Gone with the Weed: Incidence of Adolescent Marijuana Use in the United States, 1976–2021

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Abstract

Purpose. This study sought to examine grouped and right-censored (GRC) counts of adolescent marijuana use, and estimate its temporal trajectories and sociodemographic disparities over almost half a century.

Methods. After compiling 46 waves of nationally representative data from the Monitoring the Future (MTF) study from 1976 to 2021 (sample size=491,348), we utilized an innovative modified Poisson (mixture) approach to analyze past-year marijuana use quantified by GRC counts.

Results. The overall reduction in incidence rates of marijuana use was attributable to an almost 40% reduction in the risk of marijuana use (with the proportion of at-risk adolescents at 51.36% in 1979 and 31.53% in 2021). Despite substantial changes over the study period, the recent incidence rates for at-risk individuals were similar to those in the early 1980s. Living in an intact family was a protective factor that shaped adolescent marijuana use over time.

Conclusions. The incidence rates of marijuana use among at-risk students, especially those from disadvantaged families, remained high over the study period. The modified Poisson (mixture) approach serves as the preferred tool for modeling GRC responses. It is essential to distinguish among risk, at-risk incidence, and overall incidence when assessing substance use and other risky behaviors.

Keywords: marijuana; modified Poisson regression; adolescent; incidence; grouped and right-censored count

List of Abbreviations:

MTF Monitoring the Future
GRC Grouped and right-censored

Introduction

Against the backdrop of a surge in adolescent abuse of stimulants,[1] opioids,[2] and other synthetic drugs[3] in recent decades, marijuana and other cannabis products remain the most popular intoxicating substances among adolescents and young adults in the United States.[4,5] An increasing number of state-level legislators have now started to see the use of legalized medical marijuana as a less harmful substitute for opioid use, and thus one that could help curb the opioid epidemic.[6] Clinical studies have nevertheless identified the onset of marijuana use during adolescence as a vital risk factor for adverse health conditions in adulthood, and they therefore support early prevention of, and intervention against, adolescent marijuana use.[7] Adolescents who are chronic marijuana users are prone to short- and long-term functional consequences, such as cognitive decrements,[8] neuropsychological abnormalities,[7,9] and psychiatric disorders.[9] Adolescent marijuana use also impairs one's academic and social life.

Researchers investigating the trends of adolescent marijuana use often focus on usage patterns since the 1990s and report a recent increase in marijuana use among American adolescents. For example, Gu et al. observed a substantial rise in marijuana use among middle and high school students from 2006 to 2018.[10] Keyes et al. stratified adolescents by their racial identities and found an increase in marijuana use among Black students from 2006 through 2015.[11] Marijuana use among adolescents appears to show an age-related increase, with high school seniors showing more frequent marijuana use than younger students.[10] Further, many late adolescents support the legalization and decriminalization of marijuana use,[12] which may facilitate their own marijuana use.[13] Adolescent marijuana use also displays salient disparities in sex,[14] racial identity,[11] and other sociodemographic characteristics.[15] Notably, one's family background affects adolescent marijuana use through multiple mechanisms, including parental

monitoring,[16] prenatal exposure,[17] parental drug use,[18] and familial economic resources.[19] Hoffman and colleagues examined disparities in marijuana use among adolescents growing up in intact versus single-parent households and found that living with both parents was a significant protective factor for reducing the risk of marijuana use.[19,20]

Social scientists and epidemiologists have long used grouped and right-censored (GRC) count responses to assess juvenile delinquency and substance use in surveys.[21] GRC counts are especially useful when dealing with recall bias if respondents are from vulnerable populations such as children, the elderly, or socially marginalized groups with reduced cognitive capacities.[21,22] GRC counts are also a convenient tool for collecting information on sensitive topics, especially when researchers are concerned about excessive missing values or overly conservative frequency reports.[21] Nationally representative surveys, including the National Longitudinal Study of Adolescent to Adult Health, Monitoring the Future (MTF), and the Youth Risk Behavior Survey, regularly employ survey instruments that use GRC counts to assess adolescent substance use.

Yet, the analysis of marijuana use, or more broadly, substance use, has been hampered by the absence of tools for modeling GRC counts. The common practice for analyzing GRC counts is to treat those counts as categories and apply (multinomial or ordered) logistic regression models instead of Poisson-based models.[23,24] This practice fails to use information embedded in count data, tends to underestimate behavioral frequencies of repeat users, and is not conducive to developing a comprehensive understanding of the sociodemographic gradients in substance use. Moreover, the traditional method enables only an estimate of the prevalence of substance use, such as the proportion or percentage of a population using marijuana, but not the incidence, which is the rate at which marijuana use occurs.[25] Recent studies have illustrated that the newly

developed modified Poisson mixture approach would allow researchers to conduct regression analysis of GRC counts via generalized linear models and hence solve the abovementioned methodological challenges. [21,26,27]

Using an innovative modified Poisson (mixture) approach to GRC counts,[26] this study uses 46 waves of the MTF datasets to estimate temporal trajectories and sociodemographic patterns of marijuana use among 12th graders in the United States.

