in that we see evidence for decreased cotinine concentrations but not NNAL concentrations. We note that the coefficients for the formerly treated individuals, while large and statistically significant, are based on very few observations. Thus, these results should be viewed with caution.

patch, etc.). So, if self-reported smokers and/or vapers switch to using these alternative options after T21 laws, this would impact NNAL and cotinine levels, which would confound interpretation. Hence, we consider this possibility.

First, we investigate if switching to alternative tobacco products (e.g., smokeless tobacco, pipes, cigars, hookah, or other tobacco-containing products) is affected by T21 laws, as then these users, who would still have high NNAL levels but are no longer cigarette smokers, might affect our identification of changes in the propensity to self-report smoking status. We note, though, that a T21 law affects access to all tobacco products, so meaningful substitution to these alternative products seems unlikely. Nevertheless, to check whether using smokeless tobacco, pipes, cigars, hookah, or other tobacco-containing products affects our results, we rerun our models including a measure for whether individuals self-report use of any of these other products in the last 30 days. Our results are virtually unchanged, indicating that the lack of an NNAL effect is not driven by confounding substitution.

Similarly, users of nicotine-replacement therapies (NRT) may also be defined as likely vapers using this method. As with users of other tobacco-based products, users of NRT would affect our cotinine estimates if T21 laws affect the propensity of impacted individuals to use NRT while stopping use of e-cigarettes. As we did observe T21-associated declines in cotinine in Table 5, this is less of a concern for interpretation. Nevertheless, we include an indicator for whether individuals use NRT and our results on vaping participation are unchanged. Overall, we do not find evidence that supports correlated variation in alternative tobacco or NRT product use to explain the lack of consistency between the self-reported and biomarker findings.

4.2.2 Investigation: Differential Sample Effects

The biomarker sample is notably smaller than the sample used in the self-reported analysis presented in Table 2. As such, the lack of consistency between the biomarker findings in Table 5 and the self-reported findings in Table 2 could simply be driven by the change in the sample composition. In order to investigate how stable the estimates of the effects of T21 laws on self-reported smoking and vaping participation are to the smaller sample available in the biomarker data, we re-estimate the Table 2 analysis of self-reported outcomes with the smaller biomarker sample used in the analysis of biomarkers presented in Table 5. These new estimates of self-reported use can be found in Table 6, which follows the same format as Table 2 with two exceptions. First, Table 6 only uses individuals for whom we have valid biomarker information. Thus, we are unable to examine adolescents as they are not asked to give biomarker samples.

Second, we replace the overall PATH sample weights with the urinary sample weights as we examine the subset of individuals with urinary biomarker information.

While we no longer see a statistically significant effect of T21 laws on smoking participation overall (column (1)), we still estimate negative effects on smoking participation for those participants initially not smokers at survey onset (column (3)). Given that the estimates in Table 2, column (1) are driven by the "non-users" (as shown in Table 2, column (3)) the overall inference is unchanged between Table 2 and Table 6. Conversely, with the reduced biomarker sample, we now observe a notable negative effect of T21 laws on the likelihood of self-reported vaping among initially non-users (Table 6, column (4)), which before was only seen in the male or California sub-samples. This latter result would help explain the biomarker results in Table 5, which suggest that the effects of T21 laws should largely be on vaping participation. However, and importantly, the estimates in Table 6 still do not explain the lack of an NNAL (i.e., tobacco) effect for this sub-sample, as a reduction in self-reported smoking participation is still observed (see Table 6, column 3).[6]

4.2.3 Investigation: Self-Reporting Bias and T21 Policy Treatment

Another issue that could explain the inconsistency between the biomarker results and the self-reported results is a change in the willingness of smokers or vapers to correctly self-report their use of cigarettes and/or e-cigarettes in response to the presence of a T21 law. For example, if 18-to-20-year-old smokers are less likely to self-report smoking participation *because* of a T21 law's imposition, this would result in an estimated reduction in self-reported smoking participation associated with T21 laws, even if there was no actual reduction in cigarette smoking. If true, this would lead one to estimate a reduction in smoking participation (as measured by self-reports), but observe no such reduction in NNAL levels, which is the pattern we observe.

To investigate this possibility, we re-estimate the effect of T21 laws on self-reported smoking and vaping participation, but only for individuals whose biomarker levels clearly indicate that the survey participant is almost certainly a smoker or vaper. Thus, we can measure the effect of T21 laws on *self-reported* cigarette or e-cigarette use among a sample of clinically defined users of these products. A statistical relationship between self-reported user status and the T21 laws among this sample would suggest the willingness of participants to be honest in self-reported behaviors is affected by the presence of the T21 laws. First, we define cigarette smokers as individuals with a measured NNAL level over 0.03 ng/ml (30 pg/ml),

[6] We do not show the coefficient for being "formerly treated," as this variable has too few observations for meaningful inference.

a level that clinically should only include cigarette smokers.[7] Second, we define likely vapers, who are not also cigarette smokers, by a combination of urinary cotinine levels and NNAL levels. We choose a urinary cotinine level that is high enough to suggest own use of nicotine products but an NNAL level that is low enough to exclude likely users of cigarettes (or other tobacco products). Goniewicz et al. (2011) examines optimal urinary cotinine cutoffs across six samples and finds an optimal cutoff of 31.5 ng/ml across adults, and in a population more similar to our setting, Benowitz et al. (2017) finds optimal cutoffs of 25 ng/ml to 30 ng/ml identified light/intermittent smokers and 30 ng/ml for active users.[8] Hence, we choose a cutoff value of 25 ng/ml and combine this cotinine level with a restrictive NNAL level of below 0.025 ng/ml to isolate vapers who are not also smokers.

