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Age, period, and cohort effects in frequent cannabis use among US students: 1991-2018

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Abstract

Background and Aims: As the legal status of cannabis changes across the U.S. and modes of administration expand, it is important to examine the potential impact on adolescent cannabis use. This study aimed to assess changes in prevalence of frequent cannabis use in adolescents in the US and how far this varies by age, and cohort.

Design: Analysis of Monitoring the Future, a nationally-representative annual survey of 8th, 10th, and 12th grade students in the U.S. conducted from 1991-2018.

Setting: In-school surveys completed by U.S. adolescents.

Participants: 1,236,159 8th, 10th, and 12th graders; 51.5% female, 59.6% non-Hispanic White, 12.3% non-Hispanic Black, 13.4% Hispanic, and 14.7% other race/ethnicity.

Measurements: Frequent cannabis use (FCU), defined as 6+ occasions in the past 30 days, stratified by sex, race/ethnicity, and parental education.

Findings: FCU among US adolescents increased over the study period; the peak in 2010-2018 was 11.4% among 18-year old students. This increase was best explained by both period and cohort effects. Compared with respondents in 2005, adolescents surveyed in 2018 had period effects in FCU that were 1.6 times greater. Adolescents in younger birth cohorts (those born >1987) had a lower increase in FCU than those born prior to 1987. Results were consistent across sex, parent education, and race/ethnicity, with period effects indicating increasing FCU after 2005 and cohort effects indicating a lower magnitude of increase in more recent birth cohorts. Age and parental education disparities in FCU have increased over time, whereas race/ethnicity differences have converged over time; Black students were 0.67(95%C.I. 0.64-0.70) times as likely to use cannabis frequently as White students from 1991-2000, and 1.03(95%C.I. 0.98-1.09) times as likely from 2011-2018 (p-value for time interaction <0.001)

Conclusions: The prevalence of frequent cannabis use (FCU) increased from 1991 to 2018 among older adolescents in the US. Racial/ethnic differences in FCU converged whereas parental education differences have diverged.

Introduction:

Cannabis is one of the most commonly used psychoactive substances in the United States (1,2). Past year cannabis use among 12th grade students has decreased since the peak of use in the late 1970s (50.8% in 1979), although data from the past dozen years suggest that cannabis use is again rising (increasing from 31.5% in 2006 to 35.9% in 2018 among 12th grade students) (3). There is a concern that those who use cannabis may be using at higher frequency, as we have seen an increase in adult cannabis use frequency (4–6). Changes in high frequency use are especially concerning in the context of the major policy changes surrounding cannabis legalization where recreational use of cannabis is legalized in ten states and Washington, D.C as of February, 2019 (7,8). Heavy and frequent cannabis use in adolescence is associated with consequences ranging from failing to complete school to cognitive deficits (9–13). As drug use often begins in adolescence, understanding the pattern of high frequency cannabis use may foreshadow future consequences.

A thorough evaluation of historical trends in frequency of adolescent cannabis use requires assessment of the extent to which these trends reflect age, period, or cohort effects (14). Differentiating between age, period, and cohort effects disentangles developmental trends from historical time trends and illuminates whether changes across time are consistent across developmental age or influencing particular birth cohorts more than others. Cannabis use generally increases across adolescence (an age effect) (15), and declines during the transition to adulthood (16). However, given changes in population trends in cannabis use, historical changes in developmental course could occur as well, including changes in average age of onset (17,18). Period effects describe the trends over time across all examined ages, which may be coincident with broader socio-environmental changes that affect all age groups simultaneously

(e.g. availability and access due to legal changes). Lastly, cohort effects in cannabis use refer to the variance of use by the birth year or adjacent years. For example, some cohorts of youth may have particularly high levels of cannabis use because of high initiation rates during early adolescence that are maintained as they age.

Recent age-period-cohort (APC) analyses of cannabis use have mainly been conducted among adults 18 and older, among whom cannabis use is increasing (19–21). Available evidence among adults indicates that increases in adult cannabis use are predominately explained by period effects (16). In contrast, Miech and Koester (2012) examined time trends and age-period-cohort effects including both adolescent and adult cannabis use in national data from 1985 through 2009 (22), documented increases in cannabis use among youth and young adults, and found significant positive cohort effects indicating higher risk of cannabis use overall among those born after World War II. However, those data are now over a decade old, and the past decade in the US has ushered in substantial changes in adolescent cannabis use as well and environmental changes in availability of and legality around cannabis (23). Further, age-period-cohort analyses to date have not examined frequent cannabis use as a unique outcome from any cannabis use, which is critical to study given that trends in frequent use may be distinct from trends in experimental or infrequent use. Studies of adolescence have generally found that more recently born cohorts, those born between 1992 and 2004, are less likely to use cannabis throughout early adulthood (24), indicative of a cohort effect, but that these same cohorts may have a more rapid increase in cannabis use during the transition to adulthood (24). Updated age-period-cohort models incorporating younger generations are needed.

Changes over time in cannabis use may vary by demographic characteristics. Although Black youth have historically had lower prevalence of cannabis use compared with White youth, cannabis use

among Black students has increased over the past 10 years and converged with that of White students(15,25). Similarly, the prevalence of use by boys and girls has converged(3,26); while prevalence has decreased among boys, there have been some recent increases among girls' use. However, the extent to which these convergences of cannabis use by race/ethnicity and sex extend to *high frequency* cannabis use—which is of greatest consequence for public health—remains unknown. Further, family socioeconomic status has an inverse relationship with cannabis use and disorder (27,28) and this association begins as early as adolescence (29–31).

The present study consists of a systematic analysis of age, period, and cohort effects in adolescent frequent cannabis use using nationally-representative samples of 1,236,159 8th, 10th, and 12th grade students in the United States from 1991-2018. We also tested whether trends were consistent across demographic groups as defined by parental education, race/ethnicity, and sex.

Methods:

Sample

Monitoring the Future has conducted nationally representative annual cross-sectional surveys of 8th, 10th, and 12th graders since 1991, with approximately 45,000 adolescents included per year (15). Approximately 420 public and private schools are sampled each year in a multi-stage random sampling design with replacement, with a maximum of 350 students from each school; schools typically participate for two years. Schools that decline participation are replaced with schools that are similar on geographic location, size, and urbanicity. Student response rates ranged from 79% (12th grade, 2008) to 91% (8th grade, 1996, 2002, 2006, 2007, 2011, 2012). Almost all non-response is due to absenteeism; less than 1% of students refused to participate. Self-administered questionnaires were given to students, typically in

classroom settings with a teacher present. Teachers were instructed to avoid close proximity to the students during administration to ensure students could respond confidentially. Detailed description of design and procedures are provided elsewhere(15).

