Tobacco 21 laws may reduce smoking and tobacco-related health disparities among youth in the U.S

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ABSTRACT

The goal of our study is to understand the impact of Tobacco 21 (T21) laws on youth smoking and health equity. We conducted modified Poisson regression models using 2014–2019 Monitoring the Future data to measure the impact of attending school in a county 100% covered by a T21 law versus counties with <100% T21 coverage on past 30-day smoking participation (n = 262,632), first cigarette smoking initiation (n = 189,698), and daily smoking initiation among 8th, 10th, and 12th graders (n = 214,496), separately. Additive interactions were tested between T21 coverage and sex, race/ethnicity, parental education, and college plans. T21 coverage was associated with a lower likelihood of smoking participation among 12th graders. T21 coverage was most strongly associated with a lower likelihood of smoking participation among: Hispanic and NH (Non-Hispanic) Other/Multiracial individuals; respondents with parents who had less than a college education; and respondents who were not definitely planning on attending college. T21 laws were associated with a lower likelihood of smoking participation among 12th graders. T21 policies were most impactful for individuals disproportionately impacted by tobacco, indicating T21 laws might help reduce tobacco-related health disparities.

1. Introduction

In 2019, 5.7% of 12th graders reported past-month smoking, which marks an almost a 4-fold decline in smoking over the past 10 years. (Miech et al., 2020) This decline, in part, is likely due to tobacco control policies,(Levy et al., 2018) including Tobacco 21 (T21) laws. (Bryan et al., 2020; Friedman et al., 2019) Between 2005 and 2019, local, county, and state governments raised the minimum legal sales age (MLSA) of tobacco products to twenty-one. In December 2019, the Federal Food, Drug, and Cosmetic Act was amended, effectively raising the MLSA to 21 nationwide,(Food and Administration, 2020) after seeing widespread support across the country. (Winickoff et al., 2016; King et al., 2015) T21 laws aim to prevent the sale of tobacco products to youth, and in-turn potentially reduce the likelihood of cigarette smoking initiation and escalation, as 85% of people who smoke report starting smoking prior to the age of 21. (Institute of Medicine, 2015) Prior studies of T21 laws have shown that they are associated with reduced smoking participation among those between the ages of 18 and 203, (Friedman and Wu, n.d.; Friedman et al., 2019) as well as current established or daily smoking among those 18 to 20. (Bryan et al., 2020; Friedman et al., 2019) Another study using Monitoring the Future data from 2012 to 2018 found that 12th graders in T21 areas were less likely to report past 30-day smoking participation than those in non-T21 areas. (Abouk et al., 2021) Two studies have also demonstrated the potential T21 impact on smoking among those younger than 18. One national study found state-wide T21 laws to be associated with a lower likelihood of smoking participation among 16 and 17 year olds,(Bryan et al., 2020) while another found T21 laws to be associated with lower probabilities of smoking intentions among students ages 11–18 in Kansas. (Dai et al., 2020) Studies have also shown T21 laws are associated with decreases in cigarette sales (Glover-Kudon et al., 2020);(Schiff et al., 2021) – especially for brands disproportionately used by those under the age of 21. (Liber et al., 2020) Still, not all studies have found that T21 laws affect smoking behaviors, as one study using longitudinal data to analyze T21

Table 1

Weighted Descriptive Statistics for all 8th, 10th, and 12th Graders in 30-Day Smoking Participation, First Cigarette Initiation, and Daily Smoking Initiation Samples, Monitoring the Future, 2014–2019. Results Shown are Using Imputed Data (m = 10).

	Sample of 30-Day Smoking Participation		
	Grade 8	Grade 10	Grade 12
Variables	Wt. %	Wt. %	Wt. %
100% T21 Coverage	12.0%	13.1%	11.3%
Gender			
Female	50.8%	50.4%	51.3%
Male	49.2%	49.6%	48.7%
Race/Ethnicity			
Non-Hispanic White	44.1%	50.5%	51.6%
Non-Hispanic Black	13.0%	13.0%	12.7%
Hispanic	23.6%	18.8%	20.0%
Non-Hispanic Asian	4.8%	4.8%	4.2%
Non-Hispanic Other	14.6%	12.9%	11.5%
Education, Parents' Highest			
Less than High School	10.7%	9.6%	11.2%
High School	18.0%	16.8%	18.8%
Some College	14.7%	16.2%	19.5%
College or Greater	56.6%	57.4%	50.5%
College Plans (Grade 12)			
No, Probably/Definitely			19.1%
Yes, Probably			24.1%
Yes, Definitely			56.8%
Living Arrangement			
Neither Mother or Father in Household	4.2%	4.5%	6.7%
Lives with Father	3.9%	4.1%	5.3%
Lives with Mother	18.6%	18.8%	23.8%
Lives with Father and Mother	73.3%	72.5%	64.2%
Employment, Mother's Current (Grade 8/10)			
Not Employed	20.7%	20.7%	
Part Time	18.6%	15.7%	
Full Time	60.7%	63.6%	
Employment, Mother's Current (Grade 12)			
None			14.2%
Sometimes			18.7%
Most of Time			17.9%
All the Time			49.2%
High School Program			
College Prep.	34.1%	43.3%	48.8%
General	17.0%	25.2%	35.2%
Vocational/Technical	4.9%	4.0%	3.9%
Other/Don't Know	44.0%	27.5%	12.1%
Census Region			
Northeast	16.8%	18.4%	16.9%
Midwest	21.2%	22.7%	21.5%
South	38.7%	35.8%	39.8%
West	23.3%	23.1%	21.8%
Smoking Participation in Past 30-Days			
No	97.2%	94.1%	89.2%
Yes	2.8%	5.9%	10.8%
State Federal Tax (mean $ (SE), range)	2.7 (1.1), 1.1–5.5	2.7 (1.1), 1.1–5.5	2.7 (1.1), 1.1–5.5

Table 1 (*continued*)

	Sample of 30-Day Smoking Participation		
	Grade 8	Grade 10	Grade 12
Variables	Wt. %	Wt. %	Wt. %
Workplace Smoke-free Laws Coverage (mean % (SE), range)	70.4 (41.6), 0–100	69.4 (43.5), 0–100	69.3 (42.2), 0–100
Hospitality Smoke-free Laws Coverage (mean % (SE), range)	78.6 (37.3), 0–100	78.6 (38.8), 0–100	75.1 (40.1), 0–100
State Poverty (mean % (SE), range)	14.3 (5.3), 3.4–46.4	14.0 (4.6), 4.4–37.5	14.7 (5.6), 4.0–53.3
State % Black (mean % (SE), range)	12.5 (12.9), 0–73.1	12.4 (12.2), 0.1–59.0	13.1 (12.8), 0–74.2
State % Hispanic (mean % (SE), range)	18.3 (17.1), 0.2–68.5	17.4 (16.0), 0–81.3	18.2 (17.5), 0.1–68.5
State % college grad (age 25 +) (mean % (SE), range)	30.8 (10.7), 8.6–61.6	30.6 (10.5), 5.1–72.9	29.6 (10.3), 7.8–62.1
State-level Prevalence of Adult E-cigarette Use (mean % (SE), range)	2.3 (0.63), 1.3–4.9	2.3 (0.61), 1.3–4.5	2.3 (0.68), 1.3–4.9
Unweighted N	92,922	88,628	81,082

laws in California found no evidence for a reduction in the likelihood of smoking participation among 18–20 year olds. (Schiff et al., 2021).