We modify our empirical strategy from Equation (1) to conduct this analysis:

$$\begin{aligned} Y_{i,s,yq}|U_{i,s,yq} = \alpha + \delta \text{T21}_{s,yq} + \sigma_{i,yq} + \delta_{t,1820}\text{T21}_{s,yq} \times \text{age1820}_{i,yq} \\ + \gamma \text{FT}_{i,yq} + \beta X_{s,yq} + \mu_i + \tau_{yq} + \epsilon_{i,s,yq}. \end{aligned} \tag{2}$$

Here, all terms are as in Equation (1), except that we now examine self-reported smoking or vaping ($Y_{i,s,yq}$) conditional on biomarker-determined likely use of the product ($U_{i,s,yq}$). As the biomarkers are only consistently measured for adults, we only examine those aged 18-to-25. Our independent variable of interest is still the interaction of T21 laws and an indicator for an individual aged 18-to-20, measuring the differential impact of T21 laws on self-reporting among individuals impacted by the T21 law.

Table 7 shows the results from these regressions. In the first column, we evaluate self-reported smoking, and in the second column we evaluate self-reported vaping. For self-reported smoking, we find that the probability that these individuals self-report as smokers drops by about 50 percentage points for individuals under age 21. This is troubling and would suggest that the negative estimates of T21 laws on the likelihood of smoking participation estimated in Table 2 may be the result of self-reporting bias corresponding to the passage of a T21 law. Given that the negative T21 effects on self-reported smoking status are largely driven by those who were initially not users (as measured in Wave 1 of the PATH survey), this would suggest that participants who were not smokers when first interviewed are less likely to honestly admit their smoking behaviors once tobacco purchases are made illegal, hence biasing estimates toward overestimating any negative effect on self-reported smoking after treatment.

[7] The optimal NNAL cutoff level to distinguish smokers from non-smokers is not completely resolved in the literature. For example, Goniewicz et al. (2011) finds that a cutoff level of 47.3 pg/ml of NNAL is an optimal cutoff level to classify adults as smokers compared to passive smokers, while Benowitz et al. (2018) finds that 10 pg/ml of NNAL is an optimal cutoff level to classify adolescents as smokers. Benowitz et al. (2018) also write that, "the optimal urine NNAL cutoff point to discriminate smokers from nonsmokers appears to vary from approximately 10 to 50 pg/mL." Thus, we choose the median of these two numbers, 30 pg/ml, or 0.03 ng/ml.

[8] Goniewicz et al. (2017) conducts an experiment where smokers switched to electronic cigarettes. Total nicotine levels remained fairly constant after the switch, indicating that cotinine levels that distinguish cigarette smoking should also work for vaping.

Next, we replicate this approach for the sample of clinically identified likely vapers to measure if a similar bias is present in self-reported vaping participation. As noted above, it is more complicated to clearly identify vapers who are not also smokers, and our restriction of individuals with a cotinine level greater than 25 ng/ml *and* NNAL level below 0.025 ng/ml leaves us with a smaller sample than likely smokers. The results, presented in column (2), show positive statistically insignificant estimates of the effects of T21 laws on the likelihood of self-reporting vaping participation among likely vapers. Hence, there is no evidence that the reported effects of a decline in vaping participation after the passage of T21 laws shown in Table 6 (column 4) are similarly caused by reporting bias correlated with T21 laws. [9]

Owing to the age restrictions and the need to identify clinically defined smokers/vapers with the biomarker measures, the sample sizes of the estimate provided in Table 7 are quite small. Hence, a degree of caution should be taken with them. However, these outcomes, in combination with those presented in Table 6, suggest that the results of self-reported outcomes may, in and of themselves, not be reliable unless it can be shown that they are not influenced by the presence of the policy reform itself. Particularly in situations where the reform makes the behavior illegal for survey respondents.

5 Conclusion

In this study, we utilize individual-level panel data from the PATH to examine the relationship between Tobacco 21 laws and smoking/vaping participation among young adults and adolescents; measured by self-reports and laboratory-collected biomarkers. The panel structure of the PATH allows us to control for individual-level fixed effects, providing clearer evidence of detailed within-person changes in consumption behavior in response to the implementation of T21 laws. Moreover, access to biomarkers measures allows us to investigate the net effects of these policies on tobacco and nicotine consumption, as well as investigate the accuracy of self-reported measures.

We find that T21 laws lead to notable reductions in the self-reported probability that young adults (18-to-20 years old) initiate smoking cigarettes, which are largely driven by males in the sample. While we do not observe effects of T21 laws on self-reported vaping for the entire sample, we do observe reductions among young adults (18-to-20 years old) and adolescents (12-to-17 years old) within certain sub-samples. We also observe longer-run effects of T21 laws on smoking or vaping initiation among adults (21-to-25 years old) who were formerly treated by T21 laws, and evidence of cross-border shopping, as 18-20-year-olds who buy

[9] Figure 4 shows event studies to examine the parallel trends assumptions are presented in Table 7. Figure 4 shows no evidence of pre-trends for self-reported smoking or vaping among likely users. However, after a T21 law, likely smokers become less-likely to correctly self-report as smokers.

their own cigarettes are more likely to buy cigarettes in a different state after the enactment of T21 laws. Finally, we investigate how T21 laws impact clinically measured biomarker outcomes. This investigation suggests reductions in vaping behavior, but not cigarette smoking behavior after the passage of T21 laws, which is the opposite of the self-reports. Further investigation reveals that T21 laws lead to changes in the likelihood that likely smokers, as determined by biomarkers, correctly report their smoking status. This finding raises concerns that estimates of the effects of T21 laws on smoking based on self-reported data may be overstated. While we do not find evidence that T21 laws change the propensity of likely vapers to report their status, we do find evidence that the inconsistency between the self-reported and biomarkers measures for this behavior is a function of changing sample composition.