The present study includes all adolescents with valid responses for cannabis use items (97.8% of the total sample) from 1991 through 2018. Due to unreliable estimates, adolescents ages <13 and >=19 were excluded (1.8%) as were those who did not respond to cannabis use questions. The final analytic sample included 1,236,159 adolescents (448,874 8th graders, 419,127 10th graders, and 368,158 12th graders).

Measures

Cannabis use. Past 30-day cannabis use was queried of all adolescents, worded as "On how many occasions (if any) have you used marijuana (grass, pot) or hashish (hash, hash oil) during the last 30 days?" where "grass" was replaced with "weed" between 1998 and 1999. Responses were dichotomized into: frequent use (defined as 6 times or more in the past month) versus all other students (other cannabis users and non-users). Six times or more was chosen as the cut-off for frequent use as it represents use on average more than once per week. Because there is no accepted standard for frequent cannabis use, we conducted sensitivity analysis at two cutpoints: a) 3 times or more in the past month versus all others and b) 10 times or more in the past month versus all others.

Demographics. Age was measured in calendar years based on self-reported birth year; period was measured as the year of data collection, and birth cohort was the year of data collection minus age.

We categorized respondents into: non-Hispanic White (59.6%), non-Hispanic Black (12.3%), Hispanic (13.4%), and other race/ethnicity (14.7%). Those who reported more than one category were

included in other race/ethnicity. Respondents reported the highest level of education for each parent. We categorized parental education based on the highest level achieved by either parent in the following: high school or less, some college or more. Respondents self-reported sex.

Statistical Analysis

Age-period-cohort (APC) effects models were estimated using the Clayton and Schiffler approach(32,33), as we have done numerous times using MTF and other data sources(34–38). Modeling strategies are complicated by the fact that age, period, and cohort are linearly dependent variables (cohort = period-age), thus their linear effects together are overidentified. The model building and assessment begins by estimating a categorical age predictor, given that most health outcomes (including cannabis use) vary by age. Then, a parameter termed "drift" is introduced, which is the sum of the linear effects over time of period and cohort effects. Finally, first- and second-derivatives of the drift are estimated and regressed on period and cohort, such that we estimate the extent to which the overall acceleration or deceleration of trends in the outcome are greater or less for certain periods (independent of age and cohort) and for certain cohorts (independent of age and period). Period and cohort relative risks are then estimated, with a specified reference period and reference cohort for comparison. Model fit is assessed at each stage including age+drift compared to age alone, and then iteratively adding in cohort and period effects to see if the model fit statistically significantly improves with more parameters. Then, model fit is assessed as each parameter is iteratively removed, testing whether model fit statistically significantly deteriorates without the parameter in the model. We chose 1988 as the reference cohort because it was in the midpoint of the cohort distributions, and 2005 was chosen as the reference period for the analyses

based on distributions in the data. The APC modeling was conducted using "*apc.fit*" in the "*Epi*" package in the R software(39) .

APC effects of cannabis were modeled by comparing frequent cannabis users versus all others. After estimating age-period-cohort models, we then examined trends in the association between demographics and frequent cannabis use across time, categorizing time into three periods: [1991-2000, 2001-2010, 2011-2018]. These time periods were chosen to represent each decade of the past thirty years. Logistic regression models were used to estimate odds ratios. Multiplicative interactions between year and demographic variables were tested to determine whether there were significant trends over time in associations with demographics, where statistical significance was set a $p<0.05$. To conduct sensitivity analyses, all analyses were repeated with variation in the cut-off for frequent cannabis use.

Overall, 4.0% of data were excluded: 2.2% due to missing on past month cannabis use and 1.8% due to age restrictions.

Results:

Figure 1 shows descriptive statistics regarding the percent of students who were frequent cannabis users, by age, across three decades: 1991-2000, 2001-2010, and 2011-2018. Frequent cannabis use increased by age in all time periods; for older students (17-18 year olds), it increased by decade group. Among those observed in 1991-2000, 8.5% of 16-18 year olds reported frequent cannabis use. By 2011-2018, 9.6% of 16-18 year olds reported frequent cannabis use. Few trends were observed at younger ages. The result of the increase in frequent cannabis use among older adolescents is that the differences between younger and older adolescents are increasing in more recently born cohorts.

APC analysis of frequent cannabis use

Significant improvement in model fit was found with the addition of drift (overall linear trend in frequent cannabis use), period and cohort (overall non-linear trend in frequent cannabis use attributable to period and cohorts) (Supplemental Table 1), both overall and by gender, parental education, and race/ethnicity.

As shown in Figure 2, frequent cannabis use increased with age; 18 year-olds were approximately five times more likely to be frequent cannabis users than 13 year-olds. The period effect in frequent cannabis use was higher in the time period both before and after the reference period of 2005. In particular, the period effect of frequent cannabis use was 1.60 times higher in 2018 compared to 2005. Further, the period effect was also higher than the reference period for the years 1994 through 2005.

Adolescents in the 1988 birth cohort had the highest cohort effect of frequent cannabis use compared with those in preceding and following birth cohorts, with a steady decline in the cohort effect for those born after 1988. Thus, there are two countervailing forces; a positive period effect, driving up prevalence after 2005, and a negative cohort effect, with the amount of the increase by period having less of an effect among younger cohorts. These effects together produce the trends observed, where frequent cannabis use is increasing, but more so for older cohorts compared with younger cohorts.

APC Analyses by Demographics

APC analyses were consistent across gender, parental education and racial/ethnic categories with the best-fitting models including drift, period and cohort (Supplemental Tables 1-3). Supplemental Figures 1, 2, and 3 graph the age, period, and cohort effects by gender (Supplemental Figure 1), parental education (Supplemental Figure 2) and race/ethnicity (Supplemental Figure 3). Results were consistent

across all demographic groups, with period effects indicating increasing frequent cannabis use after 2005, with a lower magnitude of increase for adolescents in more recent birth cohorts.

Demographic Associations with Cannabis Use Across Time

As adolescent cannabis use has had periods of both increase and decrease between 1991-2018(40), we divided the data into three time periods, broken up by decade, to analyze demographics of frequent cannabis use (Table 1). Tests of interaction by decade indicated substantial variation in reports of frequent cannabis use. Gender differences remained relatively stable over time, with a slight increase in disparity between the 1990s and 2000s, and a slight decrease in disparity between the 2000s and 2010s. In the 1990s, Black students were less likely to report frequent cannabis use in comparison to White students, in the 2000s the strength of the effect decreased (from OR 0.67 to 0.76), and by the 2010s there was no significant difference between White and Black student frequent cannabis use; these interactions are significant as shown in Table 1. Students who had higher parental education were increasingly less likely to report frequent cannabis use compared to students with lower parental education (from OR 0.80 to 0.66), showing a diverging difference in use by parental education status ($p < 0.01$ for interactions between decades). Lastly, within each decade each additional year of age was associated with higher odds of frequent cannabis use. In comparison to 13 year olds, 16-18 year old students were increasingly more likely to be frequent cannabis users over time (16 year old OR: 4.35 to 5.05; 17 year old OR: 5.66 to 7.44; 18 year old OR: 5.57 to 8.01; $p<0.01$), showing another divergence over time.

