

Adolescent Marijuana Use in the United States and Structural Breaks:
An Age-Period-Cohort Analysis, 1991 to 2018

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ABSTRACT

To investigate temporal patterns, socio-demographic gradients, and structural breaks in adolescent marijuana use in the United States from 1991 to 2018, we used hierarchical Age-Period-Cohort logistic models to separate temporal effects of marijuana use among 8th, 10th, and 12th graders from 28 waves of the Monitoring the Future survey. Structural breaks in period effects were further detected via a dynamic-programing-based method. Net of other effects, we found a clear age-related increase in the probability of marijuana use (10.46%, 23.17%, and 31.19% for 8th, 10th and 12th graders, respectively). Period effects showed a substantial increase over time (from 16.23% in 2006 to 26.38% in 2018), while cohort effects remained stable over the period of study. Risk of adolescent marijuana use varied by sex, racial group, family status, and parental education. Significant structural breaks during 1995-1996, 2006-2008, and 2011-2013 were identified in sub-populations. A steady increase in marijuana use among adolescents over the latter years of this time period was identified. Adolescents who were male, non-African American, lived in non-intact families, and who had less educated parents were especially at risk of marijuana usage. Trends of adolescent marijuana use changed significantly during times of macro events.

Keywords: Marijuana use, Age-Period-Cohort analysis, adolescent, structural break

Marijuana use during adolescence is a significant predictor for adverse public health consequences including higher risks of high-school dropout,¹ long-term cognitive impairments,² higher risks of other illicit drug uses,^{3,4} and clinical outcomes such as anxiety and depressive symptoms.⁵⁻⁷ Individuals who start to use marijuana during adolescence are two to four times more likely to develop cannabis dependence and addiction compared to adult users.⁸ There is also a link between adolescent marijuana use and other more common forms of substance use, such as alcohol drinking and cigarette smoking.^{9,10} Marijuana use during adolescence can be especially traumatizing because the brain is actively developing during this period.¹¹ Social disparities in adolescent marijuana use exist along socio-demographic lines including sex,¹² sexual orientation,¹³ racial identity,^{14,15} academic performance,¹⁶ family status,^{17,18} and socioeconomic status of the family.^{19,20}

A holistic view of temporal patterns of substance use warrants the separation of different sources of temporal clocks. Age effects refer to physiological, psychological, and behavioral changes attributable to human growth and aging. In general, the prevalence of marijuana use increases with age during adolescence.²¹ Period effects correspond to the concurrent impacts of social, economic and environmental circumstances on all age groups and birth cohorts at a particular time. Previous studies appear to suggest an increase in marijuana use in more recent years.^{12,22} Cohort effects refer to temporal variations across individuals who share a common life-course experience (e.g., birth and school enrollment). Existing research finds that cohort differences in adolescent marijuana use are possibly associated with different social norms across cohorts.¹⁵

The use of Age-Period-Cohort (APC) models allows scholars, policy makers, and practitioners to separate temporal effects associated with the aging process, socio-

environmental changes, and shared life experiences, which further reveals key drivers for marijuana and other substance use. Using APC models, Keyes et al. found a significant relationship between cohort disapproval and individual risk of marijuana usage.¹⁵ Huang et al. analyzed age, period, and cohort effects of prescription opioid and heroin overdose mortality in the United States. They found that baby boomers born between 1947 and 1964 experienced higher risks of death from overdose.²³ Keyes and Miech used the Intrinsic Estimator to separate age, period, and cohort effects, reporting decreasing period and cohort effects of heavy episodic drinking among American adolescents.²⁴

As suggested by Hamilton et al., analyses that use the APC model to examine marijuana use typically assess temporal patterns among adults.²⁵ Although several APC analyses have been conducted on young adults, the data are mostly outdated.²⁵ Using the Hierarchical Age-Period-Cohort (HAPC) model, we aim to present temporal trends of past-year marijuana use among adolescents from 1991 to 2018 and compare socio-demographic disparities in marijuana use among 8th, 10th, and 12th graders over time. Second, using a dynamic-programming-based econometric method, we further identify structural breaks in adolescent marijuana use across different socio-demographic groups, and examine whether macro social change such as economic recessions coincide with these time-series structural changes.

METHODS

Data

This research draws on twenty-eight waves (from 1991 to 2018) of data from the Monitoring the Future: A Continuing Study of the Lifestyle and Values of Youth (MTF), an ongoing national annual survey of school-aged adolescents in the United States. The MTF has conducted annual surveys of 12th graders since 1975, with 8th and 10th graders added to the survey in 1991. Since 1991, this survey annually invites approximately 50,000 students from the 8th, 10th, and 12th grades from around 420 public and private high schools nationwide to complete self-administered questionnaires. A three-stage random sampling strategy is used that involves the selections of geographic areas (stage 1), schools within each area (stage 2), and classes within each chosen school (stage 3). A school that declines to participate is replaced by another school with geographic and demographic similarities. Questions in the MTF survey cover multiple dimensions of students' life experience and risky behaviors, including mental health conditions, physical health, civic engagement, social activities, and substance use.

We analyzed surveys of 8th, 10th, and 12th graders from 1991 to 2018. We excluded students who did not report their past-year marijuana use, and performed five rounds of imputation based on a fully conditional specification logistic regression on observations with missing values on sex, race, family status, academic performance, and parental education background (see Appendix 2 for a comparison of results based on five imputed datasets and the pooled results).^{26,27} The multiple imputation was implemented using SAS PROC MI.²⁸ The sample was retrieved and compiled from 28 waves of cross-sectional data files released by the MTF survey team for public use (N=1,261,667).

Socio-demographic variables

We included variables of individual socio-demographic characteristics: race (African-American vs. non-African-American), sex (female vs. male), academic performance (B- and above vs. C+ and below), parental education (whether at least one parent had some college education), family status (intact family vs. single- or no-parent family), geographical regions of schools (north-central, south, west, northeast), and whether a respondent resided in a Metropolitan Statistical Area (MSA). A variable denoting the ethnicity (Hispanics or Latinos) of a subject was unavailable in the MTF until 2005 and was therefore excluded from the analysis. For individuals from the 28 survey waves and the 3 grade levels, age was approximated by adding 6 years to their grades, and birth cohort was calculated using the equation $\text{birth year} = \text{survey year} - \text{age}$.

Marijuana use

Individuals were asked on how many occasions they had used marijuana (including marijuana and hashish) in the past 12 months, with response categories of “0 occasions”, “1-2 times”, “3-5 times”, “6-9 times”, “10-19 times”, “20-39 times”, and “40 and above times”. We dichotomized response variables to measure the prevalence of marijuana use: individuals who reported “0 occasions” were coded as zero and those who reported having used marijuana at least once in the past 12 months were coded as one. Since substance use in the past 30 days is often considered in existing studies,^{29,30} we also included adolescent marijuana use in the past 30 days as an alternative outcome and re-analyzed the data using the same statistical procedure described below. Our key findings remain the same in the auxiliary analysis (see Appendix 4-6).