Method

Data

We retrieved 46 waves of datasets from the nationally representative MTF study, for which the data were collected annually from 1976 to 2021. The MTF study interviews 8th, 10th, and 12th graders in American schools on various topics, including juvenile delinquency, substance use, attitudes and perceptions, and civic engagement.[1] The MTF study has surveyed around 16,000 12th graders from 133 public and private high schools annually since 1975 (with the public access data made available since 1976), and 8th and 10th graders were included beginning in 1991. Approximately 50,000 students in about 420 schools have now been interviewed annually. Since 12th graders are at greater risk of marijuana use and other risky behaviors, we restricted our analysis to this group, which also allowed for a much longer study period (1976 to 2021). We

[1] To obtain a nationally representative sample of students, the MTF study uses a multi-stage random sampling strategy that selects particular geographical areas (Stage 1), one or more schools in each selected area (Stage 2), and certain classes within each school (Stage 3). Respondents are interviewed in a classroom setting during school hours and are asked to complete a core questionnaire. They are also randomly assigned one of six sub-forms of the questionnaire focused on specific topics. School dropouts and students absent from class during the interviews are excluded from the survey.

assumed that data were missing at random (MAR) and imputed missing values using the fully conditional specification model in SAS PROC MI.

Measures

The outcome variable of past-year adolescent marijuana use was based on the survey question, "On how many occasions (if any) have you used marijuana (weed, pot) or hashish (hash, hash oil) during the last 12 months?" Its GRC response categories are: "0 occasions", "1–2 occasions", "3–5 occasions", "6–9 occasions", "10–19 occasions", "20–39 occasions", and "40 and above". We considered four control variables: sex (female vs. male), race (Black vs. non-Black), school region (northcentral, south, west, and northeast), and metropolitan statistical area. We also included four other variables to investigate sociodemographic gradients, and dichotomized those to have comparable sizes of effects.[28] The full-time mother variable indicates whether a respondent's mother was unemployed (coded as one). Those mothers who were sometimes/always employed were coded as zero. A student's school performance is measured by his/her grade point average (GPA). Those with B- or above were coded as one, while those with C+ or below were coded as zero. The MSA variable indicates whether a respondent lived in a metropolitan statistical area (MSA, coded as one) or not (coded as zero). The variable for parental college education indicates whether both parents were college-educated (coded as one) or not (coded as zero).[2] For one's family composition, a respondent living in a single- or no-parent family was coded as one. Those living in intact families were coded as zero.

[2] Most students, including those from single- or no-parent families, reported parental educational attainment. We imputed the missing values of parental educational attainment and then generated the variable for parental college education.

Statistical Models

To analyze the GRC counts of adolescent marijuana use, we implemented a recently proposed modified Poisson (mixture) approach via generalized linear models.[21,26] All analyses were implemented in R and weighted by the sampling weights provided by the MTF study. Covariates were centered by their sample means. The modified Poisson (mixture) approach can be illustrated as described below.

We considered a random variable Y to denote the count of marijuana use, which follows a Poisson distribution $\mathbf{Pois}(\mu)$ specified by a combination of covariates $\mathbf{X} = (1, X_1, \cdots, X_q)^T$ and their regression coefficients $\boldsymbol{\beta} = (\beta_0, \beta_1, \cdots, \beta_q)^T$ through the link function $\mu = \exp(\boldsymbol{\beta}^T \mathbf{X})$.[29] A GRC scheme partitions the set of all non-negative integers into $N \geq 2$ groups, and each group is a consecutive sequence of integers. We use group boundaries of a GRC grouping scheme $\mathrm{G} = \langle l_1, l_2, \cdots, l_{N+1} \rangle$ to denote one of its groups as $\{\text{integer } k : l_i \leq k \leq l_{i+1}\}$, where $0 = l_1 < 1 = l_2 < \cdots < l_{N+1} = \infty$. The left boundary l_2 of the second group is often set to 1 so that zero (e.g., 0 occasions) is included in a separate group. For example, our aforementioned GRC outcome variable can then be denoted as $\mathrm{G}^* = \langle 0, 1, 3, 6, 10, 20, 40, \infty \rangle$ with N=7. An observation of marijuana use in GRC counts has a categorical distribution $Y_{\mathrm{G}} \sim \mathbf{M}(\theta_1^{\mathrm{G}}, \cdots, \theta_N^{\mathrm{G}})$ over the N groups so that the probability of a group is the combined probability masses of $\mathbf{Pois}(\mu)$:

$$\mathbf{Prob}(Y_{\mathrm{G}} = j) = \theta_j^{\mathrm{G}} = \theta_j^{\mathrm{G}}(\mu) = \sum_{k=l_j}^{l_{j+1}-1} e^{-\mu} \frac{\mu^k}{k!}, \; j = 1, 2, \cdots, N.$$