Sensitivity analysis

To examine the robustness of our results we repeated the analysis with two alternative frequency cut points, one with a lower threshold for frequent use (3 or more times in the past month), and one with a higher threshold for frequent use (10 or more times in the past month). For both alternate cut points, results replicated the main results presented (Supplemental Table 4), with significant change in deviance for age, drift, period and cohort. Supplemental Figure 4 illustrates the age, period, and cohort effects at the alternative cutpoints, which again are consistent with the main analysis using 6+ times in the past month as the cutpoint. This indicates that while higher cutpoints of cannabis use frequency have lower prevalence, the trends over time are still consistent.

Further, trends in the demographic associations with frequent cannabis use were consistent across cutpoints (Supplemental Table 5). By gender, we see a growth in disparity between the 1990s and 2000s followed by a decrease in disparity between the 2000s and 2010s. The convergence of frequent use between Black and White students seen in the main analyses is shown in both the lower and higher cutpoints of frequent use, where Black students were less likely to report frequent cannabis use compared to White students, where the magnitude of odds ratios decreased showing a growing convergence. Over time, students who had higher parental education were less likely to report frequent cannabis use in comparison to students with lower parental education, where the magnitude of odds ratios increased showing a growing difference. Lastly, in comparison to 13 year olds, 17 and 18 year olds having increasingly higher odds of being frequent using these additional cut points, although not significant in the higher level of frequency cut point.

Discussion:

Over the past three decades, the prevalence of frequent cannabis use – using six or more times in the past 30 days - among 16 to 18 year old students has increased; age-period-cohort analyses indicate that the trends in frequent cannabis use are driven by both period and cohort effects. Since 2005 there has been a positive period effect of frequent cannabis use, indicating that there are overall shifts upward in frequent cannabis use for all ages. Simultaneously, there is a negative cohort effect, suggesting that the largest increases in frequent cannabis use are observed among older rather than younger cohorts; that is, frequent cannabis use is increasing more rapidly among those born before 1995 than those born after 1995. Observed trends are consistent across sex, parental education, and, race/ethnicity and across different cutpoints for the definition of "frequent" cannabis use, a term that is inconsistently defined in the literature (41–44). While trends are consistent even when stratified by demographic groups, the relationship between demographic groups and frequent cannabis use are themselves shifting across time. The prevalence of frequent cannabis use is converging by race/ethnicity and sex and diverging by parental education and age across time, which is consistent with previous research showing a complete convergence in use between Black and White students (25), a shrinking gap in use between boys and girls in the most recent decade(26), and a growing gap in cannabis use across age over the past 3 decades(3). To our knowledge, ours are the first data to suggest that cannabis use differences by socio-economic status among US adolescents are growing over time, indicative of the potential for an emerging health disparity.

These results have substantial implications for understanding the etiological factors that underlie changes in prevalence over time of cannabis use. The increases in frequent cannabis use during a time period in which overall cannabis use has also been slightly increasing across the past decade, suggests that prevention and intervention regarding cannabis use among youth remains an important public health

priority. Adolescents are increasingly less likely to report that cannabis use is a great risk to health(45), suggesting that acceptance of cannabis use and tolerance regarding use may underlie, at least in part, the increases in prevalence and period effects observed, and the cohort effects suggesting that older adolescents are driving much of the increase in frequent use. Repeated heavy exposure to cannabis during adolescence is hypothesized to alter brain development(46–48), and has been associated with poor educational outcomes(13,49–51), and cognitive impairment(52,53). Cohort effects observed in the present study suggest that the greatest increases in frequent cannabis use are occurring among older birth cohorts compared with younger birth cohorts. While intervention and prevention should be universally directed at all adolescents, particular attention to adolescents in the later years of high school are warranted.

Our analyses are consistent with and extend previous research. First, previous research shows in general, non-Hispanic White students are more likely to be frequent cannabis users(44) with a converging rate of frequent cannabis use among racial/ethnic groups(25,54). The convergence by racial/ethnic groups may be due to in part to the increased prevalence of blunt smoking, which is more common among Black and older youths(55); this is consistent with the increased rates of cannabis use disorder, which are most common among young Black men compared to other racial/ethnic groups(54). Given that Black and other minority youth are increasing overall cannabis use prevalence(25), outpacing other racial/ethnic groups, these results in totality suggest that attention to increasing use among minority youth is increasingly critical to the health of minority adolescents. Second, period effects are underlying increases in cannabis use across a variety of previously published analyses across recent historical time periods focused primarily on adults (16,22). Similar to other age-period-cohort analyses, we find that cohort effects are additional predictors of cannabis use prevalence across time independent of period effects. Miech and Koester (22) suggested that post-World War II cohorts, especially those within the baby boom,

have higher rates of cannabis use throughout the lifecourse compared with other cohorts. We did not examine data among adults, but add to this literature by also documenting cohort effects among current generations of adolescents, especially older adolescents, which may portend higher rates as these students progress into adulthood.

Socioeconomic status has varied associations with substance use in adolescence, with several studies suggesting that adolescents from high socioeconomic status families are more likely to use(44,56). Our results suggest that frequent cannabis use is more common among students with low parental education, suggesting that while students with high parental education may be more likely to experiment, those in lower economic positions may be more likely to use frequently. Other work suggests that high socioeconomic status young adults have heavier patterns of cannabis use during the transition to adulthood(44,56), indicating that associations between socioeconomic status and cannabis may shift across the life course. Further, low socioeconomic status is consistently associated with cannabis and other drug use(57), but due to the growth in income inequality in the United States(58) there is a discernible increasing divergence in cannabis use between high and low economic adolescents.

Limitations should be noted. The data are self-reported and adolescents may misreport their frequency of cannabis use; relatedly, there may be changes over time in the willingness of adolescents to report cannabis use. However, the trends in MTF correspond to other large national surveys(1), suggesting that self-report is a reliable proxy for overall patterns of use. The MTF survey is administered in schools and does not include adolescents who have dropped out of high school, who are more likely to be cannabis users (51,59), suggesting that the estimates reported here cannot be generalized for non-school-attending youth. However, we would anticipate that frequent use of cannabis would be greater among those in older age groups if drop-outs were observed, which would expand the age differences

observed here. School drop-outs by 8th and 10th grade are rare in the US(40,60). MTF samples three grades, and thus age variation is limited, and further, we do not observe adolescents at the same age in different grades, which again limits generalizability. Lastly, the APC models used in the present analysis do not provide the causal predictors of the age, period, and cohort effects, an important direction for future research.