Statistical analysis

Age-period-cohort logistic model. We used hierarchical age-period-cohort (HAPC) logistic regression models to analyze the repeated cross-sectional MTF survey data.³¹ To address the perfect collinearity of three temporal effects (birth year = survey year – age), HAPC models consider age effect as an individual-level fixed effect while estimating the period and cohort effects as cross-classified random effects at the population-level using best linear unbiased predictors (BLUPs). The level-1 within-group model is:

$$\log\left(\frac{m_{ijk}}{1-m_{ijk}}\right) = \beta_{0,jk} + \beta_1 Grade8_i + \beta_2 Grade10_i + \beta_3 Sex + \beta_{4,j} Black_i + \beta_{5,j} IntactFamily_i + \beta_{6,j} ParentEducation_i + \sum_{q=7}^{11} \beta_q X_q$$

where m_{ijk} refers to the probability of marijuana use of the i^{th} adolescent from the k^{th} birth cohort in the j^{th} period year. Two dummy variables (8th graders and 10th graders, with 12th graders as reference) are used to denote grades. The X_q 's consist of control variables, including academic performance, geographical regions, and metropolitan areas. To consider random period effects of socio-demographic covariates (sex, race, family status, and parental education), the level-2 between-group models is:

Intercept: $\beta_{0,jk} = \gamma_0 + p_{0j} + c_{0k}$

Sex: $\beta_{3j} = \gamma_3 + p_{3j}$

Race: $\beta_{4,j} = \gamma_4 + p_{4,j}$

Family Status: $\beta_{5j} = \gamma_5 + p_{5j}$

Parental Education: $\beta_{6j} = \gamma_6 + p_{6j}$

where γ_0 refers to the mean averaged over 28 periods and 32 cohorts when all covariate variables and control variables at level 1 are held at zero; p_{0j} is the residual random effects of period j averaged over all birth cohorts; and c_{0k} is the residual random effects of cohort k averaged over all periods. We used SAS (PROC GLIMMIX) to conduct weighted HAPC analyses.³² Given existing debates about robustness of HAPC estimators with various cohort specifications,^{33,34} we also performed a sensitivity analysis with different groupings of birth cohorts. Our main conclusions are not altered by the sensitivity analyses (see Appendix 3 for period effects estimated based on 3-year and 5-year cohort groupings).

Estimating structural breaks in time series. We used structural change models to identify potential structural breaks in time series.³⁵ Structural change models draw on asymptotic distributions of change points to construct their corresponding confidence intervals (CI).³⁵ To do so, the optimal number of structural breaks with the lowest BIC (Bayesian information criterion) are first determined by the sup-Wald type test.³⁵ The location of a combination of structural breaks among all possible ones is determined by a dynamic programming algorithm that minimizes the sum of squared residuals of recursive least squares models.^{35,36} Structural change models were applied to the overall population and each sub-population and implemented in R package **strucchange**.^{37,38}

RESULTS

Temporal effects based on HAPC analyses

Predicted probabilities and corresponding odds ratios (and 95% CIs) estimated from HAPC analyses are reported in Table 1. We calculated the probabilities of marijuana use among adolescents using the equation $p = \frac{\text{odds ratio}}{1 + \text{odds ratio}}$ with other covariates being held at their sample means. A clear age-related increase in adolescent marijuana use is shown in Figure 1a: the predicted probabilities of marijuana use increased from 10.46% for 8th graders to 23.17% for 10th graders and 31.19% for 12th graders. The observation that the sharp increase in marijuana use in early adolescence slows down in late adolescence is consistent with previous studies.^{12,22} For cohort effects shown in Figure 1b), the predicted probabilities of marijuana use dipped to a low point in the 1976 cohort (probability=14.90%), followed by a steady increase in the subsequent cohorts, and peaked in the 1988 cohort (probability=24.03%), with a recent downward trend for the 1996 cohort and after (probability=20.86% for the 1996 cohort). Overall, cohort effects are relatively stable as compared with the temporal patterns of period and cohort effects.

In general, period effects show substantial variations over the period of study. To examine period effects associated with sub-populations, we also calculated predicted probabilities of marijuana use in sub-populations defined by sex, race/ethnicity, family status, and parental education. Adjusting for all socio-demographic characteristics, the probabilities of marijuana use for the overall population steadily increased since 1991 and peaked in 1996 (probability=29.15%). After a substantial decline until 2006 (probability=16.23%), the probabilities of marijuana use rose slowly with fluctuations and reached another peak in the most recent wave (probability=26.38% in 2018). Figure 1c shows sex disparities in adolescent marijuana use, where male adolescents demonstrated

higher probabilities of marijuana use than females did until a crossover occurred in 2016 (probability=22.17% for males, probability=22.23% for females). This convergence of sex disparities in marijuana use is consistent with existing findings that the sex gap in marijuana use among school-aged youth is diminishing.³⁹ As shown in Figure 1d, non-African-American adolescents showed higher prevalence rates of marijuana use than African-American adolescents. However, the African-American–non-African-American gap narrowed gradually after 2008 and almost vanished in 2013 (probability=24.13% for African-American, probability=24.70% for non-African-American). Adolescents from intact families constantly showed lower prevalence rates of marijuana use than their peers from non-intact families (see Figure 1e). A trivial educational disparity was observed for the 1991 to 1997 waves. Due to a sharper decline in marijuana use among adolescents with a college-educated parent, the educational disparity widened after 1997 but appeared to converge in more recent waves. Odds ratios and their corresponding 95% CIs estimated from HAPC logistic models are presented in Appendix 1.

[Figure 1a, 1b, 1c, 1d, 1e, 1f around here]

Structural breaks

In Figure 1c to 1f, significant structural breaks for the period effects of the general population are denoted by vertical dotted lines. It should be noted that for some time series with a peculiar temporal pattern, differences in the sums of squared residuals calculated based on both sides of a structural break might be too large to construct a meaningful

confidence interval.³⁶ As it happens, 99% confidence intervals are reported instead. Structural breaks are detected in 1996 (99% CI: 1995, 1997), 2007 (99% CI: 2006, 2008), and 2011 (99% CI: 2010, 2012) for the general population. We further identified structural breaks in the period trends (and 95% CIs) across sub-populations (see Table 1). Every socio-demographic group showed a significant structural break in 1995 or 1996. A significant break around 2006-2008 was also found for each sub-group but occurred one or two years earlier for these sub-groups with higher prevalence rates of marijuana use (male, non-African-American, adolescents living in non-intact families, and adolescents with less-educated parents). The most recent structural break for these socio-demographic groups happened in 2011 or 2013.

[Table 1 around here]

DISCUSSION

By compiling 28 waves of survey data from the MTF project, we examined temporal trends and socio-demographic disparities in adolescent marijuana use in the United States. The main findings of this study can be summarized as follows. Net of other effects, there is a strong age effect on marijuana use. Although the age-associated increase from 8th graders to 10th graders was greater than the increase from 10th to 12th graders, the monotonic age increase provides a driving force for adult marijuana use. Cohort effects appear to be more stable than age effects. Adolescents born in the 1980s showed the highest

prevalence rates of marijuana use, while the predicted probabilities of marijuana use for the most recent birth cohorts were gradually decreasing.