A limitation of the current literature is that few studies consider the impact of T21 laws on smoking disparities. Importantly, considerable disparities in smoking exist,(U.S, 2017) as youth of lower socioeconomic status (SES) exhibiting higher rates of smoking than their higher SES counterparts. (Fryar et al., 2009) Further, while smoking rates are lower among Black and Hispanic compared to White youth, Black individuals who smoke are less likely to successfully quit smoking later in life than NH White smokers,(Trinidad et al., 2011) and Hispanic adults are less likely to use pharmacotherapy to aid in their quit attempts compared to White individuals who smoke, (Trinidad et al., 2011; Sedjo et al., 2016; Fu et al., 2005; Hooper et al., 2017) which could lead to cessation-related disparities later in life. This study examines repeated cross-sectional data from the Monitoring the Future Study (MTF), a nationally-representative survey of youth, to examine the impact of T21 laws on youth smoking behaviors, and to determine how T21 laws might differ in effectiveness by sex, race/ethnicity, and socioeconomic status.

2. Materials and methods

2.1. Sample

Our study sample consisted of cross-sectional data from 8th, 10th, and 12th graders surveyed between 2014 and 2019 through MTF, a nationally representative survey of youth in the United States. (Miech et al., 2020) Analytic samples vary by grade and outcome; the largest sample sizes were for the past 30-day smoking participation outcome, with data available for 92,922 8th graders, 88,628 10th graders, and 81,082 12th graders (Table 1). Tables 2 and 3

2.2. Smoking outcomes

We analyzed three primary outcomes related to youth smoking behaviors: past 30-day smoking participation (dichotomized as Yes/No) among the full analytic sample; first cigarette smoking initiation in the respondent's current grade (Yes/No) among individuals who had not initiated prior to the current grade; and daily cigarette smoking initiation in the respondent's current grade (Yes/No) among individuals who had not initiated daily smoking prior to the current grade.

2.3. Independent variables

Our primary exposure was T21 coverage. Information on local, county, and state T21 policy passage and effective dates were gathered from the University of Missouri Tobacco Control Research Center

Table 2
Unadjusted and Adjusted Relative Risks of 100% Tobacco 21 Coverage on Smoking by Grade, Monitoring the Future, 2014–2019. Results Shown are using Imputed Data (m = 10).

	8th graders		10th graders		12th graders	
	URR (95% CI)	ARR(95% CI)[a]	URR (95% CI)	ARR(95% CI)[a]	URR (95% CI)	ARR(95% CI)[b]
Smoking participation						
100% T21 Coverage	0.46*** (0.35,0.59)	0.91 (0.69,1.20)	0.62* (0.40,0.95)	0.96 (0.75,1.23)	0.49*** (0.39,0.61)	0.74** (0.60,0.91)
N	92,922		88,628		81,082	
First cigarette initiation						
100% T21 Coverage	0.58*** (0.44,0.77)	0.87 (0.65,1.16)	0.67*** (0.54,0.83)	0.80 (0.61,1.04)	0.68* (0.50,0.93)	0.77 (0.54,1.09)
N	84,562		74,938		30,198	
Daily smoking initiation						
100% T21 Coverage	0.49* (0.28,0.86)	1.04 (0.58,1.85)	0.40*** (0.27,0.60)	0.70 (0.44,1.11)	0.42** (0.25,0.70)	0.65 (0.36,1.16)
N	91,457		85,468		37,571	

[a]Regression models estimating adjusted risk ratios controlled for gender, age, race/ethnicity, parents' highest education, living arrangement, mother's employment, high school program type, hours worked per week, weekly earnings from allowances or other sources, grade of smoking cigarette for first time, grade of starting daily smoking, having 5 or more drinks in a row over the past 2 weeks, marijuana use in the past 30 days, the year of survey administration, census region, cigarette taxes, workplace smoke-free policy coverage, restaurant and bar (hospitality) smoke-free policy coverage, percentage of individuals in state in poverty, percentage of individuals in state that are Black, percentage of individuals in state that are Hispanic or Latino.
[b]12th grade adjusted regression models controlled for all variables included in 8th and 10th grade models, as well as college plans.

Table 3
Additive P-values Associated with Interaction Terms between 100% Tobacco 21 Coverage and Gender, Race/Ethnicity, Parental Education and Plans to Attend College for Smoking Participation, First Cigarette Initiation, and Daily Smoking Initiation across Grades, Monitoring the Future, 2014–2019. Results Shown are using Imputed Data (m = 10).

	8th graders[a]	10th graders[a]	12th graders[b]
	P-value	P-value	p-value
Smoking participation			
Gender	0.398	0.423	0.271
Race/ethnicity	0.483	0.554	0.004
Parental education	0.556	0.147	0.035
College bound	–	–	0.007
N	92,922	88,628	81,082
First cigarette initiation			
Gender	0.224	0.765	0.318
Race/ethnicity	0.432	0.167	0.548
Parental education	0.683	0.503	0.456
College bound	–	–	0.597
N	84,562	74,938	30,198
Daily smoking initiation			
Gender	0.330	0.706	0.624
Race/ethnicity	0.977	0.125	0.537
Parental education	0.607	0.111	0.645
College bound	–	–	0.472
N	91,457	85,468	37,571

[a]Regression models estimating adjusted risk ratios controlled for gender, age, race/ethnicity, parents' highest education, living arrangement, mother's employment, high school program type, hours worked per week, weekly earnings from allowances or other sources, grade of smoking cigarette for first time, grade of starting daily smoking, having 5 or more drinks in a row over the past 2 weeks, marijuana use in the past 30 days, the year of survey administration, census region, cigarette taxes, workplace smoke-free policy coverage, restaurant and bar (hospitality) smoke-free policy coverage, percentage of individuals in state in poverty, percentage of individuals in state that are Black, percentage of individuals in state that are Hispanic or Latino.
[b]12th grade adjusted regression models controlled for all variables included in 8th and 10th grade models, as well as college plans.

(Cowan, 2020) and underwent quality control checks. We defined the percentage of the county population covered by T21 laws as the number of individuals covered by a local, county, or state law (in each month), which was then summed at the county-level, and divided by the overall county population using data from the US Census Bureau's cities and towns estimates. (Census Bureau, 2010) For example, if a county-wide law went into effect on June 1, 2015, everyone in the county would be defined as 'covered' from June 2015 to June 2019 (which marks the end of the sampling period for MTF in 2019), presuming the law was not repealed. Additional information on T21 coverage definitions have been documented elsewhere,(Colston et al., 2021a; Tobacco 21 Population Coverage Database, 2022) and the database for population-level coverage is available online. (Tobacco 21 Population Coverage Database, 2022) Given the bimodal distribution of T21 exposure, with the majority of respondents going to school in counties that were either 0% (unweighted percentages range by grade from 80.3% to 82.4%) or 100% covered (ranging from 12.1% to 13.8%), county-level T21 coverage was dichotomized as 100% of the population covered or <100% of the population covered. T21 coverage was merged onto respondent-level data using the county FIPS code for the school the respondent attended, and month and year of survey administration. Because MTF administers surveys between February and June, respondents whose counties were not covered by a T21 law until after June 2019 were defined as not being covered.