Mitigating these limitations are substantial strengths. Monitoring the Future is nationally representative with large sample sizes, and has been conducted in the 8th, 10th, and 12th grades for over 25 years with time invariant procedures and measures, which allows for a robust long-term assessment of the trends in frequent cannabis use. Additionally, our sensitivity analyses show that our results are consistent across definitions of frequent use, as well as across sex, parental education and race/ethnicity.

This work has public health relevance to the goal of reducing health disparities in the United States. The protective effect of race/ethnicity is dissipating, and differences between those at lower socioeconomic positions compared to high as well as between younger and older students, are diverging. As income inequality increases in the US, intervention and prevention for marginalized groups will become increasingly relevant for public health. When this growing income inequality is combined with the continuous decrease in perceived harm of cannabis use(61), the amelioration of health disparities should remain at the forefront of intervention and policy changes.

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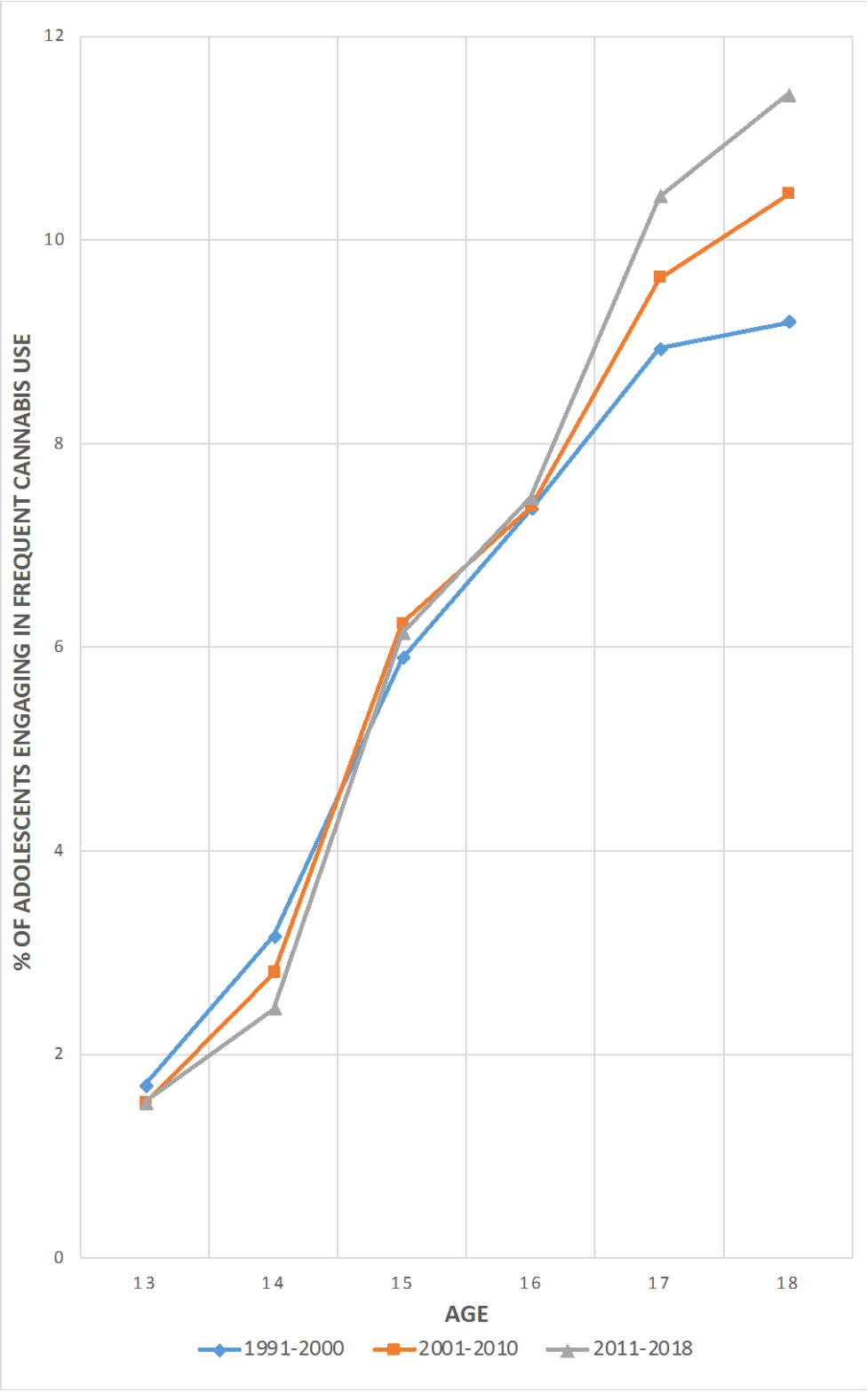
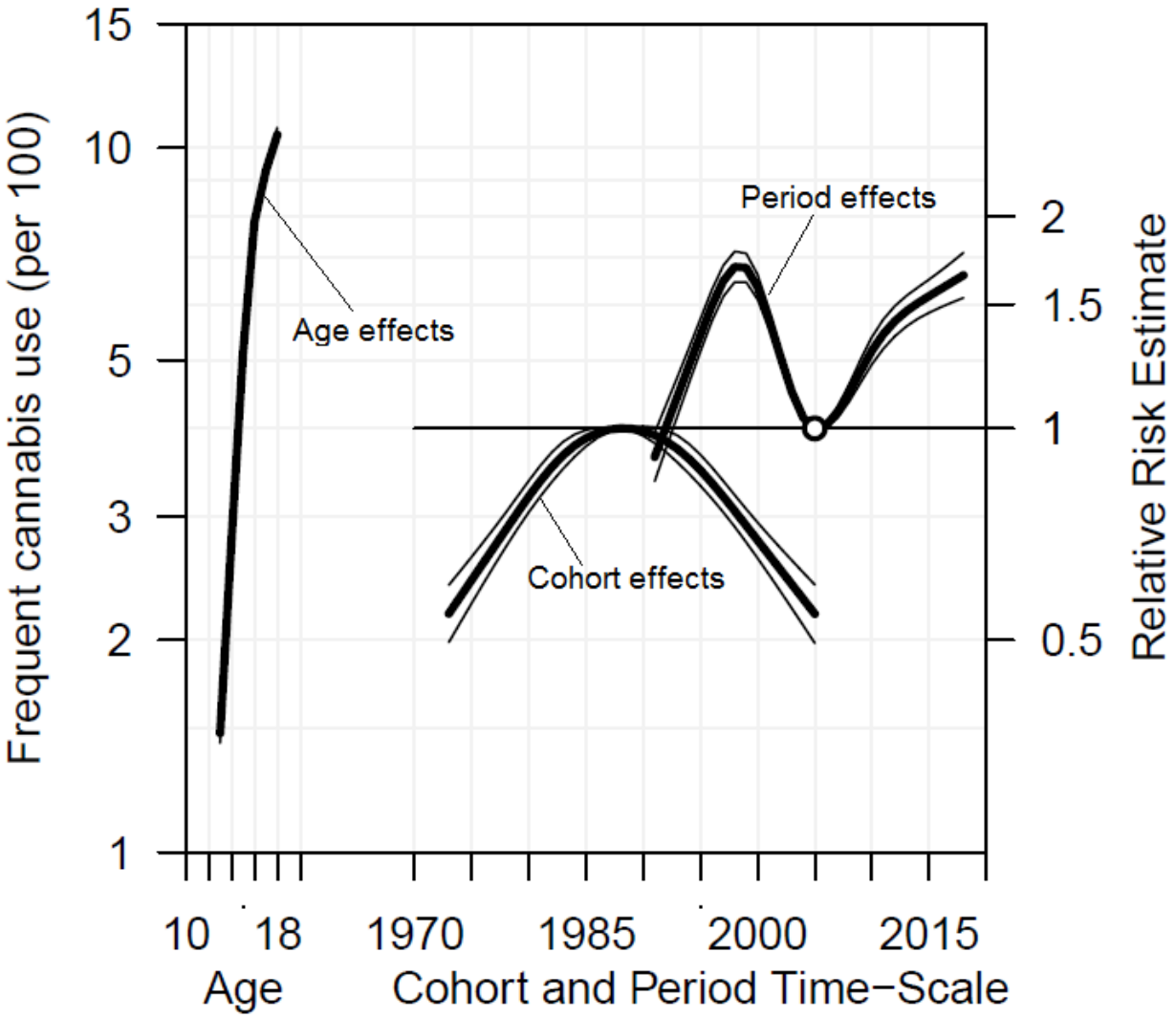
Figure 1. Percentage of adolescents engaging in frequent cannabis use* by age and time period