Period effects fluctuate over time but show a steady increase from the mid-2000s to the early 2010s, followed by fluctuations in the most recent waves. Period effects were also observed on the socio-demographic disparities in adolescent marijuana use. Adolescents who were male, non-African-American, lived in non-intact families, or had less-educated parents showed higher prevalence rates of marijuana use than did their counterparts. The convergence in sex disparities around 2016 and the crossover afterwards are particularly alarming, given the fact that marijuana use among female adolescents steadily increased in recent years. While previous research has found mixed results pertaining to racial/ethnic disparities in marijuana use, they tend to suggest that: 1) White and Hispanic adolescents report higher prevalence rates of marijuana use than do African-American adolescents;⁴⁰ and 2) the African-American vs. White gap of adolescent marijuana use has narrowed with the prevalence rates of African-Americans exceeding Whites at certain time points.³⁹ Consistent with these empirical findings, our analyses show that prevalence rates for African-American adolescents were constantly lower than non-African-American adolescents except for the 2013 wave. Living in intact families appears to be a protective factor against adolescent marijuana use over the period of study.¹⁷ Adolescents having a below-college-educated parent in general showed higher prevalence rates of marijuana use in recent years, which is also in line with existing studies.

Findings from structural-break models appear to suggest a link between the shifting socioeconomic environment in the United States and structural changes in adolescent marijuana use. In particular, we identified significant structural breaks in 2006-2008 and

2011-2013, which coincide with the 2007-2008 global financial crisis and the American debt-ceiling crisis in 2011 (“Black Friday”). The flat pattern of adolescent marijuana use until 2008 and the sudden upturns thereafter, along with the flattening trend since the last breakpoint, potentially reflect the social changes in various aspects during the recovery period of the economy from 2009 to 2013 and 2013 to 2018 in the American society. Adolescents and their parents from disadvantaged backgrounds may resort to substance use as a coping strategy during economic recessions.⁴¹ The loss of family income in precarious times could also reduce the purchase and use of gateway drugs including marijuana.⁴² Because parents may work longer to compensate for their decreased income, or on the contrary work less due to the loss of employment, changing patterns of parental supervision may help to explain the link between economic changes and marijuana use.⁴³ With the erosion of fiscal sources during economic recessions, local governments may cut expenditure on law enforcement or even create a marijuana-friendly environment (e.g., legalizing marijuana) to expand local fiscal revenues.^{44,45} Consequently, changes in local institutional arrangements will affect both the perception and accessibility of marijuana use. Third, the change of social norms and perceptions towards marijuana use may also contribute to the structural change of adolescent marijuana use, since the lower prevalence of aggregated disapproval and risk perception toward marijuana use among adolescents is associated with higher individual marijuana use.^{15,46} Policy changes, especially the state-level recreational/medical marijuana laws in the United States, may have led to the recent structural change of adolescent marijuana use.^{47,48} Although the repetitive temporal coincidence may render economic recessions a plausible explanation for changes in adolescent marijuana use, we cannot rule out the impacts of other competing mechanisms,

such as school bullying. The upward trend of adolescent marijuana use before the identified breakpoints in 1995-1996 also coincides with the peak of (violent) physical bullying in school from 1994 to 1996.⁴⁹ School bullying victims are more likely than non-victims to report substance use including marijuana, though the direction of causality is undetermined.^{50,51} A possible explanation is that individuals may choose substance use as a coping strategy against school bullying or social isolation by peers.⁵²

While our analyses are not capable of identifying causal mechanisms linking macro changes with adolescent marijuana use, socio-demographic disparities in temporal patterns across sub-groups do suggest that populations at risk (male, non-African-American, adolescents from non-intact families) were likely to be first affected by these macro events. The structural changes in adolescent marijuana use amid radical macro changes, especially for more vulnerable populations, deserve serious attention from policymakers, parents, and health professionals. Given the far-reaching impacts of the global pandemic of COVID-19 on various aspects of American society, we expect that a shifting pattern of adolescent marijuana use is underway.

Limitations of this research should be noted. First, high-school dropouts who are at higher risks of marijuana use were not included in the MTF survey due to its sampling strategy. Consequently, our estimation of adolescent marijuana use may be conservative. Second, this study would benefit from more detailed demographic information on race and ethnicity. The separate ethnic group *Hispanic/Latino* was not available in the public-use survey datasets until 2005. Existing studies show inconsistent empirical findings on ethnic differences in adolescent marijuana use but largely agree that Hispanic adolescents have relatively high prevalence rates of marijuana use.^{12,39} Likewise, non-African-Americans

represent a racially diverse group. More detailed information on one's racial/ethnic background should be considered in future studies to explore racial/ethnic heterogeneities in adolescent marijuana use. Third, we used school grades as a proxy for age because exact age information is unavailable in the dataset. Nevertheless, unless there is a serious mismatch between age and grade for students in these sampled secondary schools this approximation will not alter our main conclusions, including the strong age increase in adolescent marijuana use. Fourth, the dichotomization of ordered frequencies of marijuana use can result in a loss of information in regression analysis. Future studies may rely on ordered logistic regression models or, preferably, novel statistical models of grouped and right-censored counts for more efficient modeling of ordered frequencies.⁵³ Last but not the least, if the spatial location (e.g., state) of respondents and corresponding official statistics become available, information related to local economy, marijuana-related policies, and law enforcement should be incorporated to conduct more in-depth analysis of the relationship between local environment and adolescent marijuana use.

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Figure 1. Predicted Probabilities of Adolescent Past-year Marijuana Use in the United States via Hierarchical Age-Period-Cohort Logistic Regression Models, Monitoring the Future, 1991-2018. A) Age Effect; B) Cohort Effect; C) Male vs. Female; D) African American vs. Non-African American; E) Intact Family vs. Non-Intact Family; F) Parental College educated vs. Below College Educated.