The modified Poisson mixture model breaks the overall GRC counts into the proportion of individuals at risk of p (using a binomial model) and their GRC counts λ (using the Poisson

model). If we assume that the exact count of marijuana use follows a zero-inflated Poisson distribution $Y \sim \mathbf{ZIP}(p,\lambda)$,[29] we have:

$$\mathbf{Prob}(Y=k)=\begin{cases}(1-p)+pe^{-\lambda}, & k=0,\\ pe^{-\lambda}\dfrac{\lambda^k}{k!}, & k\geq 1.\end{cases}$$

Correspondingly, the observation of marijuana use in GRC counts follows a categorical distribution $Y_{\mathrm{G}} \sim \mathbf{M}(\pi_1^{\mathrm{G}},\cdots,\pi_N^{\mathrm{G}})$ with $\mathbf{Prob}(Y_{\mathrm{G}}=j)=\pi_j^{\mathrm{G}}$ for $1\leq j\leq N$, where:

$$\pi_j^{\mathrm{G}}=\pi_j^{\mathrm{G}}(\lambda,p)=\begin{cases}1-p+pe^{-\lambda}, & j=1,\\ p\displaystyle\sum_{k=l_j}^{l_{j+1}-1}e^{-\lambda}\frac{\lambda^k}{k!}, & 2\leq j\leq N.\end{cases}$$

To model the proportion at risk of p in the binomial part, we also used the logistic link function $p=\dfrac{1}{1+\exp\left(-\boldsymbol{\gamma}^{\mathrm{T}}\mathbf{U}\right)}$ with the set of variables $\mathbf{U}=(1,U_1,\cdots,U_s)^T$ and their corresponding regression coefficients $\boldsymbol{\gamma}=(\gamma_0,\gamma_1,\cdots,\gamma_s)^T$. The modeling of the Poisson part in the modified Poisson mixture regression is the same as that in the modified Poisson regression. A hybrid line search algorithm was implemented to obtain estimates of the modified Poisson (mixture) models.

Results

Table 1 presents the descriptive statistics of the original sample of 491,348 12th graders.[3] Almost two-thirds (61.88%) of respondents did not use marijuana over the previous 12 months.

[3] The descriptive statistics after multiple imputations (results available upon request) were similar to those presented in Table 1.

Yet, more than a quarter of the respondents reported using marijuana on two or more occasions, and heavy users (40 and above occasions) accounted for almost one-tenth of the sample (9.16%). About one-half (51.59%) of respondents were female and over one-tenth (12.30%) of them were Black. Less than one-third (32.88%) of the students were from the south region and even fewer (16.60%) were from the west. Most students (77.11%) interviewed lived in a metropolitan area. Students with college-graduate parents, who were living with a full-time mother, and who grew up in a non-intact family accounted for 22.51%, 21.09%, and 24.95% of the sample, respectively, over the study period. Most students had GPAs above B- (78.29%).

Table 2 shows estimates of the incidence rate ratios and odds ratios from the modified Poisson (mixture) regression. Results from the modified Poisson regression suggest that female (0.643 [95% CI 0.641–0.646], p<0.00001) and Black students (0.654 [95% CI 0.650–0.657] p<0.00001) reported significantly fewer incidents of marijuana use than did their counterparts. Marijuana-use incidents were not significantly different for students in the northcentral area compared to those in the west, while students in the south showed the lowest incidence rate of marijuana use, at 0.883 (95% CI 0.880–0.886, p<0.00001), compared to students in the other regions. The use of marijuana was much more frequent in metropolitan areas, with an incidence rate ratio of 1.180 (95% CI 1.177–1.183, p<0.00001). Having a full-time mother (0.880 [95% CI 0.875–0.884], p<0.00001), better school performance (0.560 [95% CI 0.558–0.562], p<0.00001), and college-educated parents (0.991 [95% CI 0.986–0.995], p<0.00001) were all protective factors against more frequent marijuana use. Students living in single- or no-parent families reported significantly more incidents of marijuana use, with an incident rate ratio of 1.241 [95% CI 1.219–1.265], p<0.00001).