Other key independent variables included sex, race/ethnicity, highest parental education, and college plans (asked only among 12th graders). Sex was categorized as male or female. Race/ethnicity was grouped into five categories: non-Hispanic (NH) White, NH Black, Hispanic/Latino/a/e, NH Asian, and all other self-descriptions, including individuals identifying as multiple races (hereafter, NH Other/Multiracial). While we grouped Hispanic and Latino/a/e individuals together in analyses, there are considerable cultural and geographic differences between Hispanic and Latino/a/e individuals,(Jaimes et al., 2013) and authors caution against using findings to highlight variability in T21 effectiveness for Hispanic or Latino/a/e populations, individually. Highest parental educational attainment for either parent was categorized into 4 groups: less than high school, high school, some college, and a bachelor's degree or greater. College plans was measured among 12th graders only, and referred to whether or not respondents planned to attend college, with responses categorized as: "definitely will," "probably will," and "probably won't" or "definitely won't." College plans is a proxy for socioeconomic status (SES), as other measures of SES, such as income, household SES, and parental education, are associated with plans to obtain a four-year college degree. (Cabrera and La Nasa, 2000; King, 1996; Hauser and Anderson, 1991) Furthermore, college plans have been used extensively in the youth tobacco control literature to assess SES-related differences in policy effectiveness. (Fleischer et al.,
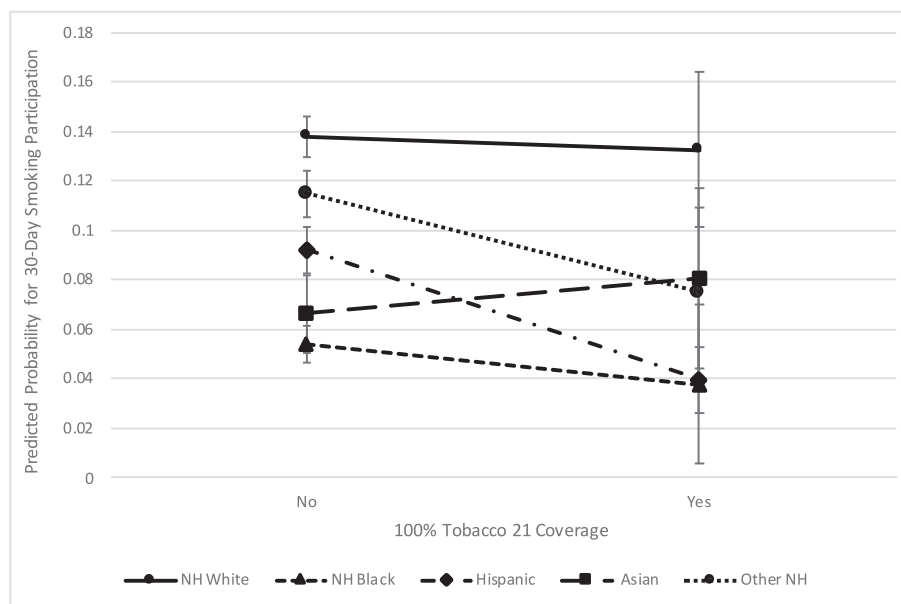
Fig. 1. Differential Association of 100% Tobacco 21 Coverage on 30-day Smoking Participation Among 12th graders, by Race/ethnicity, Monitoring the Future, 2014–2019. Results Shown are Using Imputed Data (m = 10).

2020; Titus et al., 2021; Colston et al., 2021a; Colston et al., 2021b).

Additional respondent-level covariates included living arrangement (neither mother nor father live in household, lives with father, lives with mother, lives with father and mother); mother's employment status (not employed, part time, full time); high school program type (college prep, general, vocational/technical, other/don't know); and the year of MTF survey administration. Time-varying county-level covariates included workplace or hospitality (i.e., restaurant/bar) smoke-free policy coverage from the American Non-Smokers Rights Foundation, (Foundation, 2020) defined as the percent of the county population covered by workplace or restaurant/bar smoke-free laws, and sociodemographic composition measures—county percent of non-Hispanic Black individuals, Hispanic/Latino/a/e individuals, individuals with a college degree, individuals living below the poverty line—obtained from the U. S. Census Bureau's American Community Survey. (Census Bureau et al., 2019; U.S, 2019; U.S, 2019) County-level covariates were all measured as continuous percentages. State-level covariates included the 4-category Census region (Northeast, Midwest, South, West),(US, 0000) and state-level pack price for cigarettes from the Center for Disease Control and Prevention's Tax Burden on Tobacco database. (Burden, 2018) Weighted prevalence of state-level adult e-cigarette use in the past 30 days was controlled for in sensitivity analyses to capture secular trends in the tobacco market, as youth cigarette smoking has declined in recent years while e-cigarette use increased over the study period. (Cho et al., 2021; Rigotti et al., 2015) E-cigarette data was gathered from the 2014–2015 and 2018–2019 Tobacco Use Supplement to the Current Population Survey (TUS-CPS), (Integrated public use microdata series, 2017; Integrated public use microdata series, 2018) with linear interpolation for years 2016 and 2017. Interpolation was needed as TUS-CPS did not administer surveys in 2016–17. Data on cigarette pack price was only available through 2018, and were linearly extrapolated to 2019 using 2017 and 2018 information. All prices were adjusted to reflect the dollar value as of 2016, using the Gross Domestic Product Implicit Price Deflator. (Gross Domestic Product, 2020).

2.4. Statistical analysis

We estimated grade-stratified unadjusted and adjusted modified Poisson regression models (Zou, 2004) to examine the relationship between T21 coverage and the three smoking outcomes. Grade-stratified comparisons were made across years (e.g., all respondents in T21 counties between 2014 and 2019 were compared to all respondents in non-T21 counties between 2014 and 2019). Interactions between T21 coverage and sex, race/ethnicity, parental education, and college plans were tested on the additive scale in separate adjusted models to assess whether the impact of T21 coverage differed across the sociodemographic factors. We adjusted p-values from the effect modification analyses for multiple testing using Benjamini-Hochberg correction with a false discovery rate of 5% across the interaction models for each outcome and each grade. (Benjamini and Hochberg, 1995) We plotted predicted marginal probabilities of T21 coverage on smoking outcomes when interactions were statistically significant after controlling for multiple testing.

In sensitivity analyses, we examined whether results derived from complete-case data were consistent with results using multiple-imputed data. We also tested whether there were differential effects of T21 coverage on the outcome variables over time using interactions between year and the exposure. Finally, we examined the sensitivity of our results by using an alternative T21 exposure, defined as respondents residing in a county with >0% versus 0% T21 coverage. (Colston et al., 2021a).

All analyses were conducted using Stata v.16.0 and incorporated MTF's complex surveying design including strata, the cluster the school was located in, and sampling weights for individuals. (Stata, 0000) All results are reported using Rubin's combining rules from the 10 multiply-imputed datasets. (Little and Rubin, 2002) This study was deemed not regulated by the University of Michigan Institutional Review Board due to use of de-identified secondary data.