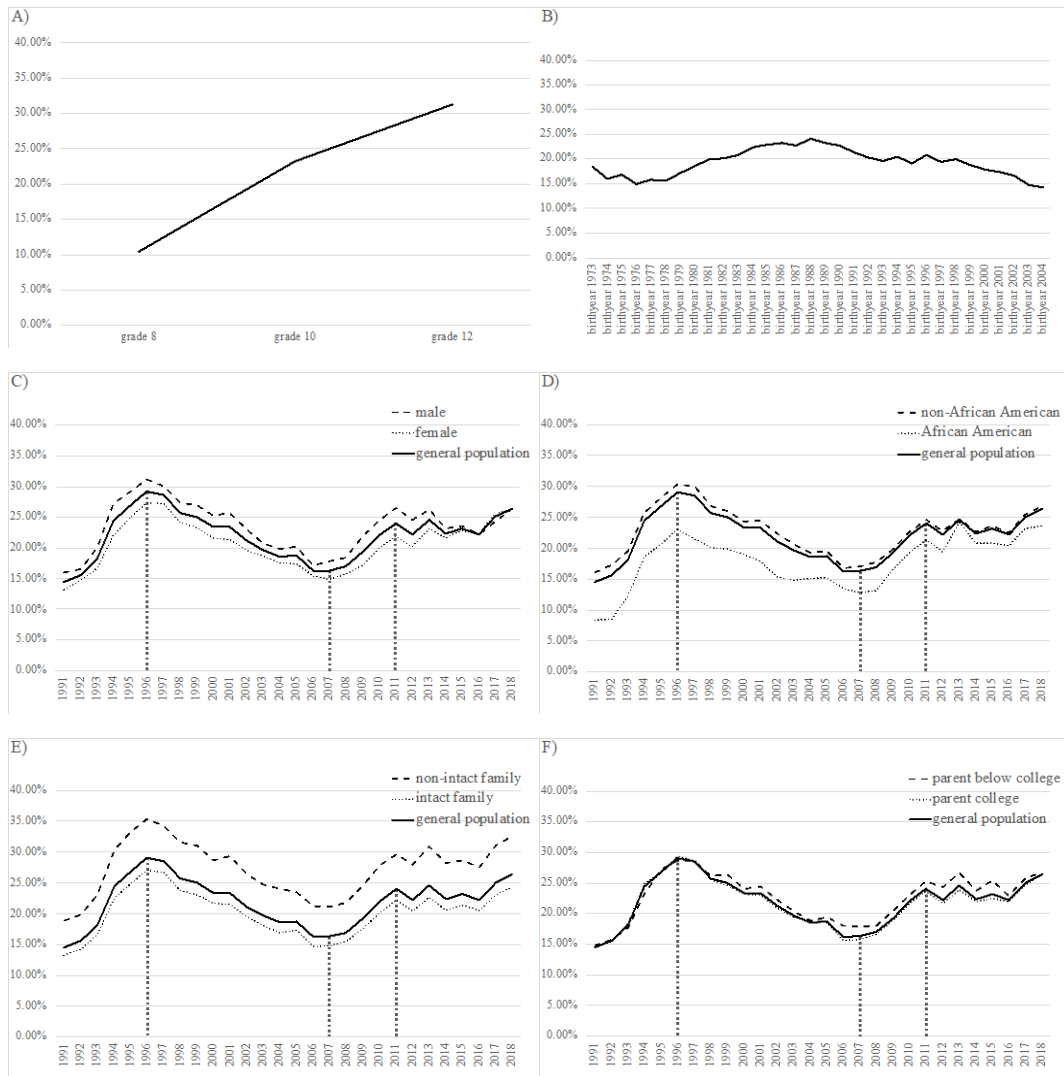


Table 1. Estimated Structural Breaks and Confidence Intervals in Period Effects of Adolescent Past-year Marijuana Use in the United States, Monitoring the Future, 1991 to 2018.

| | Break Points (in years) | 95% Confidence Interval ^a |
|------------------------------|--------------------------------|---|
| Sex | | |
| Male | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2011 | 2010, 2012 |
| Female | | |
| Female | 1996 | 1994, 1996 |
| | 2007 | 2006, 2008 |
| | 2011 | 2010, 2012 |
| Racial Identity | | |
| African-Americans | 1996 | 1995, 1997 |
| | 2008 | 2007, 2009 |
| | 2013 | 2012, 2016 |
| Non-African-Americans | | |
| Non-African-Americans | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2011 | 2010, 2012 |
| Residential Area | | |
| Intact family | 1995 | 1994, 1996 |
| | 2007 | 2006, 2008 |
| | 2011 | 2010, 2012 |
| Non-Intact family | | |
| Non-Intact family | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2015 |
| Parental Education | | |
| College | 1996 | 1995, 1997 |
| | 2007 | 2006, 2008 |
| | 2011 | 2010, 2012 |
| Below college | | |
| Below college | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2015 |

^a For the same reason stated above for the confidence intervals of general population, in our study, 95% confidence intervals cannot be produced for two sub-groups: adolescents living in intact families and adolescents with college educated parents. 99% confidence intervals are reported for these groups instead.

Appendix 1. Regression Results from Hierarchical Age-Period-Cohort Logistic Regression Analysis of Adolescent Past-year Marijuana Use in the United States, Monitoring the Future, 1991 to 2018.