* Frequent cannabis use defined as 6+ occasions of use in the past 30 days

Figure 2. Age, period, and cohort effects on frequent cannabis use from 1991 to 2018 (N=1,236,159)



* Frequent cannabis use defined as 6+ occasions of use in the past 30 days

Note: The cohort and period time-scale contains relative risk estimates for the effect of cohort (left line) and period (right line). Thin lines indicate 95% confidence intervals. The cohort estimates are compared to a referent cohort, 1988, thus the lines can be interpreted as the average proportion of US students' frequent cannabis use, regardless of time period, compared to the average proportion in 1988. The period estimates are compared to a referent period of 2005, thus the lines can be interpreted as the average proportion of US students' frequent cannabis use in that year, regardless of cohort, compared to the average proportion in 2005.

Table 1. Odds ratios for association between demographic variables and frequent cannabis use, by time period

		1991-2000	2001-2010	2011-2018	Interactions		
	n	472,092	439,849	324,218			
					91_00 vs 01_10	**00_10 vs 11_18**	**91_00vs 11_18**
Gender	Male	1	1	1			
	Female	0.57 (0.55-0.58)	0.53 (0.52-0.55)	0.57 (0.55-0.59)	*	**	N/S
Race/ ethnicity	White	1	1	1			
	Black	0.67 (0.64-0.70)	0.76 (0.73-0.80)	1.03 (0.98-1.09)	***	***	***
	Hispanic	1.02 (0.98-1.07)	0.80 (0.77-0.84)	0.90 (0.86-0.94)	***	***	***
	Others	0.92 (0.88-0.96)	0.87 (0.84-0.91)	1.04 (0.99-1.08)	N/S	***	***
Parent educ.	HS or less	1	1	1			
	College more	0.80 (0.78-0.82)	0.70 (0.68-0.72)	0.66 (0.64-0.68)	***	**	***
Age	13	1	1	1			
	14	1.76 (1.64-1.90)	1.77 (1.63-1.93)	1.51 (1.36-1.66)	N/S	*	*
	15	3.54 (3.32-3.79)	4.28 (3.97-4.62)	4.16 (3.80-4.56)	***	N/S	**
	16	4.35 (4.07-4.64)	4.91 (4.56-5.30)	5.05 (4.62-5.52)	*	N/S	**
	17	5.66 (5.31-6.03)	6.87 (6.38-7.40)	7.44 (6.81-8.13)	***	N/S	***
	18	5.57 (5.22-5.94)	7.19 (6.68-7.74)	8.01 (7.34-8.74)	***	N/S	***

N/S: not significant, * $p < .05$, ** $p < .01$, *** $p < .001$

Note: 95% confidence intervals are in parentheses.

Supplemental Table 1. Model fit statistics for age-period-cohort model on adolescent frequent cannabis use, by gender

Model parameter	Change in deviance (degrees of freedom)		
	All	Male	Female
Age	-	-	-
Age-drift	210.1 (1)***	99.2 (1)***	110.6 (1)***
Age-cohort	2612.5 (3)***	1715.3 (3)***	985.7 (3)***
Age-period-cohort	576.6 (3)***	373.1 (3)***	215.3 (3)***
Age-period	-218.1 (-3)***	-140.9 (-3)***	-70.3 (-3)***
Age-drift	-2971.0 (-3)***	-1947.5 (-3)***	-1130.7 (-3)***

*** $p < .001$

Note: cohort and period effects are iteratively added and then removed at each subsequent line. For example, the first parameter included is age, and subsequently drifted is added; the improvement in model fit by adding drift is then assessed. Positive coefficients indicate improvements in model fit with each additional parameter; negative coefficients indicate reduction in model fit with the removal of each parameter. Adding and removing each parameter is significant, indicating that all three terms are necessary for the best model fit.

Supplemental Table 2. Model fit statistics for age-period-cohort model on adolescent frequent cannabis use, by parent education

Model parameter	Change in deviance (degrees of freedom)	
	Lower Parental Education: High school or less	Higher Parental Education: College or more
Age	-	-
Age-drift	262.5 (1)***	10.6 (1)**
Age-cohort	1291.6 (3)***	1196.9 (3)***
Age-period-cohort	263.7 (3)***	288.2 (3)***
Age-period	-71.7 (-3)***	-159.1 (-3)***
Age-drift	-1483.7 (-3)***	-1326.0 (-3)***

*** $p < .001$

Note: cohort and period effects are iteratively added and then removed at each subsequent line. For example, the first parameter included is age, and subsequently drifted is added; the improvement in model fit by adding drift is then assessed. Positive coefficients indicate improvements in model fit with each additional parameter; negative coefficients indicate reduction in model fit with the removal of each parameter. Adding and removing each parameter is significant, indicating that all three terms are necessary for the best model fit.

