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Trends and age, period and cohort effects for marijuana use prevalence in the 1984–2015 US National Alcohol Surveys

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ABSTRACT

Background and Aims Epidemiological trends show marijuana use in the United States to have increased in recent years. Previous research has identified cohort effects as contributing to the rising prevalence, in particular birth cohorts born after 1945. However, given recent policy efforts to regulate marijuana use at the state level, period effects could also play a contributory role. This study aimed to examine whether cohort or period effects play a larger role in explaining trends in marijuana use. **Design** Using data from seven National Alcohol Surveys, we estimated age–period–cohort decomposition models for marijuana use, controlling for socio-demographic measures. **Setting** United States. **Participants** US general population aged 18 and older from 1984 to 2015. **Measurements** Any past-year marijuana use. **Findings** Results indicated that period effects were the main driver of rising marijuana use prevalence. Models including indicators of medical and recreational marijuana policies did not find any significant positive impacts. **Conclusions** The steep rise in marijuana use in the United States since 2005 occurred across the population and is attributable to general period effects not linked specifically to the liberalization of marijuana policies in some states.

Keywords Age, age–period–cohort, legalization, marijuana, marijuana policy, trends.

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INTRODUCTION

Marijuana use in the United States has risen steeply since 2005 throughout all age groups [1] in contrast to negative trends for tobacco use and alcohol use among underage youth [2]. In particular, age-specific rates have jumped among those aged 50 years and older from very low rates among earlier birth cohorts to high rates among the 'baby boomer' birth cohort [3]. Our 2007 study of marijuana age–period–cohort (APC) effects in the National Alcohol Survey (NAS) series found declining marijuana use from 1984 to 2000, mainly by men, and strong cohort effects differentiating those born before 1945, who have very low marijuana use, from those born after 1945 [4]. One subsequent marijuana APC analysis from 1985 to 2009 confirmed these cohort effects, and found that increasing use from 2005 to 2009 was due to period effects [5]. These findings from earlier APC studies indicate the need to track groups that are at highest risk for increased marijuana use.

Changing perceptions of marijuana in regard to riskiness for health and social problems and social acceptability have played a role in marijuana use [6,7]. One study examining youth use and social norms in a birth cohort framework found a connection between cohort disapproval of marijuana use and lower marijuana use [8]. In another APC study, period effects were found such that perceived harmfulness of marijuana among youth has been decreasing since 1991 and, in particular, in states that passed medical marijuana laws [7]. Public support for marijuana legalization has been increasing over time, and especially among younger generations [9,10]. In one APC study on marijuana legalization in the United States from 1968 to 2015, support for legalization was linked to perceptions of marijuana safety and that trends in support were primarily the result of period effects [11].

The passage of medical marijuana legislation, in particular allowing medical marijuana dispensaries or home growing, under varying policy regimes since 1996, is potentially relevant to marijuana use trends [12]. As of early 2017, 29 states and Washington DC have laws allowing medical marijuana use, with some states having particular provisions on regulating cultivation and distribution [13,14]. Beginning in 2012, legalization of recreational marijuana has become an important state-level policy, despite the continued prohibition at federal level. Eight states and Washington DC [Washington and Colorado (2012); Oregon, Alaska and DC (2014) and California, Nevada, Maine and Massachusetts (2016)] passed policies to legalize the possession and recreational use of marijuana [13]. Evaluations of the impacts of medical marijuana legalization and policy details have had mixed results, with findings of increased use among those aged 26+ [15,16] but not for younger age groups [17,18]. An analysis of the Monitoring the Future (MTF) surveys similarly found no policy effect among adolescents in the United States [19]. However, a recent MTF analysis of recreational legalization in Washington found increased use among 8th and 10th graders in Washington, but no change among 12th graders nor for any grade level in Colorado [20].

Few general adult population surveys have tracked marijuana use over time, and no information on marijuana sales is available outside states with recent legal retail sales. This study updates marijuana trends and APC decomposition analyses of the NAS series to 2015 utilizing seven surveys during 31 years. With so many policy changes in regulating use and changes in perceptions of marijuana, it is necessary to continue monitoring marijuana use to assess whether period or cohort effects are driving increased use. Furthermore, we examine how state-level marijuana policy measures, both medical and recreational legalization, have influenced marijuana use in the general population.