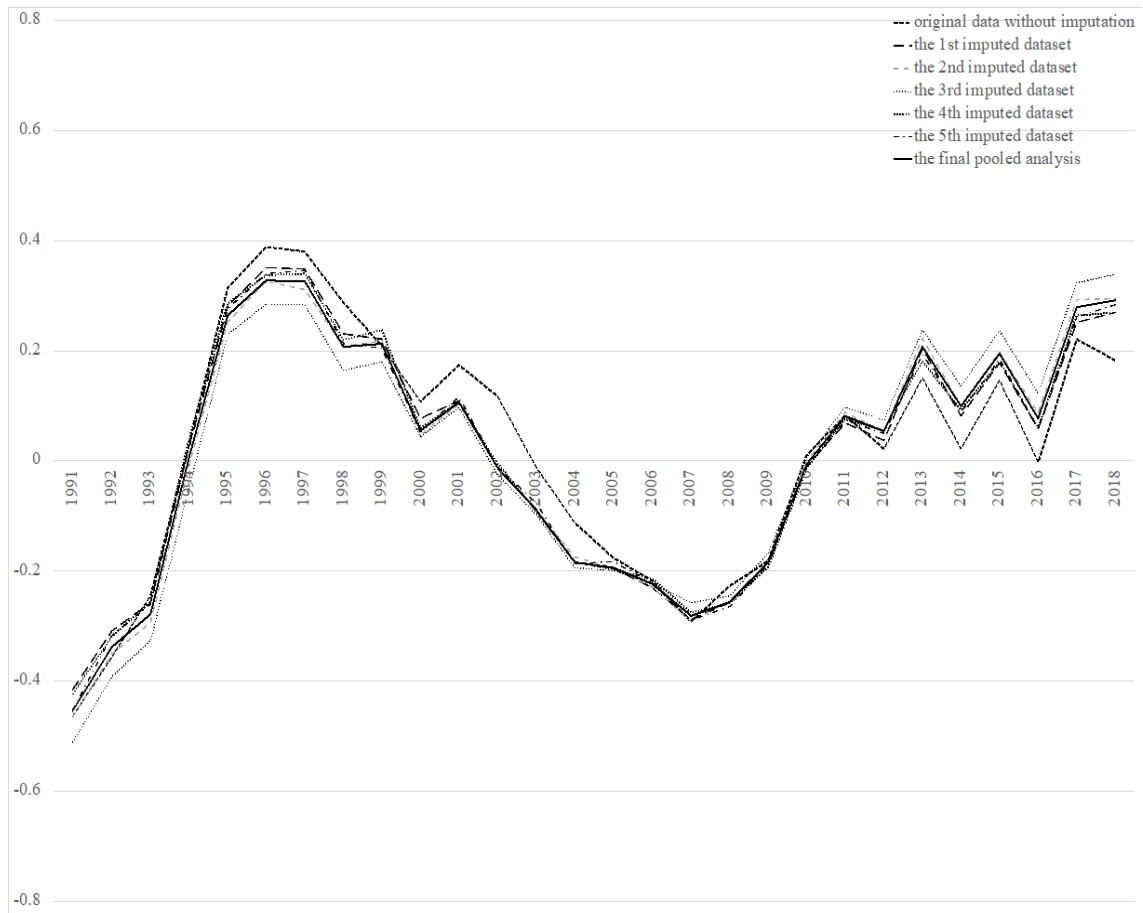
| | OR | 95% CI | | OR | 95% CI |
|------------------------------|------|------------|----------------------------|------|------------|
| <i>Fixed effects</i> | | | 2007 | 0.76 | 0.67, 0.85 |
| Intercept | 1.15 | 1.03, 1.29 | Male | 1.05 | 0.99, 1.11 |
| Grade 8 | 0.26 | 0.25, 0.27 | African American | 0.98 | 0.89, 1.08 |
| Grade 10 | 0.67 | 0.65, 0.68 | Intact family | 0.97 | 0.93, 1.01 |
| GPA | 0.46 | 0.45, 0.46 | Parental college education | 0.92 | 0.87, 0.97 |
| MSA | 1.15 | 1.13, 1.16 | 2008 | 0.77 | 0.69, 0.87 |
| North central region | 0.90 | 0.88, 0.91 | Male | 1.02 | 0.96, 1.08 |
| South region | 0.91 | 0.90, 0.92 | African American | 0.96 | 0.86, 1.07 |
| West region | 0.99 | 0.98, 1.00 | Intact family | 0.98 | 0.94, 1.02 |
| Male | 1.18 | 1.14, 1.23 | Parental college education | 0.96 | 0.91, 1.01 |
| African American | 0.73 | 0.68, 0.78 | 2009 | 0.83 | 0.74, 0.94 |
| Intact family | 0.67 | 0.66, 0.68 | Male | 1.14 | 1.08, 1.21 |
| Parental college education | 0.94 | 0.92, 0.97 | African American | 1.11 | 1.01, 1.22 |
| <i>Random period effects</i> | | | Intact family | 0.99 | 0.95, 1.03 |
| 1991 | 0.64 | 0.54, 0.75 | Parental college education | 0.96 | 0.91, 1.02 |
| Male | 1.06 | 1.00, 1.12 | 2010 | 0.99 | 0.88, 1.12 |
| African American | 0.66 | 0.57, 0.75 | Male | 1.09 | 1.03, 1.15 |
| Intact family | 0.98 | 0.94, 1.03 | African American | 1.12 | 1.01, 1.24 |
| Parent education | 1.03 | 0.97, 1.09 | Intact family | 0.99 | 0.95, 1.02 |
| 1992 | 0.71 | 0.61, 0.84 | Parental college education | 0.98 | 0.93, 1.03 |
| Male | 0.96 | 0.90, 1.03 | 2011 | 1.08 | 0.95, 1.23 |
| African American | 0.61 | 0.54, 0.69 | Male | 1.09 | 1.03, 1.15 |
| Intact family | 1.01 | 0.97, 1.05 | African American | 1.15 | 1.04, 1.27 |
| Parental college education | 1.04 | 0.98, 1.10 | Intact family | 1.02 | 0.98, 1.06 |
| 1993 | 0.76 | 0.65, 0.88 | Parental college education | 0.97 | 0.92, 1.03 |
| Male | 1.06 | 1.00, 1.12 | 2012 | 1.05 | 0.93, 1.20 |
| African American | 0.79 | 0.71, 0.88 | Male | 1.09 | 1.03, 1.15 |
| Intact family | 1.00 | 0.96, 1.04 | African American | 1.13 | 1.02, 1.24 |
| Parental college education | 1.11 | 1.05, 1.17 | Intact family | 0.99 | 0.95, 1.03 |
| 1994 | 1.01 | 0.86, 1.18 | Parental college education | 0.91 | 0.86, 0.97 |
| Male | 1.12 | 1.06, 1.18 | 2013 | 1.23 | 1.07, 1.42 |
| African American | 0.91 | 0.83, 1.00 | Male | 0.99 | 0.94, 1.05 |
| Intact family | 1.00 | 0.96, 1.04 | African American | 1.33 | 1.21, 1.47 |
| Parental college education | 1.16 | 1.10, 1.23 | Intact family | 0.98 | 0.95, 1.02 |
| 1995 | 1.30 | 1.14, 1.50 | Parental college education | 0.92 | 0.86, 0.97 |
| Male | 1.04 | 0.99, 1.10 | 2014 | 1.10 | 0.96, 1.27 |
| African American | 0.91 | 0.83, 1.00 | Male | 0.92 | 0.87, 0.98 |
| Intact family | 0.99 | 0.96, 1.03 | African American | 1.23 | 1.10, 1.38 |
| Parental college education | 1.04 | 0.98, 1.09 | Intact family | 0.98 | 0.94, 1.02 |
| 1996 | 1.39 | 1.21, 1.60 | Parental college education | 0.96 | 0.91, 1.02 |
| Male | 1.01 | 0.96, 1.06 | 2015 | 1.22 | 1.05, 1.41 |
| African American | 0.94 | 0.85, 1.04 | Male | 0.88 | 0.83, 0.93 |
| Intact family | 1.02 | 0.98, 1.05 | African American | 1.16 | 1.05, 1.29 |
| Parental college education | 1.10 | 1.04, 1.16 | Intact family | 1.02 | 0.98, 1.06 |
| 1997 | 1.38 | 1.21, 1.59 | Parental college education | 0.90 | 0.85, 0.95 |
| Male | 0.97 | 0.92, 1.02 | 2016 | 1.08 | 0.93, 1.26 |
| African American | 0.87 | 0.78, 0.98 | Male | 0.84 | 0.79, 0.89 |
| Intact family | 1.05 | 1.00, 1.10 | African American | 1.21 | 1.09, 1.33 |
| Parental college education | 1.07 | 1.02, 1.13 | Intact family | 1.02 | 0.98, 1.06 |
| 1998 | 1.23 | 1.08, 1.41 | Parental college education | 1.00 | 0.94, 1.07 |
| Male | 1.00 | 0.95, 1.05 | 2017 | 1.32 | 1.13, 1.55 |
| African American | 0.94 | 0.86, 1.04 | Male | 0.78 | 0.74, 0.83 |
| Intact family | 1.02 | 0.98, 1.06 | African American | 1.22 | 1.11, 1.34 |
| Parental college education | 1.03 | 0.98, 1.08 | Intact family | 1.00 | 0.96, 1.04 |
| | | | Parental college education | 1.00 | 0.95, 1.06 |