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Tables and Figures

Table 1: **Descriptive Statistics, PATH, 2013 - 2019**

	Means by Age Group		
	Ages 12-to-17	Ages 18-to-20	Ages 21-to-25
Dependant Variables			
Smoking Participation (Any Smoking in Last 30 days)	0.033	0.208	0.284
Vaping Participation (Any Vaping in Last 30 days)	0.051	0.185	0.152
Measured Urine Cotinine (ng/ml)*	.	670	1034
Measured Urine NNAL (ng/ml)**	.	0.063	0.098
T21 Policy Variable			
Tobacco 21 State Law	0.091	0.078	0.082
Demographics			
Female	0.488	0.492	0.496
White	0.660	0.673	0.676
Hispanic	0.251	0.244	0.223
State-Level Variables			
Excise/Pack of Cigarettes (Real $)	2.34	2.29	2.28
Any E-Cigarette Tax	0.155	0.133	0.133
E-Cigarette Minimum Legal Purchase Age Law	0.814	0.798	0.797
Recreational Marijuana Law	0.146	0.128	0.130
State Unemployment Rate	4.75	4.93	4.93
Observations	64,055	20,095	22,902

Notes: All means are weighted with appropriate survey weights. Data on smoking/vaping and biomarker outcomes and individual demographic measures were obtained from the PATH. State unemployment rate data obtained from BLS. Data on state excise taxes on cigarettes were obtained from the CDC's State Tobacco Activities Tracking and Evaluation System (CDC STATE). Data on recreational marijuana laws, as well as e-cigarette minimum legal purchasing age laws, were obtained from various state agencies and individual investigations on these policies. *Cotinine measures are derived from a biomarker sub-sample of 9,005 PATH participants from 18-to-25 years of age. **NNAL measures are derived from a biomarker sub-sample of 8,178 PATH participants from 18-to-25 years of age.

Table 2: **Estimates of the Effect of Tobacco 21 Laws on Cigarette and E-Cigarette Use, PATH, Waves 1 - 5 (2013-2019)**

	(1)	(2)	(3)	(4)	(5)	(6)
	All Participants Sample		**Wave 1 Non Users Sample**		**Wave 1 Users Sample**	
	Smoking Participation	Vaping Participation	Smoking Participation	Vaping Participation	Smoking Participation	Vaping Participation
T21 Law * 18-to-20 yr old	-0.028**	-0.029	-0.018**	-0.036	-0.074	-0.001
	(0.011)	(0.024)	(0.009)	(0.026)	(0.057)	(0.054)
T21 Law * 12-to-17 yr old	-0.001	-0.017	-0.001	-0.023	0.051	-0.131
	(0.008)	(0.013)	(0.009)	(0.015)	(0.114)	(0.169)
Tobacco 21 Law	-0.002	0.015	-0.006	0.017	-0.033	0.125**
	(0.006)	(0.014)	(0.007)	(0.014)	(0.028)	(0.043)
Formerly Treated	-0.011	-0.017	-0.032**	-0.039***	-0.021	0.016
	(0.015)	(0.014)	(0.013)	(0.011)	(0.038)	(0.067)
Pre-Treat DV Mean (18 - 20)	0.192	0.151	0.087	0.097	0.823	0.641
Pre-Treat DV Mean (12 - 17)	0.026	0.040	0.018	0.030	0.781	0.663
Observations	107,410	107,052	60,860	60,730	11,060	5,336
Demographic Controls	Y	Y	Y	Y	Y	Y
Policy Controls	Y	Y	Y	Y	Y	Y
Individual Fixed Effects	Y	Y	Y	Y	Y	Y

Notes: Aside from the variables in the table, all models also include indicators for age, and also include measures of per pack excise tax on cigarettes, indicator for the presence of a minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and the state unemployment rate. Additionally, all models include individual and year-by-quarter fixed-effects and utilize sample weights. The sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a T21 law during the estimation period. Robust standard errors clustered by state are in parentheses. Stars denote statistical significance: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

Table 3: **Estimates of the Effect of Tobacco 21 Laws on Cigarette and E-Cigarette Use by Sex, PATH, Waves 1 - 5 (2013-2019)**

	(1)	(2)	(3)	(4)
	Smoking Participation		Vaping Participation	
	Males	Females	Males	Females
T21 Law * 18-to-20 yr old	-0.056***	0.003	-0.042*	-0.021
	(0.016)	(0.019)	(0.025)	(0.030)
T21 Law * 12-to-17 yr old	-0.014	0.014	-0.011	-0.025
	(0.012)	(0.016)	(0.013)	(0.019)
Tobacco 21 Law	0.009	-0.011	0.013	0.018
	(0.010)	(0.011)	(0.014)	(0.018)
Formerly Treated	0.011	-0.033	-0.049*	0.009
	(0.016)	(0.027)	(0.026)	(0.028)
Pre-Treat DV Mean (18 - 20)	0.228	0.155	0.181	0.120
Pre-Treat DV Mean (12 - 17)	0.028	0.025	0.043	0.037
Observations	54,557	52,601	54,375	52,425
Demographic Controls	Y	Y	Y	Y
Policy Controls	Y	Y	Y	Y
Individual Fixed Effects	Y	Y	Y	Y