For the binomial part of the modified Poisson mixture regression, males, non-Black students, students in the northeast and west, those residing in metropolitan areas, and those living in non-intact families were exposed to significantly greater risks of marijuana use than their counterparts. Having a full-time mother (0.809 [95% CI 0.799–0.820], p<0.00001) and better school performance (0.545 [95% CI 0.539–0.552], p<0.00001) were protective factors that significantly lowered the risk of the exposure to marijuana use. Marijuana use risks did not significantly vary for students with different parental education levels (OR=1.007 [95% CI 0.993–1.020], p=0.325 for college-educated parents). Conclusions based on the Poisson part of the modified Poisson mixture regression are similar to those based on the modified Poisson regression. The only exception is that students in the west showed a significantly lower incident rate ratio (0.980 [95% CI 0.976–0.984], p<0.00001).

In terms of the size of effect, Table 2 shows that the effects of school performance and family composition were larger than other sociodemographic variables. Because a student's family background also constitutes a more fundamental condition for his/her social and school life,[30] these results suggest that family composition plays a key role in shaping adolescent marijuana use. We also estimated the incidence in the overall population (Figure 1), the risks (Figure 2), and the incidence for at-risk individuals (Figure 3), according to family composition. These estimates were calculated based on the effects of survey years (available upon request), while other covariates were held at their sample means. To adjust for temporal anomalies across the survey waves, we implemented a three-point moving average procedure to smooth all three trajectories in Figures 1 to 3. In Figure 1, the overall incidence of adolescent marijuana use in the past year dropped substantially, from a peak of 9.15 incidents in 1978 to a nadir of 2.42 incidents in 1991. It then increased again and reached a second peak in 1998, with 5.41 incidents.

Afterward, the overall incidence rates leveled off, albeit with some fluctuations. Those from non-intact families consumed marijuana more frequently than their counterparts throughout the study period, with the smallest gap in 1991 (2.75 and 2.30 incidents for students from non-intact families and intact families, respectively). Nevertheless, this disparity in marijuana use by family composition increased after 1991 and has remained steady in more recent waves. The family composition disparity grew rapidly after the beginning of the COVID-19 pandemic and reached its widest point in 2021, with students from non-intact families reporting 6.24 incidents and those from intact families reporting 3.50 incidents.

Figure 2 presents the proportions of students at risk of marijuana use (or risks of adolescent marijuana use at the individual level),[31] which we estimated based on the results from the binomial part of the modified Poisson mixture regression. Similar to the trend of the incidence rates shown in Figure 1, the proportions of at-risk students showed a sharp decline after peaking at 51.36% in 1979, reached a nadir of 23.71% in 1992, then rebounded to 38.14% in 1998. Although the risk of marijuana use dropped substantially after the onset of the COVID-19 pandemic, from 35.02% in 2019 to 31.53% in 2021, the trajectory of the risk has been relatively flat in more recent waves. Likewise, we discovered a disparity in the risk of adolescent marijuana use based on family composition. Adolescents from non-intact families consistently showed a higher risk of marijuana use than those from intact families. The disparity has continued to increase in more recent years, with the largest gap in 2021. In that year, the percentages of students at risk were 38.61% and 29.06% for non-intact families and intact families, respectively.

Figure 3 shows the incidence rates of at-risk students, which we estimated based on results from the Poisson part of the modified Poisson mixture regression. As expected, the incidence rates of at-risk students were much higher than those of the general population. The at-

risk incidence rates first reached a nadir in the early 1990s (10.88 incidents in 1991), then increased substantially until the early 2000s (15.03 incidents in 2002), fluctuating somewhat in more recent years. Despite the substantial changes over the last four decades, the at-risk incidence rate in 2021 (14.52 incidents) is similar to the rate in 1983 (14.42 incidents). A disparity also persists in the at-risk incidence rates based on family composition. At-risk students from non-intact households consistently showed higher incidence rates of marijuana use than their counterparts from intact families. Moreover, we observed that the gap grew wider after the early 1990s, with the family structural gap reaching its widest point during the pandemic. In 1993, at-risk students from non-intact families on average reported 1.18 more consumption incidents than their counterparts (with at-risk students from non-intact families reporting 13.02 incidents and those from intact families reporting 11.85 incidents in the preceding year). However, in 2021, the gap rose to 4.57 incidents, with at-risk students from non-intact families on average reporting 17.92 incidents of smoking marijuana, compared to 13.35 incidents for their counterparts.