Table continues

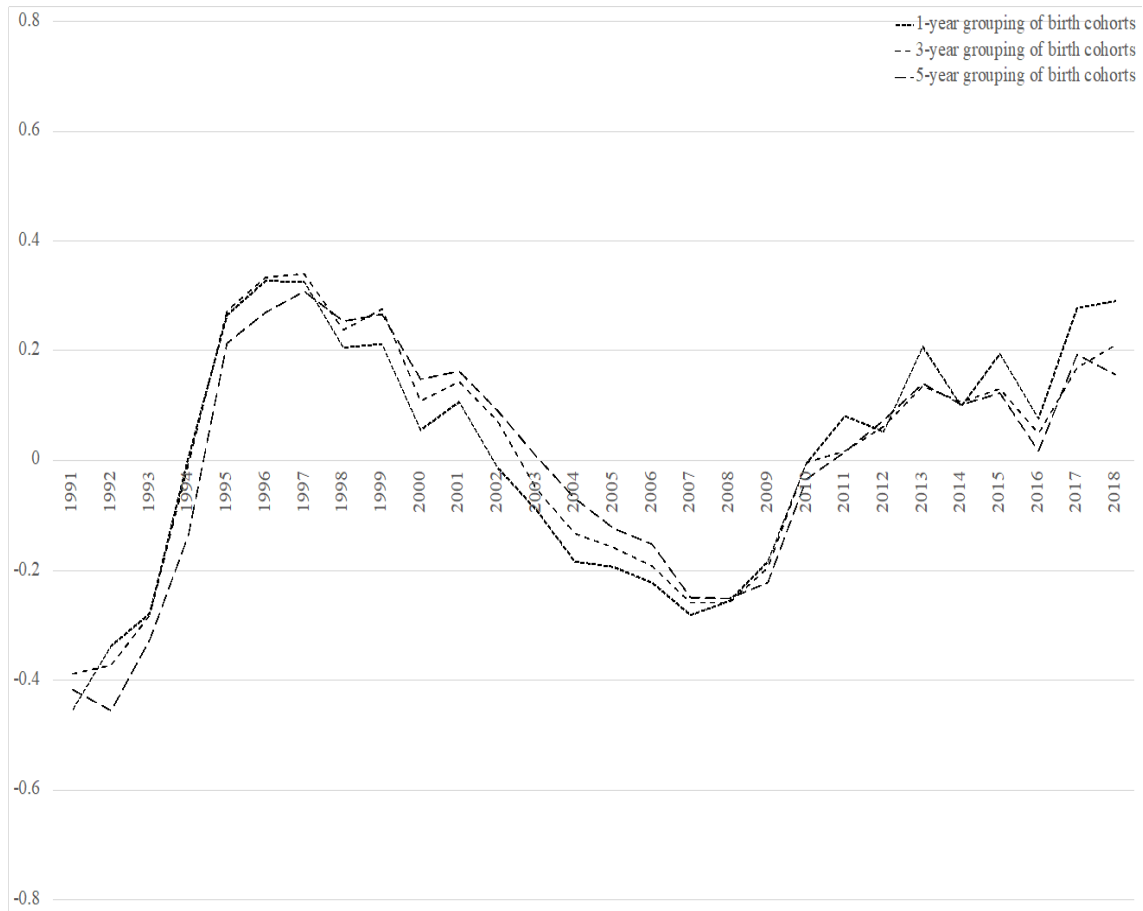
| | OR | 95% CI | | OR | 95% CI |
|----------------------------|------|------------|------------------------------|------|------------|
| 1999 | 1.24 | 1.09, 1.41 | 2018 | 1.34 | 1.14, 1.57 |
| Male | 1.03 | 0.97, 1.09 | Male | 0.85 | 0.80, 0.90 |
| African American | 0.97 | 0.87, 1.07 | African American | 1.16 | 1.05, 1.28 |
| Intact family | 1.00 | 0.96, 1.04 | Intact family | 1.00 | 0.97, 1.04 |
| Parental college education | 0.97 | 0.91, 1.02 | Parental college education | 1.04 | 0.98, 1.09 |
| 2000 | 1.06 | 0.93, 1.20 | <i>Random cohort effects</i> | | |
| Male | 1.04 | 0.98, 1.10 | birthyear 1973 | 0.96 | 0.82, 1.13 |
| African American | 1.00 | 0.91, 1.11 | birthyear 1974 | 0.81 | 0.69, 0.96 |
| Intact family | 1.03 | 0.99, 1.08 | birthyear 1975 | 0.86 | 0.75, 1.00 |
| Parental college education | 1.01 | 0.95, 1.07 | birthyear 1976 | 0.75 | 0.65, 0.86 |
| 2001 | 1.11 | 0.99, 1.25 | birthyear 1977 | 0.80 | 0.70, 0.91 |
| Male | 1.08 | 1.02, 1.14 | birthyear 1978 | 0.79 | 0.69, 0.89 |
| African American | 0.92 | 0.83, 1.02 | birthyear 1979 | 0.88 | 0.79, 0.99 |
| Intact family | 0.99 | 0.95, 1.03 | birthyear 1980 | 0.97 | 0.86, 1.09 |
| Parental college education | 0.98 | 0.92, 1.03 | birthyear 1981 | 1.06 | 0.95, 1.18 |
| 2002 | 0.99 | 0.88, 1.11 | birthyear 1982 | 1.08 | 0.97, 1.20 |
| Male | 1.03 | 0.98, 1.09 | birthyear 1983 | 1.12 | 1.02, 1.24 |
| African American | 0.86 | 0.78, 0.95 | birthyear 1984 | 1.23 | 1.12, 1.36 |
| Intact family | 1.01 | 0.98, 1.06 | birthyear 1985 | 1.27 | 1.15, 1.39 |
| Parental college education | 0.98 | 0.93, 1.04 | birthyear 1986 | 1.29 | 1.17, 1.41 |
| 2003 | 0.91 | 0.81, 1.03 | birthyear 1987 | 1.26 | 1.15, 1.38 |
| Male | 0.97 | 0.91, 1.02 | birthyear 1988 | 1.35 | 1.23, 1.48 |
| African American | 0.92 | 0.83, 1.02 | birthyear 1989 | 1.29 | 1.18, 1.41 |
| Intact family | 1.01 | 0.97, 1.05 | birthyear 1990 | 1.25 | 1.14, 1.37 |
| Parental college education | 1.00 | 0.94, 1.05 | birthyear 1991 | 1.16 | 1.05, 1.27 |
| 2004 | 0.83 | 0.74, 0.94 | birthyear 1992 | 1.08 | 0.99, 1.19 |
| Male | 0.97 | 0.92, 1.03 | birthyear 1993 | 1.04 | 0.94, 1.15 |
| African American | 1.02 | 0.92, 1.12 | birthyear 1994 | 1.10 | 0.99, 1.22 |
| Intact family | 0.97 | 0.93, 1.01 | birthyear 1995 | 1.01 | 0.90, 1.13 |
| Parental college education | 1.05 | 0.99, 1.10 | birthyear 1996 | 1.13 | 1.01, 1.26 |
| 2005 | 0.82 | 0.73, 0.93 | birthyear 1997 | 1.03 | 0.91, 1.16 |
| Male | 1.01 | 0.96, 1.07 | birthyear 1998 | 1.06 | 0.94, 1.20 |
| African American | 1.01 | 0.92, 1.12 | birthyear 1999 | 0.98 | 0.86, 1.12 |
| Intact family | 1.02 | 0.98, 1.06 | birthyear 2000 | 0.92 | 0.81, 1.05 |
| Parental college education | 1.00 | 0.95, 1.06 | birthyear 2001 | 0.89 | 0.77, 1.03 |
| 2006 | 0.80 | 0.71, 0.90 | birthyear 2002 | 0.85 | 0.74, 0.99 |
| Male | 0.96 | 0.90, 1.01 | birthyear 2003 | 0.73 | 0.62, 0.87 |
| African American | 1.05 | 0.94, 1.17 | birthyear 2004 | 0.71 | 0.60, 0.84 |
| Intact family | 0.96 | 0.92, 1.00 | | | |
| Parental college education | 0.90 | 0.85, 0.95 | | | |