Notes: Aside from the variables in the table, all models also include indicators for age, and also include measures of per pack excise tax on cigarettes, indicator for the presence of a minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and the state unemployment rate. Additionally, all models include individual and year-by-quarter fixed-effects and utilize sample weights. The sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a T21 law during the estimation period. Robust standard errors clustered by state are in parentheses. Stars denote statistical significance: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Table 4: **Estimates of the Effect of Tobacco 21 Laws on the Methods of Purchasing Cigarettes, PATH, Waves 1 - 5 (2013-2019)**

	(1)	(2)	(3)
	Purchasing Own Cigarettes in State	Purchasing Own Cigarettes	Buy Cigarettes in Own State
T21 Law * 18-to-20 yr old	-0.436***	-0.328***	-0.255***
	(0.133)	(0.123)	(0.103)
T21 Law * 12-to-17 yr old	0.046	-0.119	0.029
	(0.184)	(0.125)	(0.123)
Tobacco 21 Law	0.018	0.001	-0.02
	(0.031)	(0.034)	(0.014)
Pre-Treat DV Mean (18 - 20)	0.806	0.839	0.966
Pre-Treat DV Mean (12 - 17)	0.192	0.227	0.944
Observations	13,008	13,008	10,222
Demographic Controls	Y	Y	Y
Policy Controls	Y	Y	Y
Individual Fixed Effects	Y	Y	Y

Notes: Sample in column (1) includes only individuals who were reported as smokers, and the sample in column (2) is made up of individuals who reported they bought their own cigarettes. All models include age, individual, and year-by-quarter fixed-effects, measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, an indicator if they were formerly treated by a T21 law and state unemployment rates. All models use sample weights. Additionally, the sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a Tobacco 21 law during the estimation period. Robust standard errors clustered by state are in parentheses. Stars denote statistical significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 5: **Estimates of the Effect of Tobacco 21 Laws on Biomarker Measures, PATH, Waves 1 - 5 (2013-2019)**

	(1)	(2)	(3)	(4)	(5)	(6)
	Cotinine			**NNAL**		
	All Participants	Wave 1 Non-Users	Wave 1 Users	All Participants	Wave 1 Non-Users	Wave 1 Users
T21 Law * 18-to-20 yr old	-275.9*	-138.1**	-436.3	-0.009	-0.01	-0.005
	(155.6)	(67.0)	(346.4)	(0.018)	(0.007)	(0.045)
Tobacco 21 Law	-60.9	-9.8	-97.5	-0.019***	-0.015**	-0.029**
	(53.4)	(41.2)	(141.1)	(0.006)	(0.005)	(0.012)
Pre-Treat DV Mean (18 - 20)	410.5	87.6	1185.1	0.034	0.014	0.084
Observations	9,005	3,697	5,303	8,178	3,294	4,880
Demographic Controls	Y	Y	Y	Y	Y	Y
Policy Controls	Y	Y	Y	Y	Y	Y
Individual Fixed Effects	Y	Y	Y	Y	Y	Y

Notes: All models include an indicator variable for the presence of a Tobacco 21 law, an indicator if the PATH survey participant was 18-to-20 years old, and the corresponding policy/age interaction (as shown above). All models include age, individual, and year-by-quarter fixed-effects, measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, an indicator if they were formerly treated by a T21 law and state unemployment rates. All models use sample weights. Additionally, the sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a Tobacco 21 law during the estimation period. Robust standard errors clustered by state are in parentheses. Stars denote statistical significance: ***p<0.01, **p<0.05, *p<0.10.

Table 6: **Estimates of the Effect of Tobacco 21 Laws on Cigarette Use, PATH, Waves 1 - 5 (2013-2019): Biomarkers Sample**

	(1)	(2)	(3)	(4)	(5)	(6)
	All Participants Sample		**Wave 1 Non Users Sample**		**Wave 1 Users Sample**	
	Smoking Participation	Vaping Participation	Smoking Participation	Vaping Participation	Smoking Participation	Vaping Participation
T21 Law * 18-to-20 yr old	0.037	-0.060	-0.054**	-0.087*	-0.043	0.232
	(0.028)	(0.084)	(0.025)	(0.049)	(0.065)	(0.274)
Tobacco 21 Law	-0.046**	0.019	0.029*	0.030	-0.133*	0.060
	(0.020)	(0.024)	(0.017)	(0.031)	(0.067)	(0.046)
Pre-Treat DV Mean (18 - 20)	0.295	0.161	0.044	0.026	0.878	0.728
Observations	9006	8943	3702	3693	4833	2354
Demographic Controls	Y	Y	Y	Y	Y	Y
Policy Controls	Y	Y	Y	Y	Y	Y
Individual Fixed Effects	Y	Y	Y	Y	Y	Y