Discussion

Using 46 waves of datasets from the MTF study, we estimate the incidence of adolescent marijuana use and its sociodemographic gradients in the United States from 1976 to 2021. This study draws on an innovative modified Poisson (mixture) approach to estimate the overall incidence rates, risks, and at-risk incidence rates. We find that males, non-Black students, students from the northeast school region, and urban students were significantly associated with higher levels of incidents and risks of marijuana use. In terms of sociodemographic variables, the protective effects of living in an intact family and having better school performance were more

pronounced than the presence of a full-time mother and having college-educated parents. Based on our analysis of the data, we conclude that one's family composition is an important context that helps researchers understand adolescent marijuana use over the last four decades. In particular, individuals from non-intact families consistently showed higher risks of marijuana use and more frequent consumption than those from intact families, and that gap has grown in more recent years (particularly during the COVID-19 pandemic). Consistent with previous studies,[19,20] we therefore argue that more research should focus on adolescents from non-intact families.

The modified Poisson (mixture) approach we employed in this study allowed for a direct analysis of incidence (rather than prevalence) of adolescent marijuana use based on GRC counts. While key estimates of adolescent marijuana use (incidence rates, risks, and incidence rates of at-risk individuals) show similar trends, the reduction in overall incidence rates from 1979 to 2021 is attributable to an almost 40% reduction in the risk of marijuana use (51.36% in 1978 and 31.53% in 2021). Despite substantial changes over the study period, the recent incidence rates for at-risk individuals are similar to those in the early 1980s. Adolescents interviewed from the late 1970s to early 1980s – a period that coincides with the movement to decriminalize marijuana[32] – showed the highest risks and levels of marijuana consumption. In this period, about half of the high school seniors were at risk of marijuana use, and these at-risk individuals on average reported more than 15 incidents of marijuana use over the last 12 months. When the federal government enacted stricter laws and regulations against the distribution of marijuana in the 1980s,[32] there was a correspondingly sharp decrease in the incidence and risks of adolescent marijuana use. However, those estimates climbed throughout the 1990s and remained relatively stable. Proportions of at-risk individuals in the late 1970s (e.g., 51.36% in 1979) were much higher than those in the most recent waves (e.g., 31.53% in 2021). Yet, at-risk high school seniors have smoked marijuana since the late 1990s at similar frequencies as in the early 1980s,

which suggests that the levels of marijuana use among at-risk adolescents remained relatively stable over almost half a century. The stability in marijuana use among at-risk students, especially members of Gen Y (born roughly between the 1980s to the early 1990s) and Gen Z (born in the late 1990s), suggests a possible research agenda to explore the persistence, cohort differences/similarities, and uneven distribution of adolescent substance use.

Finally, we note several limitations of this study. First, the sampling strategy of the MTF project excludes high school dropouts, which may produce conservative estimates of adolescent marijuana use, given that there is more substance use reported by dropouts.[33] Second, other forms of marijuana consumption, such as vaping, edibles, and extracts, have become more prevalent among U.S. adolescents in recent years.[34,35] Since these various forms of marijuana consumption have not been fully considered by the MTF project over the study period, our study cannot fully capture the emerging complexities of adolescent marijuana use. A modified Poisson (mixture) analysis of more recent datasets with new forms of marijuana consumption may provide a more holistic understanding of adolescent marijuana use, especially in more recent years. Third, because the MTF project did not include information on ethnicity before 2005, racial/ethnic disparities in adolescent marijuana use need to be further investigated using other datasets. Fourth, we restricted our analysis to 12th graders because of their greater risk of substance use compared to younger age groups,[10] but the development of more advanced mixed-effect models capable of analyzing GRC counts is warranted to disentangle age, period, and cohort effects while differentiating the risk and intensity of adolescent risky behaviors.

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Table 1. Descriptive statistics of 12th graders, Monitoring the Future project, 1976–2021 (N=491,348)

	Mean	
Dependent variable		
Past-year marijuana use		
1 = 0 occasions	304,069	61.88%
2 = 1–2 occasions	49,873	10.15%
3 = 3–5 occasions	30,262	6.16%
4 = 6–9 occasions	20,983	4.27%
5 = 10–19 occasions	23,214	4.72%
6 = 20–39 occasions	17,926	3.65%
7 = 40 and above occasions	45,021	9.16%
Control variables		
Female	253,499	51.59%
Black	60,423	12.30%
School region		
Northcentral	139,046	28.30%
South	161,570	32.88%
West	81,585	16.60%
Northeast	109,147	22.21%
Metropolitan area (MSA)	378,883	77.11%
Sociodemographic variables		
College-educated parents	110,583	22.51%
Full-time mother	103,647	21.09%
High GPA (B- and above)	384,664	78.29%
Non-intact families	122,606	24.95%
Total observations	N=491,348	