3. Results

3.1. Description of population

Table 1 provides descriptive statistics for the 8th, 10th, and 12th graders in the sample of respondents asked about past 30-day smoking participation for years 2014 to 2019. The demographic composition of samples varied by grade. The majority of respondents were female (50.4–51.3%), non-Hispanic White (44.1–51.6%), and had at least one parent with a college degree (50.5–57.4%). During the study period, between 11.3% and 13.1% of respondents were in a county 100% covered by a T21 law, which varied based on the respondent's grade.
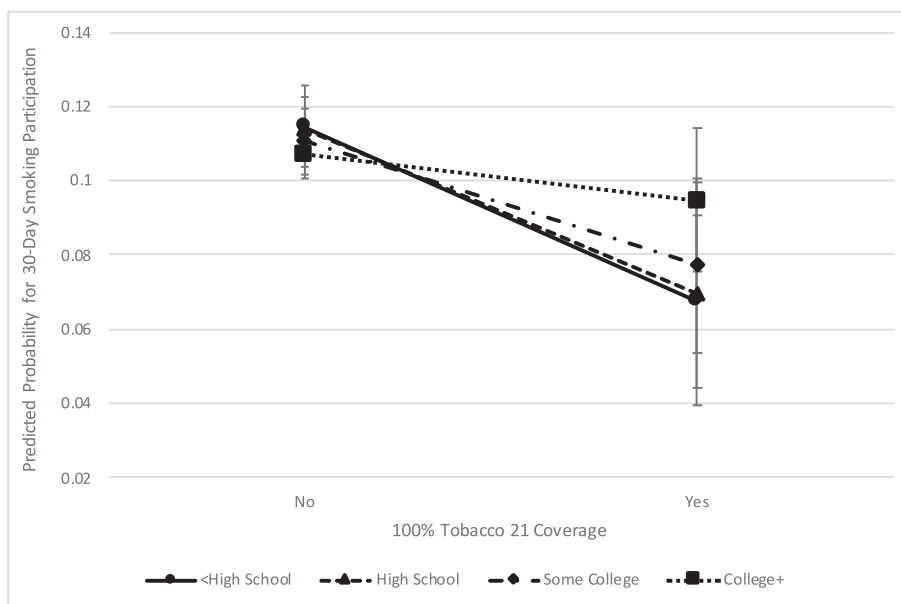
Fig. 2. Differential Association of 100% Tobacco 21 Coverage on 30-day Smoking Participation Among 12th graders, by Parental Education, Monitoring the Future, 2014–2019. Results Shown are Using Imputed Data (m = 10).
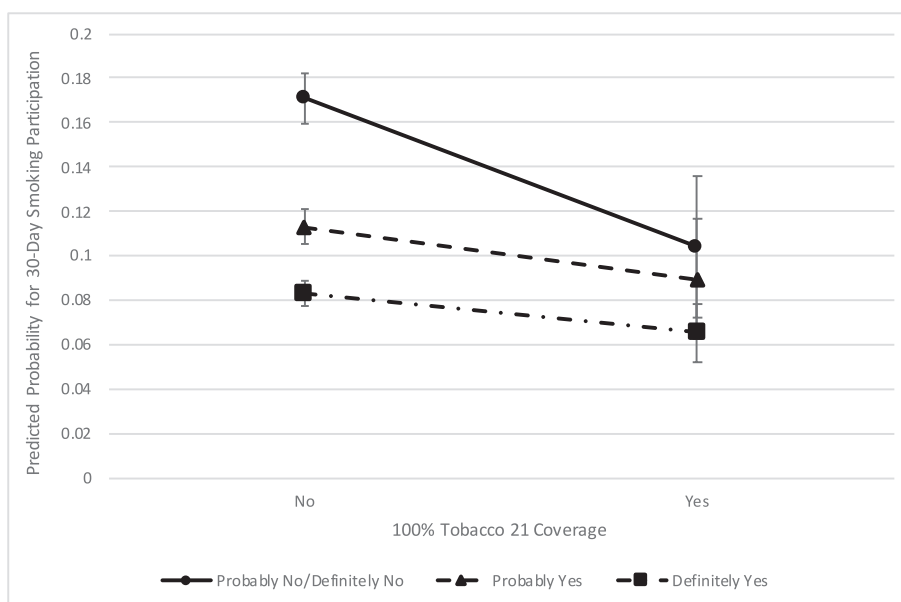

Fig. 3. Differential Association of 100% Tobacco 21 Coverage on 30-day Smoking Participation Among 12th graders, by Plans to Attend College, Monitoring the Future, 2014–2019. Results Shown are Using Imputed Data (m = 10).

Among all 12th graders, 19.1% definitely or probably did not plan to attend college, 24.1% probably planned to attend college, and 56.8% definitely planned on attending college. Regarding smoking status, 2.8% of 8th graders, 5.9% of 10th graders, and 10.8% of 12th graders reported smoking in the past 30 days. All the reported percentages were calculated across the duration of the study. The initiation samples were restricted to those who had not initiated their first cigarette or daily smoking before their current grade; descriptive statistics for these samples are shown in Appendix Table A1.

3.2. Main effects models

Unadjusted main effects regression models show that MTF respondents from counties covered 100% by T21 laws had a lower likelihood of past 30-day smoking participation, first cigarette smoking initiation, and daily smoking initiation in the current grade among 8th, 10th, and 12th graders when compared to respondents from counties that had <100% T21 coverage (Table A2). After controlling for covariates, results were attenuated for 8th and 10th graders for all outcomes, and for 12th graders for first and daily smoking initiation. In adjusted models, 12th graders attending school in counties with 100% T21 coverage were less likely to report having smoked a cigarette in the past 30 days (Adjusted Risk Ratio (ARR): 0.74; 95% CI: 0.60–0.91), than 12th graders in counties not covered 100% by a T21 law.

3.3. Differential impact of T21 coverage on youth smoking

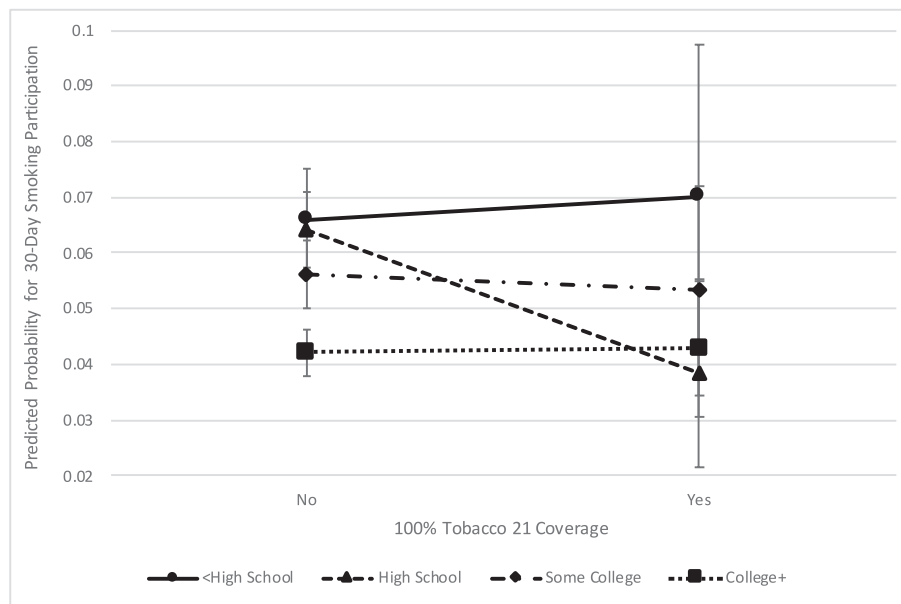After adjusting for multiple testing, we observed effect modification