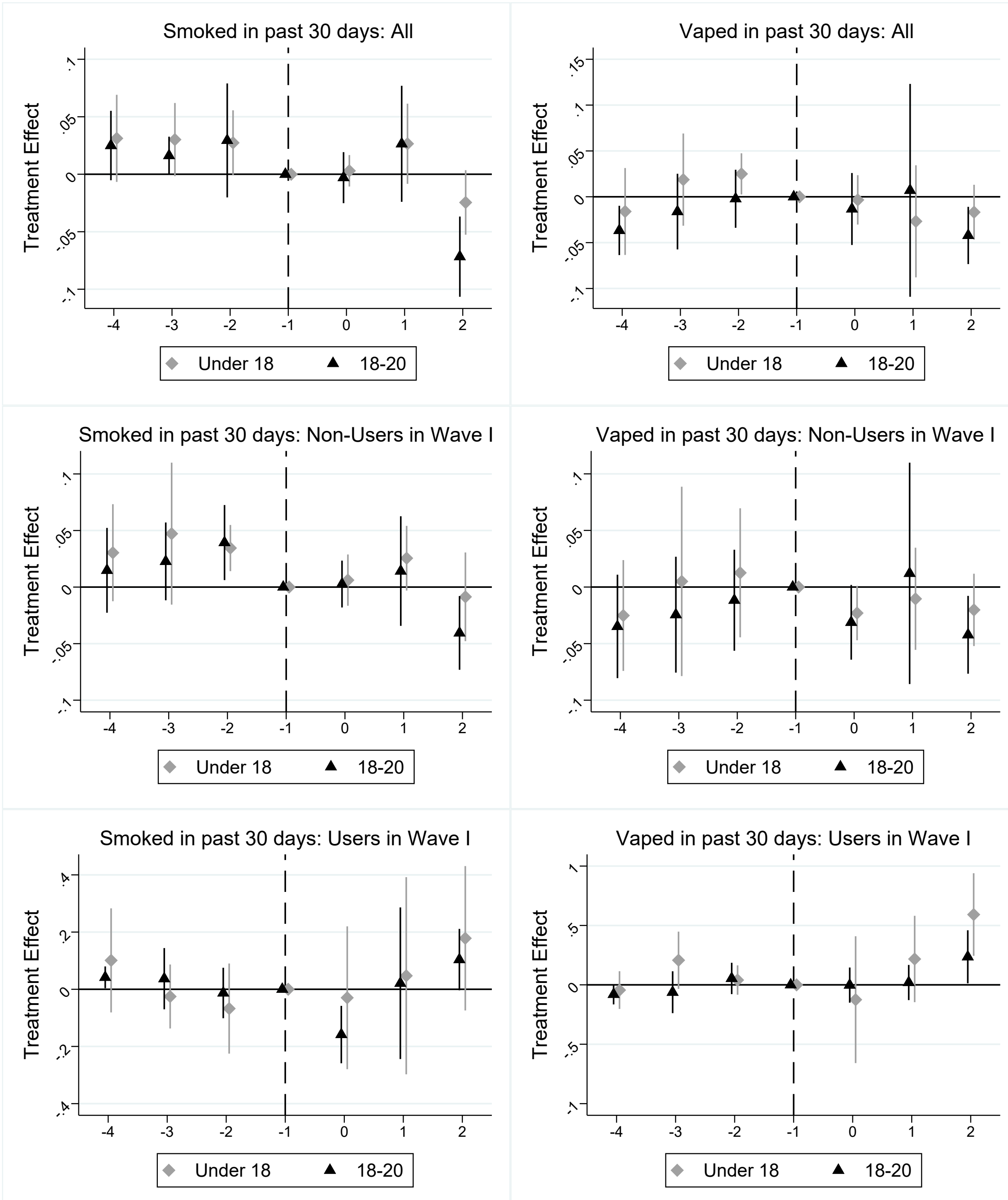
Notes: All models include an indicator variable for the presence of a Tobacco 21 law, an indicator if the PATH survey participant was 18-to-20 years old, and the corresponding policy/age interaction (as shown above). All models include age, individual, and year-by-quarter fixed-effects, measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, an indicator if they were formerly treated by a T21 law and state unemployment rates. All models use sample weights. Additionally, the sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a Tobacco 21 law during the estimation period. Robust standard errors clustered by state are in parentheses. Stars denote statistical significance: ***p<0.01, **p<0.05, *p<0.10.

Table 7: **Estimates of the Effect of Tobacco 21 Laws on the Likelihood of Self-Reporting, PATH, Waves 1 - 5 (2013-2019): Biomarker-Determined User Sample**

	(1)	(2)
	Smoking Participation	Vaping Participation
T21 Law * 18-to-20 yr old	-0.515*	0.152
	(0.263)	(0.386)
Tobacco 21 Law	-0.108	0.035
	(0.065)	(0.035)
Pre-Treat DV Mean (18 - 20)	0.795	0.442
Observations	748	221
Demographic Controls	Y	Y
Policy Controls	Y	Y
Individual Fixed Effects	Y	Y