Table 2. Regression Estimates from Modified Poisson (Mixture) Models, Monitoring the Future project, 1976–2021

	Modified Poisson Model	**Modified Poisson Mixture Models**	
		Binomial	Poisson
	IRR with 95% CI	OR with 95% CI	IRR with 95% CI
Intercept	4.859*** (4.852,4.865)	0.569*** (0.566,0.572)	14.646*** (14.624,14.669)
Female	0.643*** (0.641,0.646)	0.800*** (0.791,0.808)	0.737*** (0.734,0.741)
Black	0.654*** (0.650,0.657)	0.631*** (0.619,0.644)	0.853*** (0.846,0.860)
School region (reference: Northcentral)			
South	0.883*** (0.880,0.886)	0.848*** (0.837,0.860)	0.975*** (0.972,0.979)
West	1.000 (0.997,1.004)	1.035** (1.020,1.052)	0.980*** (0.976,0.984)
Northeast	1.200*** (1.196,1.204)	1.239*** (1.221,1.258)	1.073*** (1.069,1.077)
MSA	1.180*** (1.177,1.183)	1.254*** (1.238,1.269)	1.029*** (1.026,1.033)
Full-time mother	0.880*** (0.875,0.884)	0.809*** (0.799,0.820)	0.993^{+} (0.987,0.998)
GPA B- and above	0.560*** (0.558,0.562)	0.545*** (0.539,0.552)	0.792*** (0.789,0.794)
College-educated parents	0.991*** (0.986,0.995)	1.007 (0.993,1.020)	0.985*** (0.981,0.990)
Non-intact family	1.241*** (1.219,1.265)	1.199** (1.101,1.304)	1.133*** (1.109,1.158)

Note: [a] $^{+}$ p<0.01; * p<.001; ** p<.0001;*** p<.00001 (two-tailed tests).

[b] Abbreviations: IRR, incidence rate ratio; CI, confidence interval; OR, odds ratio.