Abbreviations: OR, odds ratio; CI, confidence interval.

Appendix 2. Period Effects of Past-year Adolescent Marijuana Use Estimated Based on Original Data without Imputation, Five Sets of Imputed Data, and The Pooled Imputed Data, Monitoring the Future, 1991 to 2018.



Appendix 3. Sensitivity Analysis: Period Effects of Past-year Adolescent Marijuana Use Estimated Using Different Groupings of Birth Cohorts, Monitoring the Future, 1991 to 2018.



Appendix 4. Predicted Probabilities of Adolescent Past-month Marijuana Use in the United States via Hierarchical Age-Period-Cohort Logistic Regression Models, Monitoring the Future, 1991-2018. A) Age Effect; B) Cohort Effect; C) Male vs. Female; D) African American vs. Non-African American; E) Intact Family vs. Non-Intact Family; F) Parental College educated vs. Below College Educated.



Appendix 5. Estimated Structural Breaks and Confidence Intervals in Period Effects of Adolescent Past-month Marijuana Use in the United States, Monitoring the Future, 1991 to 2018.

| | Break Points (in years) | 95% Confidence Interval |
|---------------------------|--------------------------------|--------------------------------|
| Sex | | |
| Male | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2011 | 2010, 2012 |
| Female | | |
| Female | 1996 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2014 |
| Racial Identity | | |
| African-Americans | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2015 |
| Non-African-Americans | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2014 |
| Residential Area | | |
| Intact family | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2014 |
| Non-Intact family | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2015 |
| Parental Education | | |
| College | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2015 |
| Below college | 1995 | 1994, 1996 |
| | 2006 | 2005, 2007 |
| | 2013 | 2012, 2015 |

Appendix 6. Regression Results from Hierarchical Age-Period-Cohort Logistic Regression Analysis of Adolescent Past-month Marijuana Use in the United States, Monitoring the Future, 1991 to 2018.

| | OR | 95% CI | | OR | 95% CI |
|------------------------------|------|------------|----------------------------|------|------------|
| <i>Fixed effects</i> | | | 2007 | 0.72 | 0.62, 0.82 |
| Intercept | 0.58 | 0.52, 0.66 | Male | 1.05 | 0.98, 1.12 |
| Grade 8 | 0.27 | 0.26, 0.28 | African American | 0.96 | 0.86, 1.08 |
| Grade 10 | 0.67 | 0.66, 0.68 | Intact family | 0.97 | 0.92, 1.02 |
| GPA | 0.44 | 0.44, 0.45 | Parental college education | 0.93 | 0.87, 0.99 |
| MSA | 1.14 | 1.13, 1.16 | 2008 | 0.73 | 0.64, 0.84 |
| North central region | 0.86 | 0.84, 0.87 | Male | 1.02 | 0.96, 1.09 |
| South region | 0.87 | 0.85, 0.88 | African American | 1.00 | 0.89, 1.12 |
| West region | 0.92 | 0.91, 0.94 | Intact family | 0.97 | 0.93, 1.02 |
| Male | 1.28 | 1.24, 1.33 | Parental college education | 0.99 | 0.93, 1.05 |
| African American | 0.75 | 0.70, 0.81 | 2009 | 0.80 | 0.70, 0.92 |
| Intact family | 0.66 | 0.64, 0.67 | Male | 1.15 | 1.08, 1.23 |
| Parental college education | 0.95 | 0.92, 0.97 | African American | 1.14 | 1.02, 1.28 |
| | | | Intact family | 1.01 | 0.96, 1.06 |
| <i>Random period effects</i> | | | Parental college education | 0.98 | 0.93, 1.05 |
| 1991 | 0.63 | 0.53, 0.75 | 2010 | 0.93 | 0.81, 1.06 |
| Male | 1.04 | 0.97, 1.12 | Male | 1.16 | 1.09, 1.23 |
| African American | 0.65 | 0.54, 0.77 | African American | 1.10 | 0.99, 1.23 |
| Intact family | 0.98 | 0.93, 1.03 | Intact family | 1.00 | 0.95, 1.04 |
| Parent education | 1.03 | 0.96, 1.10 | Parental college education | 1.01 | 0.96, 1.08 |
| 1992 | 0.74 | 0.62, 0.87 | 2011 | 1.06 | 0.92, 1.22 |
| Male | 0.91 | 0.85, 0.99 | Male | 1.13 | 1.06, 1.20 |
| African American | 0.60 | 0.52, 0.69 | African American | 1.23 | 1.11, 1.36 |
| Intact family | 0.99 | 0.94, 1.04 | Intact family | 1.02 | 0.97, 1.06 |
| Parental college education | 1.07 | 1.00, 1.14 | Parental college education | 0.99 | 0.94, 1.05 |
| 1993 | 0.75 | 0.64, 0.88 | 2012 | 1.05 | 0.91, 1.21 |
| Male | 1.10 | 1.03, 1.17 | Male | 1.06 | 0.99, 1.13 |
| African American | 0.81 | 0.72, 0.92 | African American | 1.14 | 1.02, 1.28 |
| Intact family | 1.03 | 0.97, 1.08 | Intact family | 0.99 | 0.95, 1.04 |
| Parental college education | 1.12 | 1.05, 1.20 | Parental college education | 0.94 | 0.88, 1.00 |
| 1994 | 1.12 | 0.96, 1.30 | 2013 | 1.21 | 1.04, 1.40 |
| Male | 1.15 | 1.08, 1.22 | Male | 0.98 | 0.92, 1.05 |
| African American | 0.95 | 0.86, 1.06 | African American | 1.36 | 1.22, 1.52 |
| Intact family | 0.99 | 0.95, 1.04 | Intact family | 0.99 | 0.94, 1.04 |
| Parental college education | 1.16 | 1.09, 1.24 | Parental college education | 0.94 | 0.88, 1.01 |
| 1995 | 1.35 | 1.17, 1.56 | 2014 | 1.08 | 0.93, 1.25 |
| Male | 1.01 | 0.95, 1.07 | Male | 0.94 | 0.88, 1.01 |
| African American | 0.91 | 0.81, 1.02 | African American | 1.15 | 1.03, 1.29 |
| Intact family | 1.01 | 0.96, 1.06 | Intact family | 0.97 | 0.92, 1.02 |
| Parental college education | 1.06 | 1.00, 1.12 | Parental college education | 0.96 | 0.90, 1.03 |
| 1996 | 1.52 | 1.32, 1.76 | 2015 | 1.19 | 1.02, 1.39 |
| Male | 0.95 | 0.90, 1.01 | Male | 0.88 | 0.82, 0.94 |
| African American | 0.92 | 0.83, 1.03 | African American | 1.26 | 1.13, 1.40 |
| Intact family | 1.03 | 0.98, 1.08 | Intact family | 1.01 | 0.97, 1.06 |
| Parental college education | 1.06 | 1.00, 1.12 | Parental college education | 0.91 | 0.85, 0.97 |
| 1997 | 1.42 | 1.24, 1.64 | 2016 | 1.05 | 0.90, 1.23 |
| Male | 0.98 | 0.92, 1.04 | Male | 0.89 | 0.83, 0.96 |
| African American | 0.87 | 0.77, 0.98 | African American | 1.23 | 1.11, 1.37 |
| Intact family | 1.05 | 1.00, 1.11 | Intact family | 1.01 | 0.96, 1.05 |
| Parental college education | 1.05 | 0.99, 1.11 | Parental college education | 1.01 | 0.95, 1.08 |
| 1998 | 1.30 | 1.13, 1.49 | 2017 | 1.38 | 1.17, 1.62 |
| Male | 0.97 | 0.92, 1.03 | Male | 0.79 | 0.74, 0.85 |
| African American | 0.91 | 0.81, 1.01 | African American | 1.22 | 1.09, 1.36 |
| Intact family | 1.01 | 0.96, 1.05 | Intact family | 0.99 | 0.94, 1.03 |
| Parental college education | 1.01 | 0.95, 1.06 | Parental college education | 1.00 | 0.94, 1.07 |