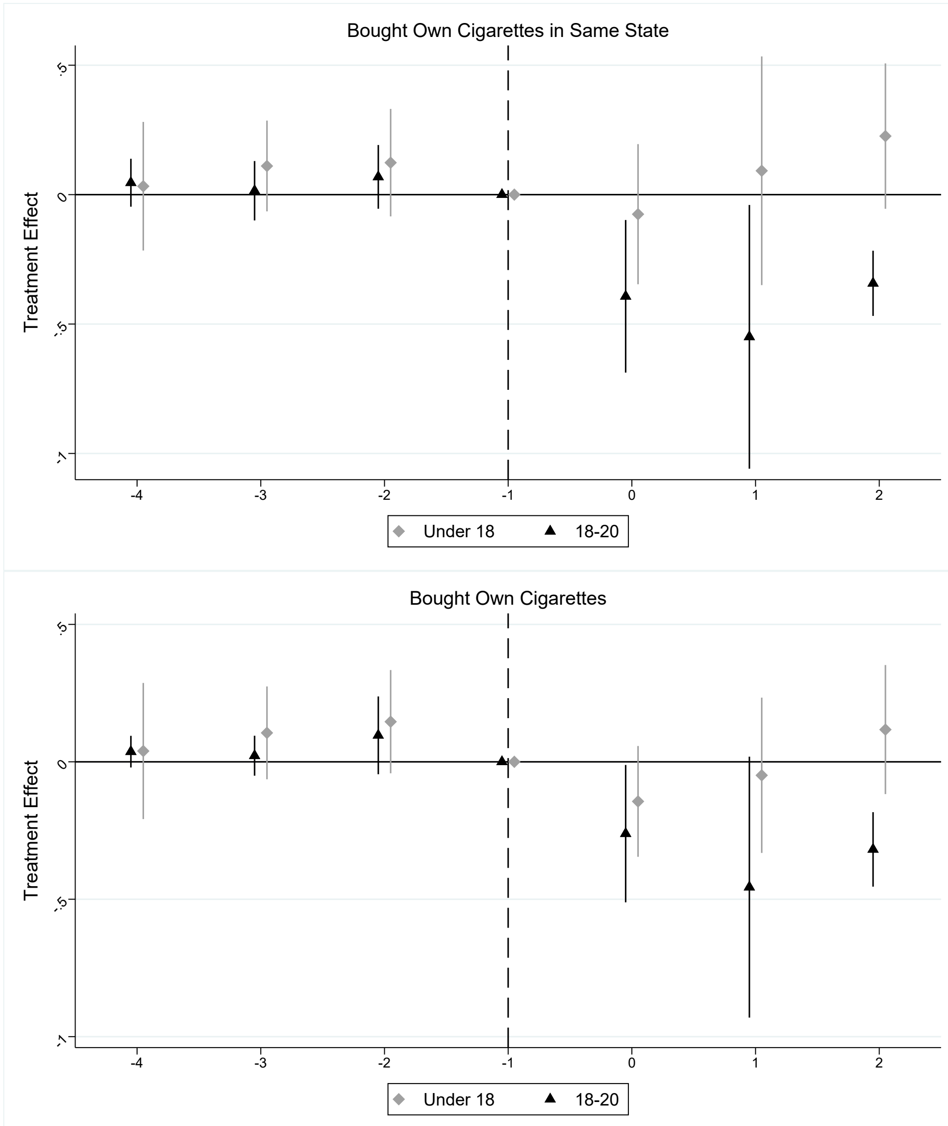
Notes: Sample in column (1)includes only participants who had a urine NNAL level of greater than or equal to 0.030 ng/ml. Sample in column (2) includes only participants who had a urine cotinine level of greater than or equal to 25 ng/ml but NNAL levels below 0.025 ng/ml. All models include age, individual, and year-by-quarter fixed-effects, measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and state unemployment rates. All models use sample weights. Additionally, the sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a Tobacco 21 law during the estimation period. Robust standard errors clustered by state are in parentheses. Stars denote statistical significance: *** p<0.01, ** p<0.05, * p<0.10.

Figure 1: **Event Studies of Effect of T21 Laws on Self-Reported Use**



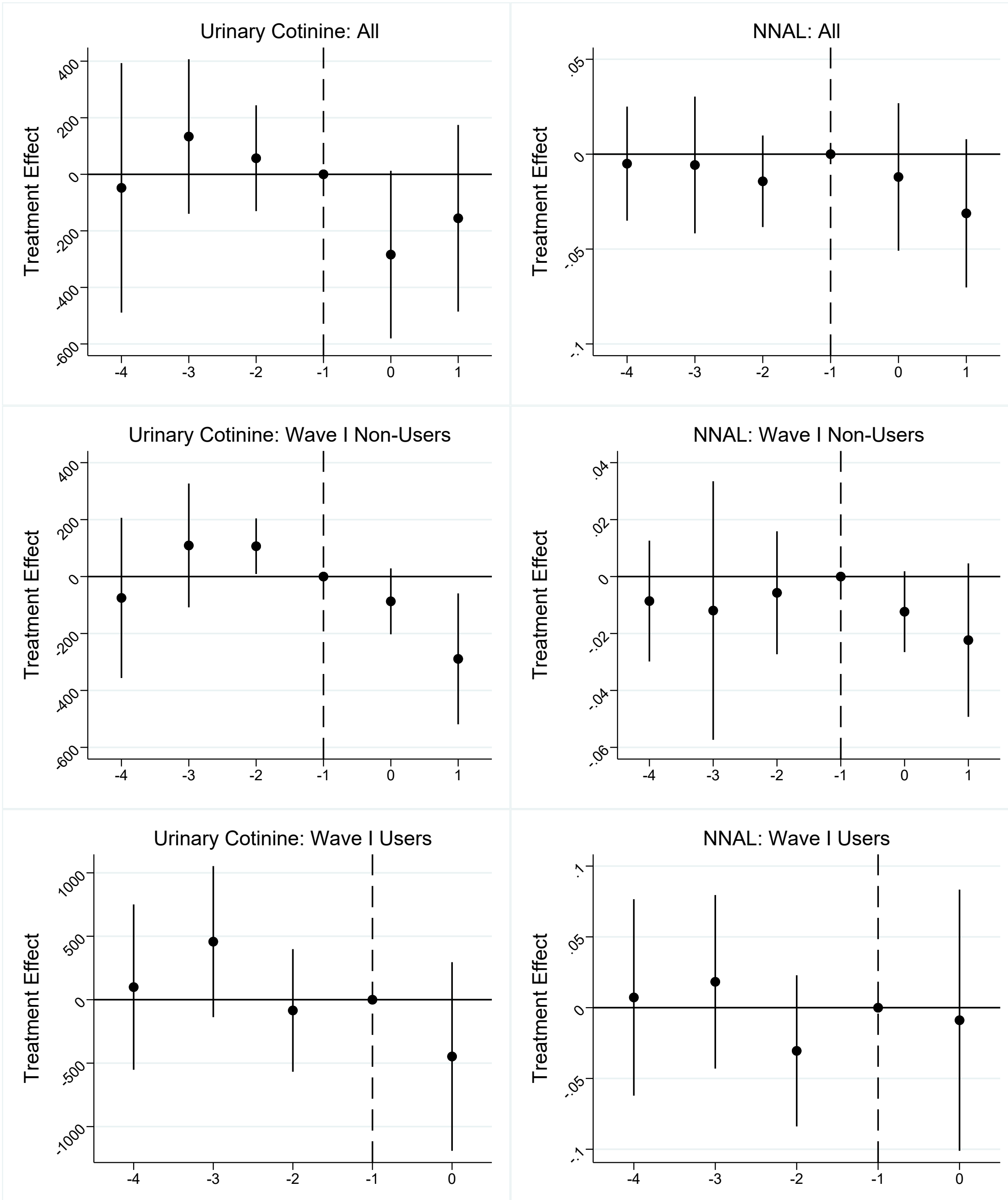
Notes: The figures show coefficients and 95% confidence intervals for the years leading up to and following T21 laws, with the year before the policy as the excluded category. We show separate event study series for 12-to-17 year olds and 18-to-20 year olds, which are run through interacting the event study indicators with age group. All models also include indicators for participant age, and also include measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and state unemployment rates. Additionally, all models include individual and year-by-quarter fixed-effects, and utilize sample weights. The sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a T21 law during the estimation period.