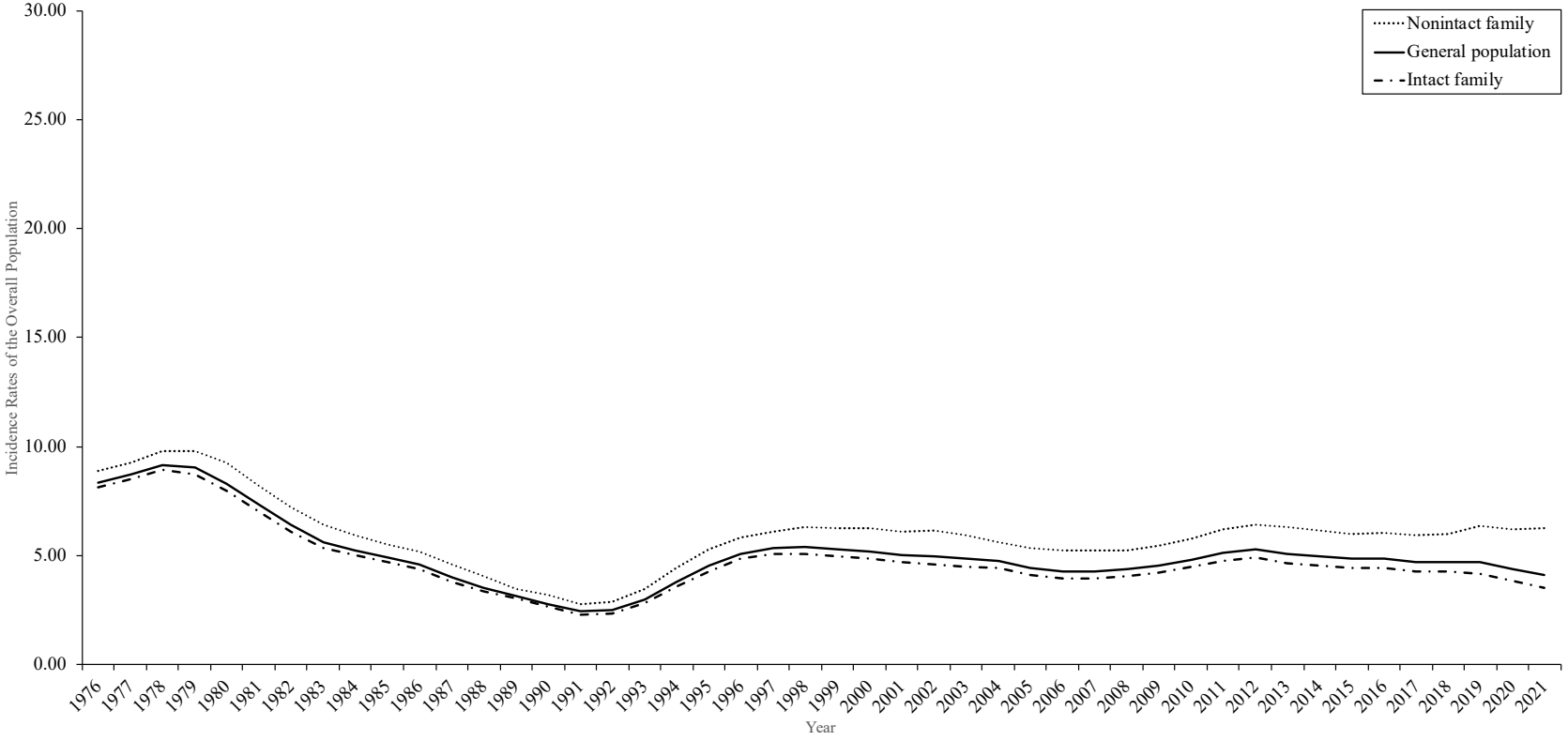

Figure 1. Estimated Overall Incidence Rates of Past-year Adolescent Marijuana Use, Monitoring the Future Study, 1976–2021

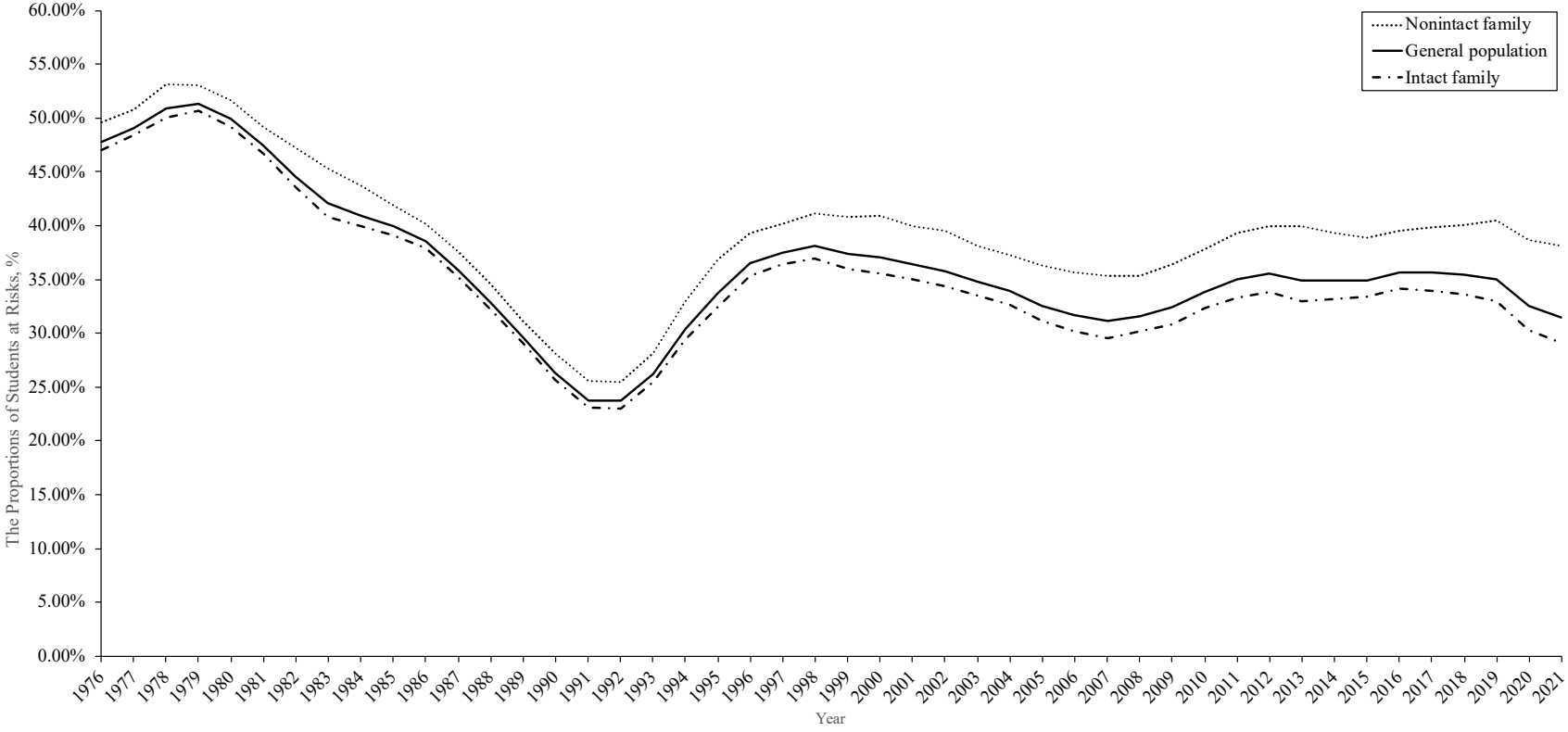

Figure 2. Estimated Proportions of Adolescents at Risk of Past-year Marijuana Use, Monitoring the Future Study, 1976–2021