Table continues

| | OR | 95% CI | | OR | 95% CI |
|----------------------------|------|------------|------------------------------|------|------------|
| 1999 | 1.27 | 1.11, 1.46 | 2018 | 1.32 | 1.12, 1.55 |
| Male | 1.00 | 0.94, 1.06 | Male | 0.88 | 0.82, 0.94 |
| African American | 0.96 | 0.86, 1.08 | African American | 1.20 | 1.07, 1.34 |
| Intact family | 1.03 | 0.98, 1.08 | Intact family | 1.01 | 0.97, 1.06 |
| Parental college education | 0.96 | 0.91, 1.02 | Parental college education | 1.01 | 0.95, 1.07 |
| 2000 | 1.07 | 0.94, 1.23 | <i>Random cohort effects</i> | | |
| Male | 1.07 | 1.00, 1.13 | birthyear 1973 | 0.98 | 0.84, 1.15 |
| African American | 0.97 | 0.87, 1.08 | birthyear 1974 | 0.77 | 0.66, 0.90 |
| Intact family | 1.04 | 0.99, 1.09 | birthyear 1975 | 0.85 | 0.74, 0.98 |
| Parental college education | 0.97 | 0.91, 1.03 | birthyear 1976 | 0.70 | 0.61, 0.80 |
| 2001 | 1.12 | 0.98, 1.28 | birthyear 1977 | 0.77 | 0.68, 0.87 |
| Male | 1.07 | 1.00, 1.14 | birthyear 1978 | 0.74 | 0.65, 0.84 |
| African American | 0.88 | 0.76, 1.01 | birthyear 1979 | 0.84 | 0.75, 0.95 |
| Intact family | 1.00 | 0.96, 1.05 | birthyear 1980 | 0.92 | 0.82, 1.03 |
| Parental college education | 0.97 | 0.91, 1.03 | birthyear 1981 | 1.00 | 0.89, 1.12 |
| 2002 | 0.97 | 0.85, 1.11 | birthyear 1982 | 1.06 | 0.95, 1.19 |
| Male | 1.00 | 0.94, 1.07 | birthyear 1983 | 1.09 | 0.98, 1.22 |
| African American | 0.84 | 0.74, 0.94 | birthyear 1984 | 1.23 | 1.10, 1.37 |
| Intact family | 1.00 | 0.95, 1.04 | birthyear 1985 | 1.26 | 1.13, 1.39 |
| Parental college education | 0.98 | 0.92, 1.04 | birthyear 1986 | 1.31 | 1.18, 1.46 |
| 2003 | 0.92 | 0.81, 1.05 | birthyear 1987 | 1.29 | 1.16, 1.43 |
| Male | 1.00 | 0.94, 1.06 | birthyear 1988 | 1.41 | 1.27, 1.56 |
| African American | 0.93 | 0.83, 1.04 | birthyear 1989 | 1.34 | 1.21, 1.49 |
| Intact family | 1.00 | 0.95, 1.05 | birthyear 1990 | 1.29 | 1.16, 1.43 |
| Parental college education | 0.97 | 0.91, 1.03 | birthyear 1991 | 1.20 | 1.08, 1.34 |
| 2004 | 0.79 | 0.69, 0.90 | birthyear 1992 | 1.11 | 1.00, 1.24 |
| Male | 0.94 | 0.88, 1.00 | birthyear 1993 | 1.05 | 0.94, 1.17 |
| African American | 1.02 | 0.91, 1.13 | birthyear 1994 | 1.12 | 1.01, 1.25 |
| Intact family | 0.96 | 0.92, 1.01 | birthyear 1995 | 1.02 | 0.91, 1.14 |
| Parental college education | 1.05 | 0.99, 1.12 | birthyear 1996 | 1.15 | 1.02, 1.28 |
| 2005 | 0.75 | 0.66, 0.86 | birthyear 1997 | 1.03 | 0.91, 1.16 |
| Male | 1.04 | 0.98, 1.11 | birthyear 1998 | 1.12 | 0.99, 1.26 |
| African American | 0.93 | 0.84, 1.04 | birthyear 1999 | 0.97 | 0.86, 1.11 |
| Intact family | 1.03 | 0.98, 1.09 | birthyear 2000 | 0.94 | 0.83, 1.07 |
| Parental college education | 1.00 | 0.94, 1.06 | birthyear 2001 | 0.91 | 0.79, 1.05 |
| 2006 | 0.76 | 0.66, 0.87 | birthyear 2002 | 0.89 | 0.77, 1.03 |
| Male | 0.94 | 0.88, 1.00 | birthyear 2003 | 0.70 | 0.60, 0.82 |
| African American | 1.07 | 0.94, 1.22 | birthyear 2004 | 0.69 | 0.59, 0.81 |
| Intact family | 0.94 | 0.89, 0.99 | | | |
| Parental college education | 0.91 | 0.85, 0.97 | | | |

Abbreviations: OR, odds ratio; CI, confidence interval.