Figure 2: **Event Studies of Effect of T21 Laws on Methods of Cigarette Purchasing**



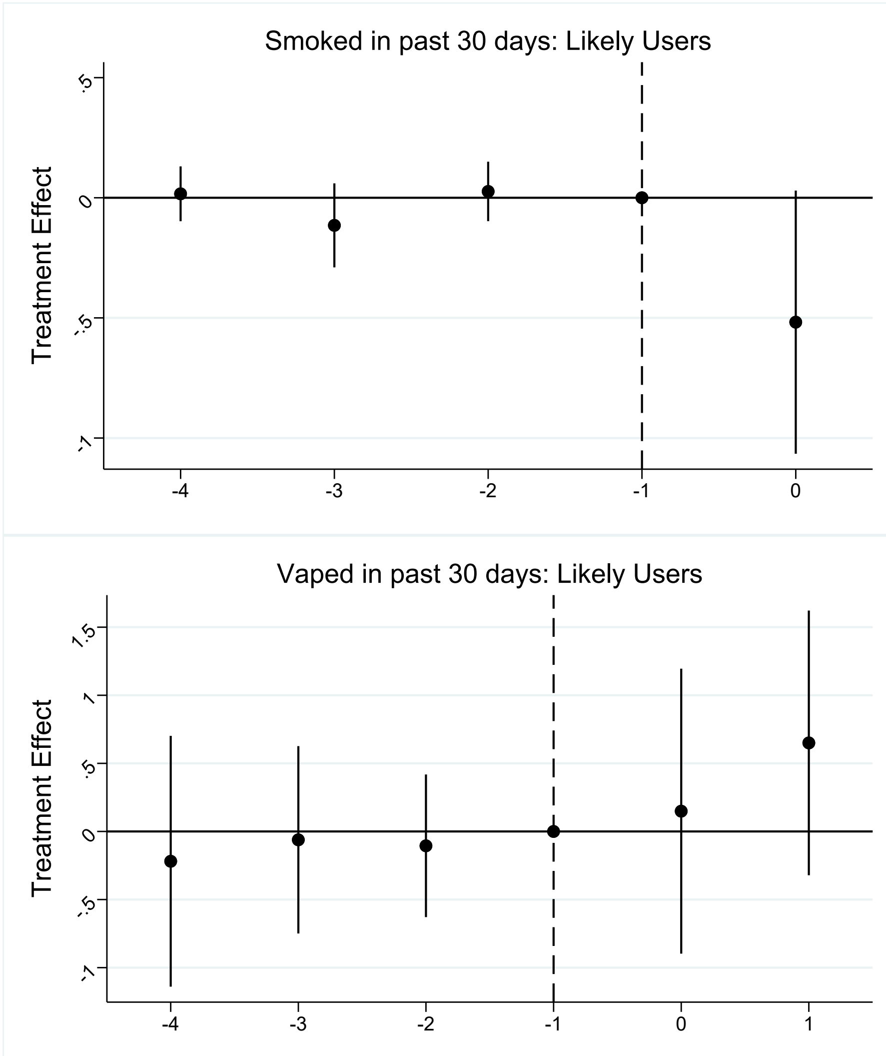
Notes:The figures show coefficients and 95% confidence intervals for the years leading up to and following T21 laws, with the year before the policy as the excluded category. We show separate event study series for 12-to-17 year olds and 18-to-20 year olds, which are run through interacting the event study indicators with age group. All models also include indicators for participant age, and also include measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and state unemployment rates. Additionally, all models include individual and year-by-quarter fixed-effects, and utilize sample weights. The sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a T21 law during the estimation period.

Figure 3: **Event Studies of Effect of T21 Laws on Biomarkers**



Notes: The figures show coefficients and 95% confidence intervals for the years leading up to and following T21 laws, with the year before the policy as the excluded category. We interact the event study indicators with age group indicator for being 18-20 years old. All models also include indicators for participant age, and also include measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and state unemployment rates. Additionally, all models include individual and year-by-quarter fixed-effects, and utilize sample weights. The sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a T21 law during the estimation period.

Figure 4: **Event Studies of Effect of T21 Laws on Likelihood of Self-Reporting Among Clinical Users**



Notes: The figures show coefficients and 95% confidence intervals for the years leading up to and following T21 laws, with the year before the policy as the excluded category. We interact the event study indicators with age group indicator for being 18-20 years old. All models also include indicators for participant age, and also include measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and state unemployment rates. Additionally, all models include individual and year-by-quarter fixed-effects, and utilize sample weights. The sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a T21 law during the estimation period.