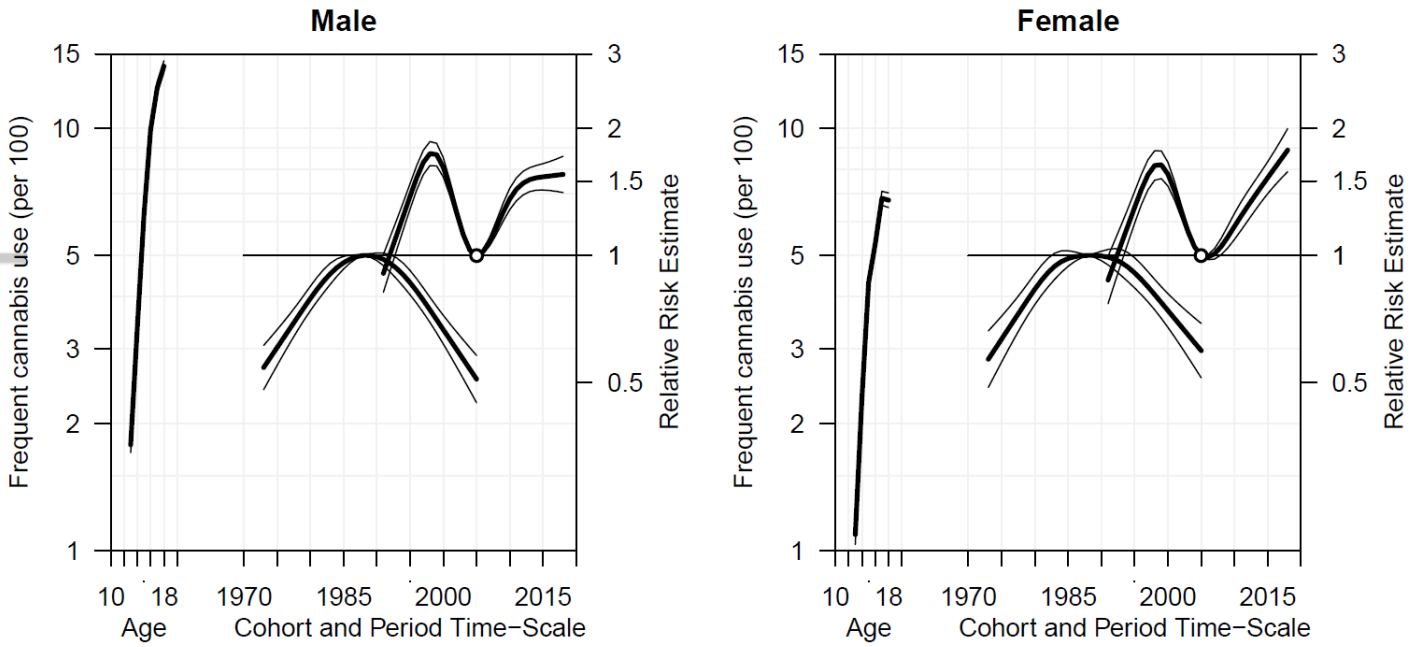
Supplemental Table 3. Model fit statistics for age-period-cohort model on adolescent frequent cannabis use, by race/ethnicity

Model parameter	Change in deviance (degrees of freedom)			
	Black	White	Hispanic	Others
Age	-	-	-	-
Age-drift	345.2 (1)***	65.1 (1)***	0.2 (1)	44.4 (1)***
Age-cohort	398.6 (3)***	1794.4 (3)***	371.9 (3)***	218.6 (3)***
Age-period-cohort	86.6 (3)**	544.7 (3)***	56.5 (3)***	42.3 (3)***
Age-period	-48.9 (-3)**	-189.2 (-3)***	-82.1 (-3)***	-37.1 (-3)***
Age-drift	-436.4 (-3)***	-2149.9 (-3)***	-346.3 (-3)***	-223.7 (-3)***

** $p < .01$, *** $p < .001$

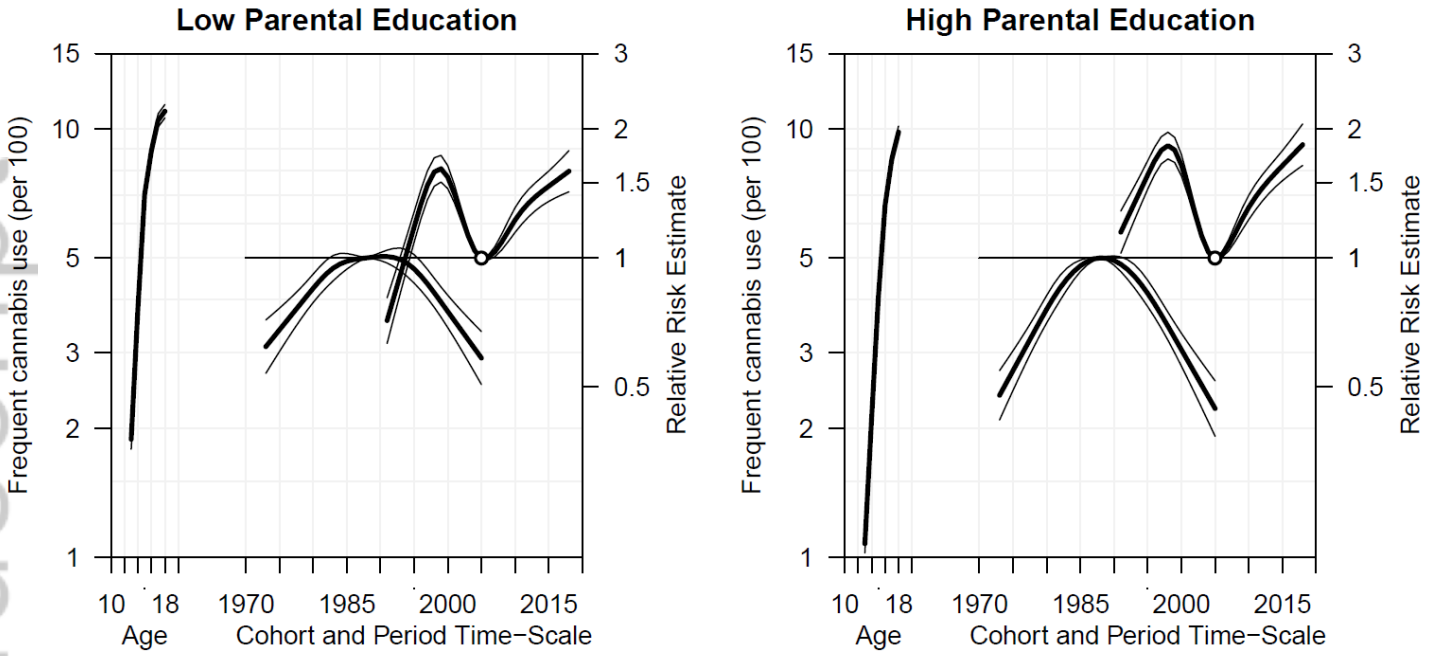
Note: cohort and period effects are iteratively added and then removed at each subsequent line. For example, the first parameter included is age, and subsequently drifted is added; the improvement in model fit by adding drift is then assessed. Positive coefficients indicate improvements in model fit with each additional parameter; negative coefficients indicate reduction in model fit with the removal of each parameter. Adding and removing each parameter is significant, indicating that all three terms are necessary for the best model fit.