METHODS

Data

The NAS is a population-based survey of randomly selected US adults aged 18 years and over that, since 1979, is conducted approximately every 5 years. We pooled seven waves of NAS data from 1984 [n = 5221; response rate (RR) = 72%], 1990 (n = 2058; RR = 70%), 1995 (n = 4925; RR = 77%), 2000 (n = 7612; cooperation rate (CR) = 58%), 2005 (n = 6919; CR = 56%), 2010 (n = 7969; CR = 52%),and 2015 (n = 7071; CR = 44%). Key changes have occurred in sampling design and survey mode, with a shift from multi-stage clustered design with in-person interviews to random-digit-dialing (RDD) in 2000 and to duel-frame landline and mobile RDD in 2010, both with telephone interviews. African Americans and Hispanics were oversampled in all surveys except for 1990 [21,22]. Prior methodological studies have shown no significant differences in key alcohol measures throughout the shift from in-person to telephone mode [23–25]. In a telephone follow-up to the 1995 NAS no significant differences in past year marijuana use were found [25,26]. All surveys were weighted to the US adult population, taking into account age, gender, ethnic group and geographic area. The final analytical sample included 21 298 females and 16 061 males.

Measures

Marijuana use

In 1984 to 2005 surveys, respondents were asked: 'How often have you used marijuana, hash, THC or grass during the past 12 months?'. In 2010 and 2015, the question changed slightly to reflect more contemporary terminology: 'How often have you used marijuana, hash, pot, THC or "weed" during the last 12 months?'. The dependent variable indicates whether the individual reported any marijuana use during the past 12 months. Starting in the 2000 survey, marijuana use was the first question asked in the illegal drugs section, while in previous surveys this question was placed in the middle of the drugs section, with questions on cocaine, heroin and amphetamine use preceding marijuana. This placement change should have no effect on participants' responses, given that in all waves the drug use questions were preceded by questions on demographic characteristics, alcohol use and alcohol-related problems.

Covariates

We examined trends by gender, age groups, race/ethnicity (African American, Asian, Hispanic, white and Native American and all others) and period or NAS survey year. Using Kerr's alcohol region construct [27], US states were categorized into regions corresponding to dry-to-wet environments: South, mid-Atlantic, Pacific Coast, South Coast, New England and North Central. While these categories were developed for alcohol, they also have relevance for marijuana use with higher levels of use expected in the Pacific and New England regions [28]. Other covariates include educational status [less than high school (HS), HS degree, some college, and college degree or more], inflation-adjusted annual income ($0–19 K, $20–39 K, $40–69 K, $70 K+, missing), marital status (married, widowed, divorced/separated and never married), religion (Catholic, Jewish, no religion and all others) and employment status (employed, unemployed, student and retired/other).

Marijuana policy variables

To examine policy effects, we included indicators for state-level medical and recreational marijuana use policies that were in effect by 2015. Following earlier analyses, we distinguished between states with medical marijuana laws that included provisions for dispensaries and home cultivation of medical marijuana [12].

APC

Age was grouped into eight categories, starting with 18–20-, 21–24- and 25–30-year-olds, and then 10-year age groups thereafter until the oldest age group of 71+. We used the 41–50 age group as the reference in the APC models. Period is represented by 7 NAS years, with 2015 as the reference. Birth cohort was categorized into 15 groups, starting with 1900–20, followed by 5-year groupings from 1921–25 to 1986–90, and ending with a 1991–97 cohort. The 1956–60 birth cohort is the reference group.

Analysis

We first conducted descriptive analyses of any marijuana use by survey year. These analyses were gender-stratified, and examined trends by age, race/ethnicity and US region. Statistical tests for linear trends were conducted by fitting logistic regression predicting any marijuana use with survey year coded from 0 to 6 and its estimated coefficients were used to identify significant changes over the period of observation.

Consistent with prior APC studies using NAS data, we used a fixed-effects (FE) approach for the marijuana APC models [21,22,29]. While a hierarchical or cross-classified random effects approach is more common in recent APC studies [30], we were able to account more clearly for NAS's different survey modes, sampling designs and oversampling in a FE approach using Stata's survey design feature (−svy− command). Principal components analyses of the age, period and cohort measures found condition numbers of 22.5 for men and 20.9 for women [31]. These are both greater than 15, indicating concern regarding multi-collinearity and identification, but below 30 as the informal cut-off for serious concern. These analyses indicate the need for caution in determining the final model specification and support the use of outside information in this decision. We conducted a series of gender-specific logistic regression models of any marijuana use in the past year unadjusted and adjusted with covariates [21,22,29]. Due to low marijuana prevalence in the oldest age groups and earliest cohort groups, some of the 5-year age groups had empty cells. Female birth cohorts from 1901 to 1920 and from 1921 to 1930 were combined to create more stable groups. For the male APC models, we initially obtained age coefficients that, implausibly, increased with older ages, and included extreme values for period and cohort effects (see Supporting information, Table S1). We tried an alternative strategy by constraining age to a linear effect with odds ratio of 0.96 per year, based on estimates from the 2010 and 2015 NAS surveys where post-1945 cohorts had reached older age groups, in order to insure a declining age effect on marijuana use.