Appendix

Table A.1: **Effective Dates of State Tobacco-21 Laws**

State	Effective Date	Meaningful contribution to the PATH Survey	Presence of pre-existing sub-state T21 laws
Hawaii*	1/1/2016	Y	N
California*	6/9/2016	Y	N
District of Columbia*	2/18/2017	Y	N
New Jersey	11/1/2017	Y	Y
Oregon*	1/1/2018	Y	N
Maine*	7/1/2018	Y	N
Massachusetts	12/31/2018	Y	Y
Illinois	7/1/2019	Y	Y
Virginia*	7/1/2019	Y	N
Delaware	7/16/2019	N	N
Arkansas*	9/1/2019	Y	N
Texas*	9/1/2019	Y	N
Vermont	9/1/2019	N	N
Connecticut*	10/1/2019	Y	N
Maryland*	10/1/2019	Y	N
Ohio	10/16/2019	Y	Y
New York	11/13/2019	Y	Y

Source: Preventing Tobacco Addiction Foundation, available at: https://tobacco21.org/. * Treatment states included in the analytical sample.

Table A.2: **Estimates of the Effect of Tobacco 21 Laws on Cigarette Use, PATH, Waves 1 - 5 (2013-2019): California Only Treatment Sample**

	(1)	(2)	(3)	(4)	(5)	(6)
	All Participants Sample		Wave 1 Non Users Sample		Wave 1 Users Sample	
	Smoking Participation	Vaping Participation	Smoking Participation	Vaping Participation	Smoking Participation	Vaping Participation
T21 Law * 18-to-20 yr old	-0.036***	-0.051***	-0.024**	-0.061***	-0.098***	0.001
	(0.012)	(0.012)	(0.010)	(0.012)	(0.031)	(0.039)
T21 Law * 12-to-17 yr old	-0.007	-0.028***	-0.009	-0.037***	0.026	-0.271***
	(0.010)	(0.010)	(0.008)	(0.008)	(0.121)	(0.088)
Tobacco 21 Law	-0.001	0.027***	-0.008	0.033***	-0.067**	0.161***
	(0.007)	(0.007)	(0.010)	(0.008)	(0.030)	(0.036)
Formerly Treated	-0.023	-0.021	-0.038***	-0.041	-0.047	-0.003
	(0.016)	(0.015)	(0.012)	(0.012)	(0.040)	(0.042)
T21 Law * 18-to-20 yr old (p-value)	0.200	0.082	0.33	0.032	0.315	0.988
T21 Law * 12-to-17 yr old (p-value)	0.799	0.231	0.667	0.066	0.863	0.409
Pre-Treat DV Mean (18 - 20)	0.170	0.120	0.067	0.055	0.818	0.648
Pre-Treat DV Mean (12 - 17)	0.024	0.023	0.012	0.015	0.864	0.633
Observations	80,339	80,064	45,422	45,322	8,334	3,918
Demographic Controls	Y	Y	Y	Y	Y	Y
Policy Controls	Y	Y	Y	Y	Y	Y
Individual Fixed Effects	Y	Y	Y	Y	Y	Y

Notes: All models include an indicator variable for the presence of a Tobacco 21 law, an indicator if the PATH survey participant was 12-to-17 years old or 18-to-20 years old, and the corresponding policy/age interactions (as shown above). All models also include controls for participant age, and also include measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and state unemployment rates. Additionally, all models include individual, year-by-quarter fixed-effects, and utilize sample weights. The California Only Treatment sample includes 28 states, where California is the only state that implemented a Tobacco 21 law during the estimation period. Robust standard errors clustered by state are in parentheses. Bootstrapped P-Values are presented in brackets for all estimates. Stars denote statistical significance: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Table A.3: **Estimates of the Effect of Tobacco 21 Laws on Biomarker Measures, PATH, Waves 1 - 5 (2013-2019) California Treatment Only Sample**

	(1)	(2)	(3)	(4)	(5)	(6)
	Cotinine			NNAL		
	All Participants	Wave 1 Non-Users	Wave 1 Users	All Participants	Wave 1 Non-Users	Wave 1 Users
T21 Law * 18-to-20 yr old	-217.3	-159.2*	-164.4	-0.004	-0.011	-0.016
	(133.3)	(82.2)	(248.9)	(0.013)	(0.009)	(0.032)
Tobacco 21 Law	-79.4	-20.3	-180.8	-0.018**	-0.014**	-0.029*
	(56.9)	(50.7)	(158.9)	(0.008)	(0.007)	(0.016)
T21 Law * 18-to-20 yr old (p-value)	0.220	0.152	0.544	0.784	0.206	0.657
Pre-Treat DV Mean (18 - 20)	174.2	28.5	499.1	0.013	0.003	0.033
Observations	6,696	2,722	3,969	6,080	2,421	3,655
Demographic Controls	Y	Y	Y	Y	Y	Y
Policy Controls	Y	Y	Y	Y	Y	Y
Individual Fixed Effects	Y	Y	Y	Y	Y	Y

Notes: All models include an indicator variable for the presence of a Tobacco 21 law, an indicator if for those aged 18-to-20 years, and the corresponding policy/age interaction (as shown above). All models also include controls for participant age, and also include measures of per pack excise tax on cigarettes, the minimum legal purchasing age for e-cigarettes (if below 21 years old), the presence of an e-cigarette tax, an indicator for the legalization of recreational marijuana, and state unemployment rates. Additionally, all models include individual, year-by-quarter fixed-effects, and utilize biomarker sample weights. The sample includes 36 states and the District of Columbia, among which 10 states (see Appendix Table A.1) implemented a Tobacco 21 law during the estimation period. Stars denote statistical significance: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.