Fig. A1. Differential Association of 100% Tobacco 21 Coverage on 30-day Smoking Participation Among 10th graders, by Parental Education, Monitoring the Future, 2014–2019. Results Shown are Using Complete Cases.
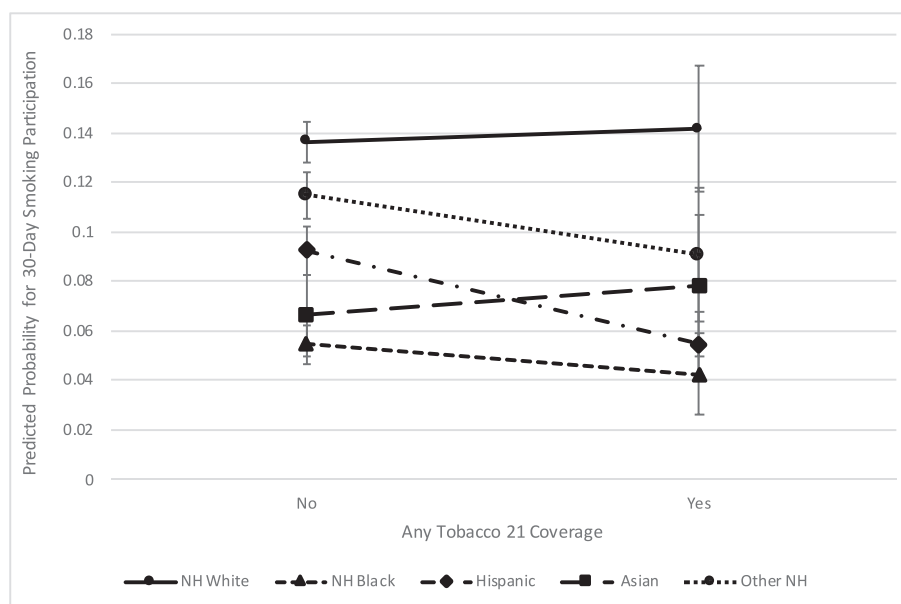

Fig. A2. Differential Association of Any Tobacco 21 Coverage on 30-day Smoking Participation Among 12th graders, by Race/ethnicity, Monitoring the Future, 2014–2019. Results Shown are Using Imputed Data (m = 10).

between T21 coverage and past 30-day smoking participation by race/ethnicity, parental education, and college plans among 12th graders (Appendix Table A2). We found that the association between residing in a county with 100% T21 coverage and past 30-day smoking participation was most pronounced among 12th graders who identified as Hispanic or were categorized as NH Other/Multiracial, while little to no effect was seen for NH White, NH Black, and Asian respondents (Fig. 1). Regarding parental education, 12th graders with parents who had less than high school, high school, or some college education had a greater reduction in the likelihood of 30-day smoking participation when covered by T21 laws, while respondents with a parent who had a college degree had relatively little change in the likelihood of 30-day smoking participation when covered by T21 laws (Fig. 2). We also found that 12th graders who probably did not and definitely did not plan to attend

college had a greater reduction in the likelihood of 30-day smoking participation when covered by T21 laws than students who had planned to attend college (Appendix Fig. A1). No other additive interactions (by sex, race/ethnicity, parental education, or college plans) were statistically significant after adjusting for multiple testing.

3.4. Sensitivity analysis

In sensitivity analyses, we found adjusted models that controlled for the state-level prevalence of adult e-cigarette use showed results in the same direction and significance as our primary, imputed main effects analyses (Appendix Table A3). Further, in complete case sensitivity analyses, the association between 100% T21 coverage and smoking participation was no longer significant, but 100% and any percentage of

Table A1

Weighted Descriptive Statistics for all 8th, 10th, and 12th Graders in First Cigarette Initiation, and Daily Smoking Initiation Samples, Monitoring the Future, 2014–2019. Results Shown are Using Imputed Data (m = 10).

	Sample of First Cigarette Initiation in Current Grade			Sample of Daily Smoking Initiation in Current Grade		
	Grade 8	Grade 10	Grade 12	Grade 8	Grade 10	Grade 12
Variables	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
100% T21 Coverage	12.6%	13.8%	12.4%	12.1%	13.3%	11.6%
Gender						
Female	51.0%	50.9%	52.9%	50.8%	50.5%	51.8%
Male	49.0%	49.1%	47.1%	49.2%	49.5%	48.2%
Race/Ethnicity						
Non-Hispanic White	44.2%	49.6%	49.6%	44.0%	50.1%	50.9%
Non-Hispanic Black	13.2%	13.9%	14.4%	13.1%	13.3%	13.2%
Hispanic	23.6%	18.7%	20.3%	23.6%	18.9%	20.2%
Non-Hispanic Asian	5.1%	5.2%	4.8%	4.8%	4.9%	4.4%
Non-Hispanic Other	13.9%	12.5%	10.9%	14.4%	12.8%	11.3%
Education, Parents' Highest						
Less than High School	10.1%	9.0%	10.7%	10.6%	9.4%	10.9%
High School	17.4%	15.9%	18.0%	17.9%	16.6%	18.4%
Some College	14.4%	15.6%	19.0%	14.7%	16.0%	19.5%
College or Greater	58.1%	59.5%	52.3%	56.9%	58.0%	51.1%
College Plans (Grade 12)						
No, Probably/Definitely			15.8%			17.7%
Yes, Probably			23.2%			23.8%
Yes, Definitely			61.0%			58.4%
Living Arrangement						
Neither Mother or Father in Household	3.7%	3.7%	5.3%	4.0%	4.2%	6.0%
Lives with Father	3.6%	3.7%	4.6%	3.8%	4.0%	5.0%
Lives with Mother	18.1%	18.2%	23.1%	18.5%	18.7%	23.5%
Lives with Father and Mother	74.6%	74.3%	67.0%	73.6%	73.1%	65.5%
Employment, Mother's Current (Grade 8/10)						
Not Employed	20.0%	20.0%		20.5%	20.4%	
Part Time	18.8%	15.8%		18.7%	15.7%	
Full Time	61.2%	64.2%		60.8%	63.9%	
Employment, Mother's Current (Grade 12)						
None			14.5%			14.6%
Sometimes			18.4%			18.5%
Most of Time			17.7%			17.9%
All the Time			49.4%			49.0%
High School Program						
College Prep.	35.1%	45.6%	52.2%	34.3%	44.0%	50.4%
General	16.8%	24.1%	33.0%	16.9%	25.0%	34.4%
Vocational/Technical	4.8%	3.6%	3.3%	4.9%	3.9%	3.5%
Other/Don't Know	43.3%	26.7%	11.5%	43.9%	27.2%	11.6%
Census Region						
Northeast	17.4%	19.0%	17.2%	16.9%	18.5%	16.9%
Midwest	21.0%	22.7%	21.7%	21.1%	22.7%	21.5%
South	38.2%	35.1%	38.9%	38.6%	35.6%	39.6%
West	23.3%	23.2%	22.1%	23.3%	23.2%	22.0%
Smoking First Cigarette in Current Grade						
No	98.0%	97.5%	95.7%			
Yes	2.0%	2.5%	4.3%			
Initiation to Daily Smoking in Current Grade						
No				99.3%	98.9%	97.8%
Yes				0.7%	1.1%	2.2%
State Federal Tax (mean $ (SE), range)	2.8 (1.1), 1.1–5.5	2.8 (1.1), 1.1–5.4	2.7 (1.1), 1.1–5.5	2.7 (1.1), 1.1–5.5	2.7 (1.1), 1.1–5.5	2.7 (1.1), 1.1–5.5
Workplace Smoke-free Laws Coverage (mean % (SE), range)	71.0 (41.3), 0–100	70.3 (43.1), 0–100	70.1 (41.9), 0–100	70.5 (41.6), 0–100	69.7 (43.3), 0–100	69.5 (42.1), 0–100
Hospitality Smoke-free Laws Coverage (mean % (SE), range)	79.2 (36.9), 0–100	79.5 (38.2), 0–100	76.3 (39.4), 0–100	78.7 (37.2), 0–100	78.9 (38.6), 0–100	75.5 (39.9), 0–100