Supplemental Figure 1. Age, period, and cohort effects on the probability of adolescents reporting frequent cannabis use from 1991 to 2018, by *gender*



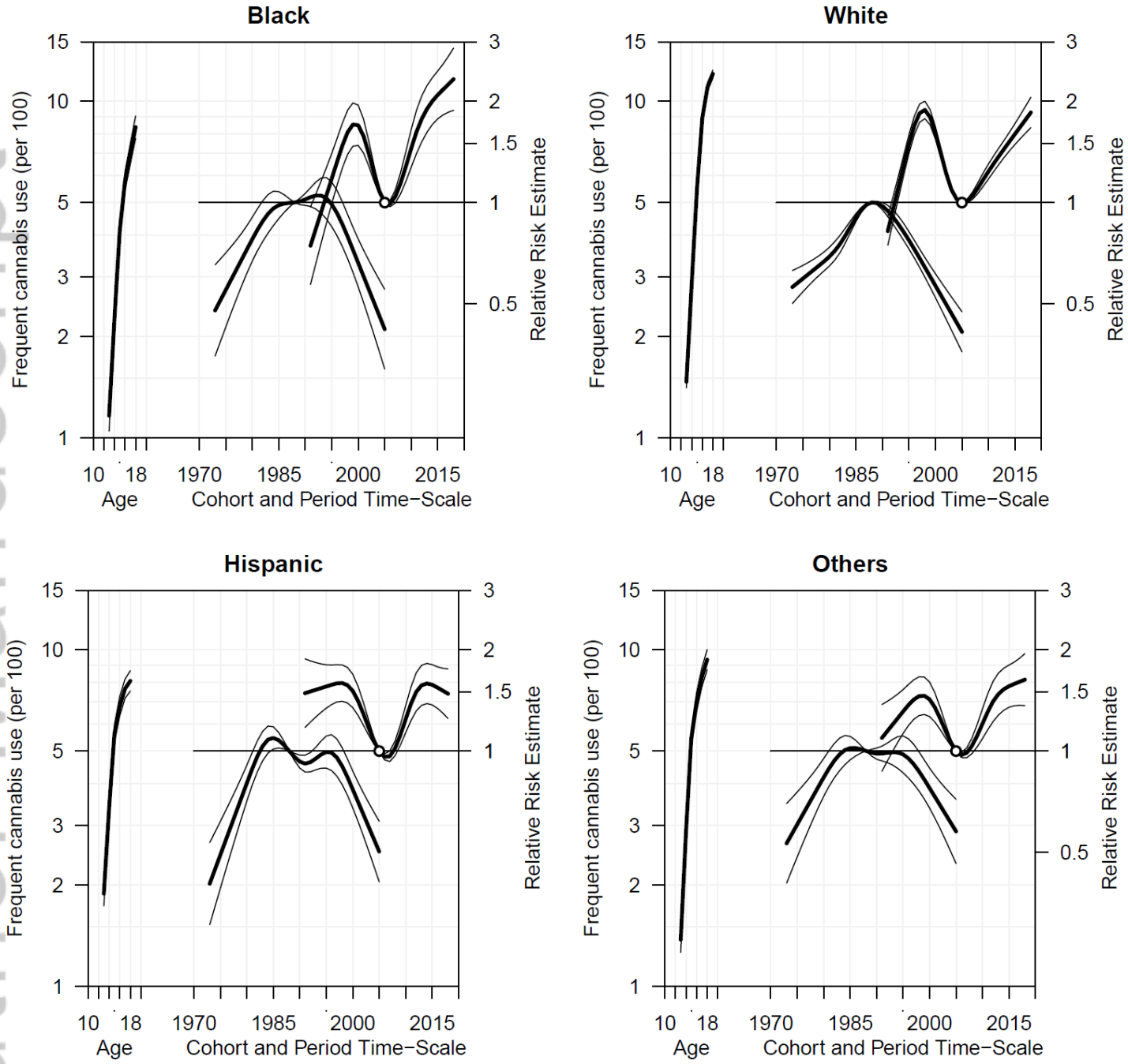
* Frequent cannabis use defined as 6+ occasions of use in the past 30 days

Supplemental Figure 2. Age, period, and cohort effects on frequent cannabis use* from 1991 to 2018, by low (both parents less than high school) and high (both parents more than high school) parental education



* Frequent cannabis use defined as 6+ occasions of use in the past 30 days

Supplemental Figure 3. Age, period, and cohort effects on the probability of adolescents reporting frequent cannabis use from 1991 to 2018, by *race/ethnicity*



* Frequent cannabis use defined as 6+ occasions of use in the past 30 days

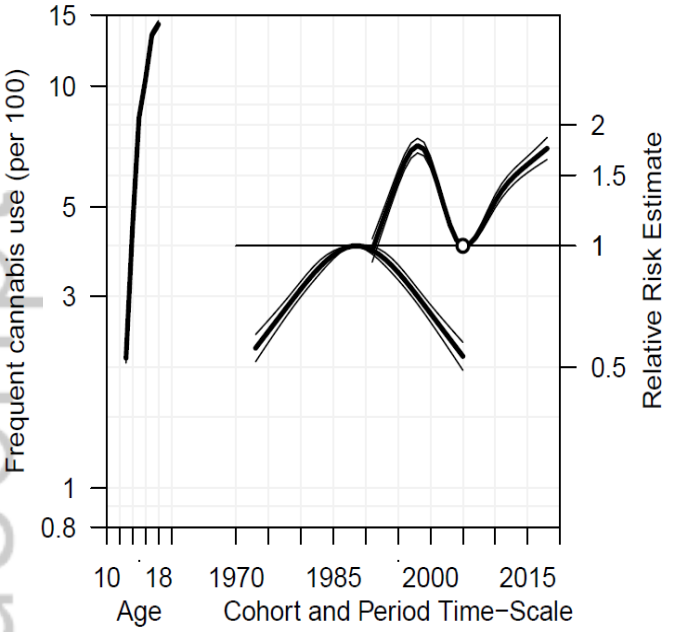
Supplemental Table 4. Model fit statistics for age-period-cohort model with alternative cut points