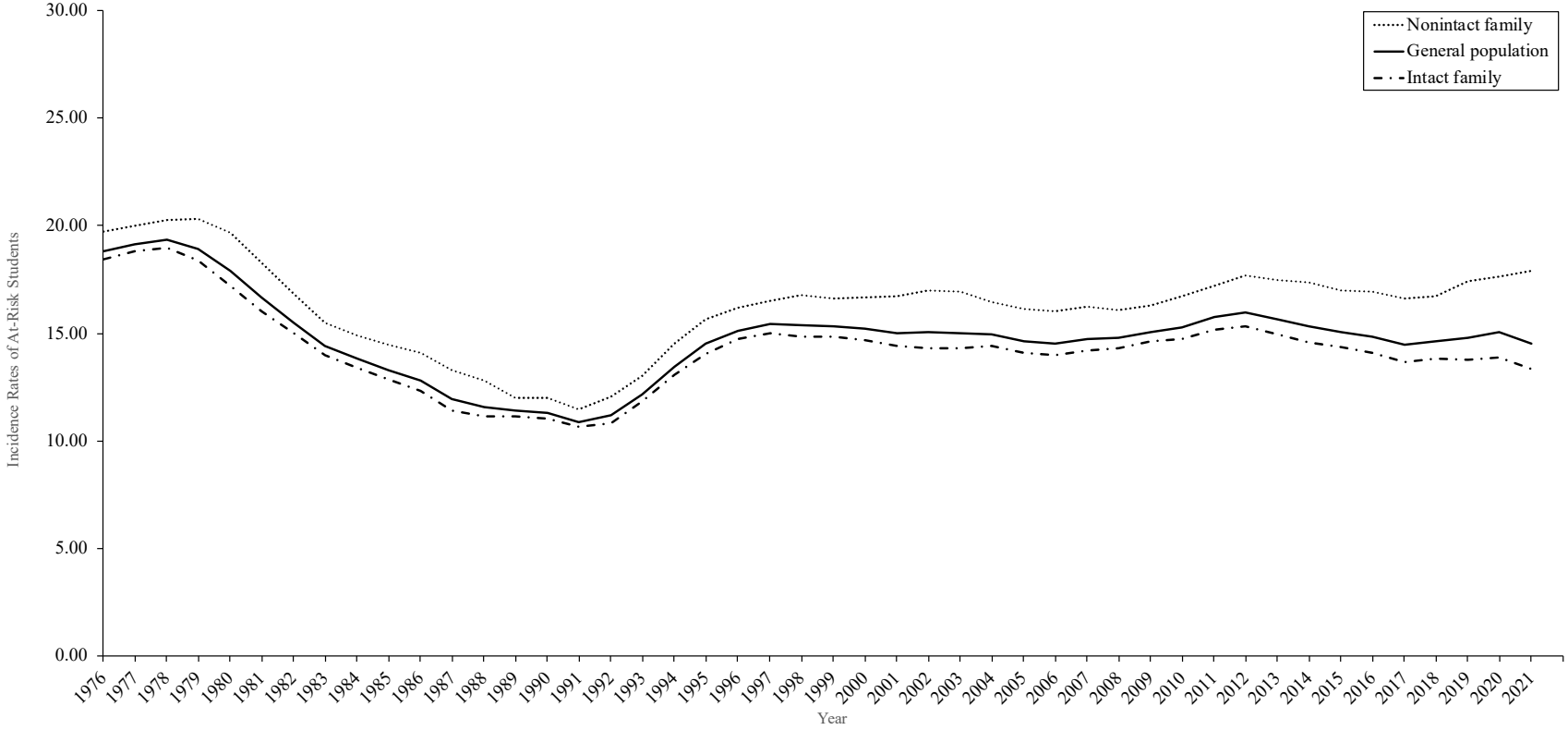

Figure 3. Estimated At-Risk Incidence Rates of Past-year Adolescent Marijuana Use, Monitoring the Future Study, 1976–2021