Table A1 (*continued*)

Variables	Sample of First Cigarette Initiation in Current Grade			Sample of Daily Smoking Initiation in Current Grade		
	Grade 8	Grade 10	Grade 12	Grade 8	Grade 10	Grade 12
	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
State Poverty (mean % (SE), range)	14.2 (5.2), 3.4–46.4	13.9 (4.6), 4.4–37.5	14.6 (5.5), 4.0–53.3	14.3 (5.3), 3.4–46.4	13.9 (4.6), 4.4–37.5	14.7 (5.6), 4.0–53.3
State % Black (mean % (SE), range)	12.6 (12.9), 0–73.1	12.7 (12.2), 0.1–59.0	13.3 (12.8), 0–74.2	12.5 (12.9), 0–73.1	12.5 (12.2), 0.1–59.0	13.1 (12.7), 0–74.2
State % Hispanic (mean % (SE), range)	18.5 (17.1), 0.2–68.5	17.6 (15.8), 0–81.3	18.7 (17.6), 0.1–68.5	18.4 (17.1), 0.2–68.5	17.5 (16.0), 0–81.3	18.5 (17.6), 0.1–68.5
State % college grad (age 25 +) (mean % (SE), range)	31.1 (10.7), 8.6–61.6	31.1 (10.4), 5.1–72.9	30.0 (10.2), 7.8–62.1	30.8 (10.7), 8.6–61.6	30.7 (10.4), 5.1–72.9	29.7 (10.3), 7.8–62.1
State-level Prevalence of Adult E-cigarette Use (mean % (SE), range)	2.3 (0.62), 1.3–4.9	2.3 (0.61), 1.3–4.5	2.3 (0.68), 1.3–4.9	2.3 (0.63), 1.3–4.9	2.3 (0.61), 1.3–4.5	2.3 (0.68), 1.3–4.9
Unweighted N	84,562	74,938	30,198	91,457	85,468	37,571

Table A2

Sensitivity Analysis Additionally Controlled for State E-cigarette Prevalence. Adjusted Relative Risks of 100% Tobacco 21 Coverage on Smoking by Grade, Monitoring the Future, 2014–2019. Results Shown are using Imputed Data (m = 10).

	8th graders[a]	10th graders[a]	12th graders[b]
	ARR(95% CI)	ARR(95% CI)	ARR(95% CI)
Smoking participation			
100% T21 Coverage	0.91 (0.69,1.20)	0.96 (0.75,1.23)	0.74** (0.60,0.91)
N	92,922	88,628	81,082
First cigarette initiation			
100% T21 Coverage	0.88 (0.65,1.17)	0.80 (0.61,1.04)	0.77 (0.54,1.10)
N	84,562	74,938	30,198
Daily smoking initiation			
100% T21 Coverage	1.04 (0.58,1.85)	0.70 (0.44,1.11)	0.64 (0.36,1.15)
N	91,457	85,468	37,571

[a]Regression models estimating adjusted risk ratios controlled for gender, age, race/ethnicity, parents' highest education, living arrangement, mother's employment, high school program type, hours worked per week, weekly earnings from allowances or other sources, grade of smoking cigarette for first time, grade of starting daily smoking, having 5 or more drinks in a row over the past 2 weeks, marijuana use in the past 30 days, the year of survey administration, census region, cigarette taxes, workplace smoke-free policy coverage, restaurant and bar (hospitality) smoke-free policy coverage, percentage of individuals in state in poverty, percentage of individuals in state that are Black, percentage of individuals in state that are Hispanic or Latino.
[b]12th grade adjusted regression models controlled for all variables included in 8th and 10th grade models, as well as college plans.

T21 coverage was associated with lower likelihoods of first cigarette smoking initiation among 10th graders, compared to those with <100% and no T21 coverage, respectively (Appendix Table A4, Appendix Table A5b). That said, multiply imputed sensitivity analyses found no significant associations between any T21 coverage and smoking outcomes, compared to those not covered at all by a T21 law (Appendix Table A5a).

Sensitivity analyses assessing effect modification of 100% T21 coverage using complete case data showed evidence for effect modification similar to imputed analyses in both direction and significance, though also highlighted evidence for effect modification between T21 coverage and smoking participation by parental education among 10th graders (Appendix Table A6). Specifically, the association between 100% T21 coverage and lower likelihood of smoking participation was stronger for 10th graders whose parents had a high school education, compared to all other parental education categories (Appendix Fig. A2). Interaction models evaluating any T21 coverage only found evidence for effect modification between T21 and smoking participation among 12th graders by race/ethnicity (Appendix Table A6), in a direction similar to

Table A3

Adjusted Relative Risks of 100% Tobacco 21 Coverage on Smoking by Grade, Monitoring the Future, 2014–2019. Results Shown are Complete Cases.

	8th graders[a]	10th graders[a]	12th graders[b]
	ARR(95% CI)	ARR(95% CI)	ARR(95% CI)
Smoking participation			
100% T21 Coverage	0.77 (0.56,1.06)	0.92 (0.69,1.21)	0.79 (0.61,1.03)
N	70,649	74,750	63,928
First cigarette initiation			
100% T21 Coverage	0.81 (0.59,1.12)	0.73* (0.54,0.99)	0.81 (0.53,1.23)
N	59,052	59,735	22,222
Daily smoking initiation			
100% T21 Coverage	0.60 (0.33,1.09)	0.63 (0.38,1.06)	0.71 (0.38,1.34)
N	65,061	69,189	27,560

[a]Regression models estimating adjusted risk ratios controlled for gender, age, race/ethnicity, parents' highest education, living arrangement, mother's employment, high school program type, hours worked per week, weekly earnings from allowances or other sources, grade of smoking cigarette for first time, grade of starting daily smoking, having 5 or more drinks in a row over the past 2 weeks, marijuana use in the past 30 days, the year of survey administration, census region, cigarette taxes, workplace smoke-free policy coverage, restaurant and bar (hospitality) smoke-free policy coverage, percentage of individuals in state in poverty, percentage of individuals in state that are Black, percentage of individuals in state that are Hispanic or Latino.
[b]12th grade adjusted regression models controlled for all variables included in 8th and 10th grade models, as well as college plans.

our primary interaction models (Appendix Fig. 3). Fig. 3.

4. Discussion

Our results show T21 coverage is associated with a lower likelihood of smoking participation and daily smoking initiation among 12th graders, but found no association between T21 coverage and first or daily smoking initiation among 12th graders, and no association between T21 and all smoking outcomes for 8th and 10th graders. Importantly, we also found that the impact of T21 coverage on smoking behaviors among 12th graders differed by race/ethnicity, parental educational attainment, and college plans. Specifically, T21 laws were more effective in reducing the likelihood of smoking participation for Hispanic/Latino/a/e and NH Other/Multiracial adolescents, whereas there was no relationship between T21 coverage and smoking participation for NH White, NH Black, and Asian respondents. With respect to SES, T21 coverage was found to be more strongly associated with a reduced likelihood of smoking participation among individuals with parents of lower educational attainment. Furthermore, T21 coverage was most strongly associated with a decreased probability of smoking participation among 12th graders who probably did not or definitely did

Table A4a
Adjusted Relative Risks of Any Tobacco 21 Coverage on Smoking by Grade, Monitoring the Future, 2014–2019. Results Shown are using Imputed Data (m = 10).