Model parameter	Change in deviance (degrees of freedom)	
	Lower level of frequency (3 or more cannabis use in the last 30 days)	Higher level of frequency (10 or more cannabis use in the last 30 days)
Age	-	-
Age-drift	146.0 (1)***	352.1 (1)***
Age-cohort	3107.0 (3)***	2104.2 (3)***
Age-period-cohort	874.0 (3)***	448.3 (3)***
Age-period	-306.0 (-3)***	-96.1 (-3)***
Age-drift	-3675.0 (-3)***	-2456.5 (-3)***

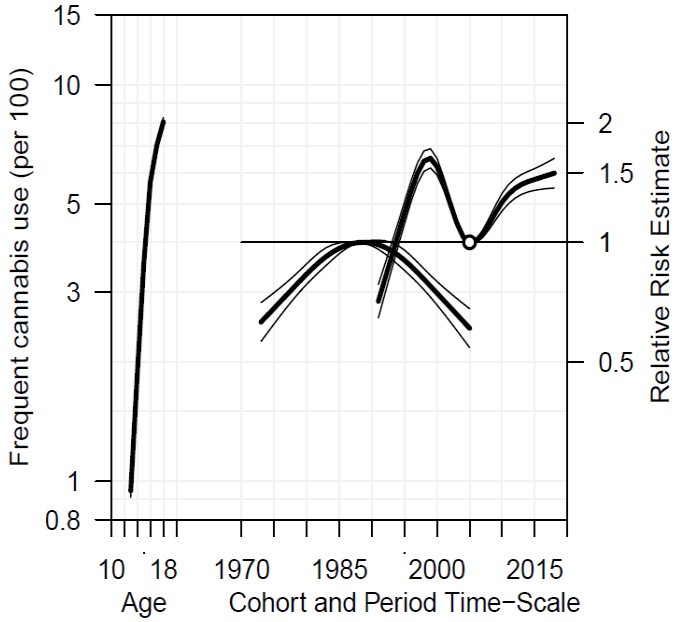
*** $p < .001$

Note: cohort and period effects are iteratively added and then removed at each subsequent line. For example, the first parameter included is age, and subsequently drifted is added; the improvement in model fit by adding drift is then assessed. Positive coefficients indicate improvements in model fit with each additional parameter; negative coefficients indicate reduction in model fit with the removal of each parameter. Adding and removing each parameter is significant, indicating that all three terms are necessary for the best model fit.

Supplemental Figure 4. APC sensitivity analyses on the probability of adolescents reporting frequent cannabis use with alternative cut points



(a) Lower level of frequency
(3 or more cannabis use in the last 30 days)



(b) Higher level of frequency
(10 or more cannabis use in the last 30 days)

Supplemental Table 5. Sensitivity analyses on the association between demographic variables and probability of frequent cannabis use with alternative cut points

(a) Lower level of frequency (3 or more cannabis use in the last 30 days)

		1991-2000	2001-2010	2011-2018	Interactions		
	n	472,092	439,849	324,218			
					91_00 vs 01_10	00_10 vs 11_18	91_00 vs 11_18
Gender	Male	1	1	1			
	Female	0.64 (0.62-0.65)	0.60 (0.59-0.62)	0.65 (0.63-0.67)	***	***	N/S
Race/ ethnicity	White	1	1	1			
	Black	0.68 (0.66-0.71)	0.78 (0.75-0.81)	1.06 (1.01-1.10)	***	***	***
	Hispanic	1.07 (1.03-1.10)	0.85 (0.82-0.88)	0.97 (0.94-1.01)	***	***	***
	Others	0.92 (0.89-0.95)	0.89 (0.86-0.92)	1.06 (1.02-1.10)	N/S	***	***
Parent educ.	HS or less	1	1	1			
	College more	0.84 (0.82-0.86)	0.73 (0.71-0.74)	0.69 (0.68-0.71)	***	*	***
Age	13	1	1	1			
	14	1.70 (1.61-1.80)	1.62 (1.52-1.73)	1.56 (1.44-1.69)	N/S	N/S	N/S
	15	3.27 (3.10-3.44)	3.88 (3.65-4.12)	4.08 (3.79-4.40)	***	N/S	***
	16	3.88 (3.69-4.09)	4.34 (4.09-4.60)	4.77 (4.43-5.12)	**	*	***
	17	4.86 (4.62-5.11)	5.87 (5.53-6.23)	6.74 (6.27-7.24)	***	**	***
	18	4.76 (4.52-5.01)	6.03 (5.68-6.39)	7.29 (6.79-7.83)	***	***	***

(b) Higher level of frequency (10 or more cannabis use in the last 30 days)

		1991-2000	2001-2010	2011-2018	Interactions		
	n	472,092	439,849	324,218			
					91_00 vs 01_10	00_10 vs 11_18	91_00 vs 11_18
Gender	Male	1	1	1			
	Female	0.50 (0.49-0.52)	0.47 (0.46-0.49)	0.51 (0.49-0.53)	**	**	N/S
Race/ ethnicity	White	1	1	1			
	Black	0.68 (0.64-0.71)	0.75 (0.71-0.79)	1.01 (0.95-1.06)	**	***	***
	Hispanic	0.99 (0.94-1.05)	0.75 (0.72-0.79)	0.85 (0.81-0.90)	***	***	***
	Others	0.92 (0.88-0.97)	0.86 (0.82-0.90)	1.02 (0.97-1.07)	N/S	***	**
Parent educ.	HS or less	1	1	1			
	College more	0.78 (0.76-0.80)	0.69 (0.67-0.71)	0.63 (0.61-0.65)	***	***	***
Age	13	1	1	1			
	14	1.89 (1.72-2.07)	1.83 (1.65-2.02)	1.56 (1.38-1.76)	N/S	N/S	*
	15	4.19 (3.84-4.57)	4.63 (4.21-5.08)	4.44 (3.98-4.96)	N/S	N/S	N/S
	16	5.26 (4.83-5.73)	5.45 (4.97-5.97)	5.34 (4.79-5.95)	N/S	N/S	N/S
	17	7.29 (6.70-7.92)	8.17 (7.46-8.95)	8.47 (7.61-9.42)	N/S	N/S	N/S
	18	7.42 (6.83-8.08)	8.49 (7.75-9.29)	9.13 (8.21-10.15)	N/S	N/S	*

N/S: not significant, * $p < .05$, ** $p < .01$, *** $p < .001$

Note: 95% confidence intervals are in parentheses.