	8th graders[a]	10th graders[a]	12th graders[b]
	ARR(95% CI)	ARR(95% CI)	ARR(95% CI)
Smoking participation			
Any T21 Coverage	0.95 (0.75,1.21)	1.00 (0.76,1.32)	0.87 (0.75,1.02)
N	92,922	88,628	81,082
First cigarette initiation			
Any T21 Coverage	0.96 (0.73,1.28)	0.83 (0.65,1.06)	0.83 (0.65,1.08)
N	84,562	74,938	30,198
Daily smoking initiation			
Any T21 Coverage	1.13 (0.73,1.75)	0.82 (0.55,1.20)	0.83 (0.57,1.22)
N	91,457	85,468	37,571

[a]Regression models estimating adjusted risk ratios controlled for gender, age, race/ethnicity, parents' highest education, living arrangement, mother's employment, high school program type, hours worked per week, weekly earnings from allowances or other sources, grade of smoking cigarette for first time, grade of starting daily smoking, having 5 or more drinks in a row over the past 2 weeks, marijuana use in the past 30 days, the year of survey administration, census region, cigarette taxes, workplace smoke-free policy coverage, restaurant and bar (hospitality) smoke-free policy coverage, percentage of individuals in state in poverty, percentage of individuals in state that are Black, percentage of individuals in state that are Hispanic or Latino.
[b]12th grade adjusted regression models controlled for all variables included in 8th and 10th grade models, as well as college plans.

Table A4b
Adjusted Relative Risks of Any Tobacco 21 Coverage on Smoking by Grade, Monitoring the Future, 2014–2019. Results Shown are using Complete Cases.

	8th graders[a]	10th graders[a]	12th graders[b]
	ARR(95% CI)	ARR(95% CI)	ARR(95% CI)
Smoking participation			
Any T21 Coverage	0.91 (0.68,1.21)	0.90 (0.71,1.13)	0.82 (0.67,1.00)
N	70,649	74,750	63,928
First cigarette initiation			
Any T21 Coverage	0.93 (0.66,1.31)	0.74* (0.56,0.97)	0.87 (0.64,1.20)
N	59,052	59,735	22,222
Daily smoking initiation			
Any T21 Coverage	0.94 (0.57,1.56)	0.77 (0.51,1.18)	0.89 (0.52,1.52)
N	65,061	69,189	27,560

[a]Regression models estimating adjusted risk ratios controlled for gender, age, race/ethnicity, parents' highest education, living arrangement, mother's employment, high school program type, hours worked per week, weekly earnings from allowances or other sources, grade of smoking cigarette for first time, grade of starting daily smoking, having 5 or more drinks in a row over the past 2 weeks, marijuana use in the past 30 days, the year of survey administration, census region, cigarette taxes, workplace smoke-free policy coverage, restaurant and bar (hospitality) smoke-free policy coverage, percentage of individuals in state in poverty, percentage of individuals in state that are Black, percentage of individuals in state that are Hispanic or Latino.
[b]12th grade adjusted regression models controlled for all variables included in 8th and 10th grade models, as well as college plans.

not plan to attend college, relative to those who probably or definitely planned to attend college.

Our finding that T21 laws were related to lower likelihoods of smoking participation among 12th graders is consistent with previous work. Specifically, one study using MTF data found T21 coverage is associated with a lower likelihood of smoking among 12th graders. (Abouk et al., 2021) Additional work has demonstrated T21 coverage is

Table A5
Additive P-values Associated with Interaction Terms between 100% Tobacco 21 Coverage and Gender, Race/Ethnicity, Parental Education and Plans to Attend College for Smoking Participation, First Cigarette Initiation, and Daily Smoking Initiation across Grades, Monitoring the Future, 2014–2019. Results Shown are using Complete Cases.

	8th graders[a]	10th graders[a]	12th graders[b]
	P-value	P-value	p-value
Smoking participation			
Gender	0.034	0.069	0.622
Race/ethnicity	0.581	0.437	0.001
Parental education	0.191	0.005	<0.001
College bound	–	–	0.027
N	70,649	74,750	63,928
First cigarette initiation			
Gender	0.282	0.880	0.658
Race/ethnicity	0.293	0.109	0.526
Parental education	0.154	0.490	0.392
College bound	–	–	0.868
N	59,052	59,735	22,222
Daily smoking initiation			
Gender	0.613	0.550	0.669
Race/ethnicity	0.626	0.024	0.597
Parental education	0.200	0.063	0.174
College bound	–	–	0.994
N	65,061	69,189	27,560

[a]Regression models estimating adjusted risk ratios controlled for gender, age, race/ethnicity, parents' highest education, living arrangement, mother's employment, high school program type, hours worked per week, weekly earnings from allowances or other sources, grade of smoking cigarette for first time, grade of starting daily smoking, having 5 or more drinks in a row over the past 2 weeks, marijuana use in the past 30 days, the year of survey administration, census region, cigarette taxes, workplace smoke-free policy coverage, restaurant and bar (hospitality) smoke-free policy coverage, percentage of individuals in state in poverty, percentage of individuals in state that are Black, percentage of individuals in state that are Hispanic or Latino.
[b]12th grade adjusted regression models controlled for all variables included in 8th and 10th grade models, as well as college plans.

associated with lower probabilities of recent smoking among 18–203, (Friedman et al., 2019; Friedman and Wu, n.d.) and 18–22 year olds. (Friedman et al., 2019) Some have even shown that T21 laws are associated with lower probabilities of smoking participation among 16 and 17 year olds,(Bryan et al., 2020) and that 11 to 18 year-olds in Kansas with knowledge of a T21 law in their area had a lower likelihood of intending to smoke, (Dai et al., 2020) though these contrast our findings that suggest T21 laws are not associated with lower likelihoods of smoking outcomes among 8th and 10th graders. Further, some research has shown T21 laws to be associated a lower likelihood of daily smoking among 18 to 20 year-olds, which differs from our findings that showed no significant association between the two. (Bryan et al., 2020) Finally, research has shown T21 laws are associated with lower likelihoods of youth purchasing tobacco12, (Schiff et al., 2021) and reductions in purchases of tobacco brands disproportionately used by those under 21. (Liber et al., 2020).

Sensitivity analyses controlling for e-cigarette use showed results that were not substantively different than primary analyses, which suggests our findings were robust to the inclusion of the shifting landscape of tobacco product use in the US.

4.1. Tobacco-related health disparities

Our findings suggest T21 laws might have a greater impact on reducing the likelihood of smoking participation among 12th graders who identify as Hispanic/Latino/a/e or were categorized as NH Other/ Multiracial, though given the considerable heterogeneity within these

Table A6

Additive P-values Associated with Interaction Terms between Any Tobacco 21 Coverage and Gender, Race/Ethnicity, Parental Education and Plans to Attend College for Smoking Participation, First Cigarette Initiation, and Daily Smoking Initiation across Grades, Monitoring the Future, 2014–2019. Results Shown are using Imputed Data (m = 10).

	8th graders[a]	10th graders[a]	12th graders[b]
	P-value	P-value	p-value
Smoking participation			
Gender	0.131	0.874	0.689
Race/ethnicity	0.339	0.462	0.007
Parental education	0.702	0.062	0.083
College bound	–	–	0.159
N	92,922	88,628	81,082
First cigarette initiation			
Gender	0.308	0.971	0.285
Race/ethnicity	0.678	0.388	0.451
Parental education	0.752	0.956	0.685
College bound	–	–	0.594
N	84,562	74,938	30,198
Daily smoking initiation			
Gender	0.667	0.826	0.541
Race/ethnicity	0.984	0.085	0.324
Parental education	0.889	0.120	0.775
College bound	–	–	0.815
N	91,457	85,468	37,571

[a]Regression models estimating adjusted risk ratios controlled for gender, age, race/ethnicity, parents' highest education, living arrangement, mother's employment, high school program type, hours worked per week, weekly earnings from allowances or other sources, grade of smoking cigarette for first time, grade of starting daily smoking, having 5 or more drinks in a row over the past 2 weeks, marijuana use in the past 30 days, the year of survey administration, census region, cigarette taxes, workplace smoke-free policy coverage, restaurant and bar (hospitality) smoke-free policy coverage, percentage of individuals in state in poverty, percentage of individuals in state that are Black, percentage of individuals in state that are Hispanic or Latino.

[b]12th grade adjusted regression models controlled for all variables included in 8th and 10th grade models, as well as college plans.

categories, authors caution against extrapolating findings to all Hispanic/Latino/a/e individuals. Furthermore, we found T21 laws might have a stronger impact on reducing the likelihood of smoking participation among 12th graders whose parents have lower levels of educational attainment and 12th graders who do not plan to attend college. We caution against We are not aware of any other studies that have used interactions to directly contrast the impact of T21 laws across sociodemographic characteristics, however two studies showed potential for effect modification using stratified models. (Bryan et al., 2020; Abouk et al., 2021) Both studies found that T21 coverage was related with a significantly lower likelihood of smoking participation among males but not females (p < 0.05), (Bryan et al., 2020; Abouk et al., 2021) which contrasts our finding that there were no significant interactions by gender. Both studies also suggested T21 laws were associated with a lower likelihood of smoking participation among Black individuals, (Bryan et al., 2020; Abouk et al., 2021) though one study also found T21 laws to be associated with a lower likelihood of smoking participation and everyday smoking among White individuals, (Bryan et al., 2020) while the other (which used MTF data) found T21 laws to be associated with a lower likelihood of smoking participation among Hispanic individuals, (Abouk et al., 2021) in agreement with our findings. Regarding SES, one study showed T21 laws were associated with lower likelihoods of smoking participation among those with and without a high school degree, and for those below and above the poverty line, though T21 laws were only significantly associated with lower likelihoods of everyday smoking among those living above the poverty line. (Bryan et al., 2020) No other studies have evaluated the differential

impact of T21 coverage on smoking outcomes for specific sociodemographic groups.

Our findings suggest that T21 laws might not only reduce youth smoking, but also have potential to decrease smoking disparities, and thus downstream health disparities, with respect to SES and race/ethnicity. For example, youth living below the poverty line smoke at far greater percentages than those above it. (Fryar et al., 2009) The potential prevention of smoking participation among Hispanic respondents is also quite compelling, as previous work has demonstrated that Hispanic youth have the highest rates of smoking susceptibility throughout adolescence,(El-Toukhy et al., 2016; Kamke et al., 2020) though some studies have shown this does not always translate to an earlier age of onset to regular smoking. (Trinidad et al., 2004) Still, Hispanic smokers are less likely to utilize evidence-based treatment such as pharmacotherapy their NH White counterparts,(Trinidad et al., 2011; Sedjo et al., 2016; Fu et al., 2005; Hooper et al., 2017) which could make it more difficult for Hispanic individuals to quit later in life. The increased susceptibility for youth smoking and the relatively lower levels of pharmacotherapy use in quit attempts make prevention a priority in this population.

4.2. Limitations

This study has several limitations. First, due to the bimodal distribution of the data (counties mostly 0 or 100% covered), we were unable to consider T21 coverage as continuous percentages. Our sensitivity analysis defining exposure as >0% versus 0% of the population covered by a T21 law allowed us to account for areas that may not have been 100% covered. Second, we recognize that, while college plans is a measure that has been shown to be correlated with other measures of SES, and is commonly used in the tobacco control literature, it is an imperfect measure for SES on its own, in part due to its established relationship with academic performance. (Hauser and Anderson, 1991) Still, the inclusion of a second proxy measure for SES – parental education – allows us to be more confident in our assessment of the differential impact T21 laws may have had related to SES. Third, our study did not capture the heterogeneity in policies passed (i.e., sunset clauses that grandfather in youth of a certain age, exemptions for military, details for enforcement) or the level at which the policies were passed (local, county, state), which could have a considerable impact on enforcement, and downstream tobacco use. Ensuring adequate and equitable enforcement must be at the forefront of evaluation moving forward. Differential enforcement by area could result in uneven public health impacts across the US, which could be further with the addition of the national T21 law if the rollout and enforcement is uneven.

Furthermore, we did not include data after the federal T21 policy was enacted, which inhibits our ability to determine how the national law impacted youth tobacco use. This approach was intentional, though, as it allowed us to demonstrate the utility of local-, county-, and state-level Tobacco 21 policies to potentially reduce the likelihood of youth tobacco use and improve downstream health equity. Recent work has underscored the importance of the continual passage of sub-national T21 laws, even after the national law has gone into effect, as passing model T21 legislation at the sub-national level could ensure local retailers are complying with and enforcing the elevated MLSA. (Dobbs et al., 2021) Also, additional time was provided to the FDA to set the language and enforce the national law, (Foundation, 2020) meaning if we chose to utilize restricted 2020 MTF data to assess the impact of the federal law – as all youth in the US would technically have been 'covered' by a T21 law – we would likely be overestimating youths' exposure to active T21 laws as some might have been in an area that was not enforcing the policy until later in the year. Future research should evaluate the impact of the national T21 law, and assess the potential differential effectiveness between national and sub-national laws.

Finally, given the morbidity and mortality associated with cigarette smoking and the well-established literature base related to smoking-

related disparities, our analysis focused exclusively on the T21 impact on youth cigarette smoking. That said, future research should explore the potential effect of T21 laws on ENDs product usage and disparities.

5. Conclusions

We found T21 laws were associated with lower likelihoods of smoking participation among 12th graders. We also found evidence for effect modification by race/ethnicity and SES in this age group. Specifically, associations between T21 coverage and lower probabilities of smoking participation were most pronounced among Hispanic/Latino/a/e individuals and individuals categorized as NH Other/Multiracial, individuals with lower levels of parental education, and those that did not plan on attending college, while little associations were found between T21 laws and lower likelihoods of smoking outcomes among NH White, NH Black, NH Asian, or youth of higher SES. This study shows the potential importance of T21 laws to reduce the likelihood of youth smoking and disparities with respect to race/ethnicity and SES, meaning T21 laws could improve public health, and possibly improve downstream health equity.

The authors have no conflicts of interest relevant to this article to disclose.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Fig. A1 and A2; Appendix A1-A6.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2022.101762.

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