We also ran an alternative APC model using an intrinsic estimator (IE) method as a sensitivity analysis. The IE method estimates a 'unique estimable function based on the linear and nonlinear components of the parameter vector' of the APC model [32]. As the IE method requires the APC design matrix to be singular, age was coded in 5-year groups, period into 5-year intervals and cohort equaled to period minus age. This analysis was restricted to those aged 67 or younger to avoid empty cells in earlier cohorts, and accounted for survey weights.

After selection of the final APC models for women and men, we then estimated a series of models including marijuana policy measures, both individually and in combinations. Analyses were conducted in Stata/SE version 14 and accounted for survey weights and changes in sampling design throughout the pooled data files [33].

RESULTS

Descriptive trends

Trends in past-year marijuana use prevalence are presented in Table 1. Overall, there was a J-shaped trend in use, with declines amounting to approximately 30% during 1984–2005 followed by a near-doubling to 12.9% in 2015. For men, there was a U-shaped trend where use decreased from 1984 to 2005 and then increased sharply from 2010 to 2015, returning to 1984's level. However, when examined by age, these trends showed some differing patterns. For men aged under 40, rates in 2015 were similar to 1984 rates, while for those aged 50 years and older, rates increased in 2010 and 2015 compared to earlier years. For women, significant increases were found in all age groups throughout the period. For women aged under 40 years there was a J-shaped trend, while for aged women 40 years and older use was rare in 1984 and generally increased over time. Among men, the U-shaped trend was evident among all groups except for Hispanics, who showed an especially steep rise in 2015. For women, varying patterns were seen throughout groups, but an upwards trend is significant for all but Hispanics. Regional rates of use also varied, although the U-shaped trend for men and increasing trend for women was seen in most areas. The region with the highest estimated rates of use varied throughout time with the Pacific region, which includes several states with legalized recreational use since 2010, and the highest rates for both men and women in 2015.

APC trends

Trends in marijuana use prevalence were decomposed into age, period, cohort and socio-demographic characteristics

Table 1 Percentage of population or subpopulation reporting any marijuana use in the past year, National Alcohol Survey (NAS) 1984–2015.

Year	*NAS7* *1984*	*NAS8* *1990*	*NAS9* *1995*	*NAS10* *2000*	*NAS11* *2004–05*	*NAS12* *2009–10*	*NAS13* *2014–15*	*P* *trend*
All	9.9%	9.1%	7.5%	7.2%	6.7%	10.2%	12.9%	0.003
All male	14.9%	12.7%	10.7%	8.8%	9.1%	13.3%	14.7%	0.659
All female	5.5%	5.7%	4.6%	5.7%	4.4%	7.3%	10.6%	< 0.001
By age (years)				Males				
18–29	29.9%	26.2%	21.0%	19.6%	17.7%	23.2%	29.2%	0.437
30–39	18.1%	13.3%	14.5%	8.8%	11.9%	16.2%	14.8%	0.650
40–49	9.6%	9.0%	10.3%	7.7%	7.6%	12.9%	11.7%	0.296
50–59	0.5%	4.6%	0.6%	3.6%	6.3%	11.2%	11.6%	< 0.001
60+	0.6%	0.8%	0.1%	0.5%	1.5%	1.8%	7.0%	< 0.001
				Females				
18–29	13.3%	11.5%	11.5%	14.6%	12.3%	16.9%	23.7%	0.002
30–39	7.5%	9.1%	6.0%	6.9%	3.9%	10.1%	15.0%	0.029
40–49	0.2%	4.4%	3.0%	4.7%	4.5%	6.3%	8.7%	< 0.001
50–59	0.1%	0.4%	1.3%	2.1%	1.8%	4.0%	7.3%	< 0.001
60+	0.0%	0.2%	0.5%	0.0%	0.5%	1.0%	1.9%	0.001
By race/ethnicity				Males				
White	14.4%	12.5%	10.6%	7.6%	8.8%	13.4%	13.4%	0.861
Black	17.4%	17.4%	12.5%	11.2%	16.8%	18.1%	16.4%	0.587
Hispanic	11.9%	12.3%	9.6%	12.9%	4.7%	10.1%	19.1%	0.079
Others	27.4%	3.7%	10.0%	12.7%	9.9%	11.9%	15.8%	0.870
				Females				
White	5.6%	5.6%	4.7%	5.7%	4.5%	8.2%	10.1%	<0.001
Black	7.2%	6.8%	5.3%	4.7%	4.2%	7.6%	13.4%	0.028
Hispanic	2.8%	7.6%	3.6%	5.9%	2.1%	2.8%	9.3%	0.091
Others	0.0%	0.0%	1.8%	6.5%	8.8%	5.8%	12.8%	0.002
By region				Males				
Mid-Atlantic	14.8%	11.9%	8.4%	9.1%	9.2%	10.5%	11.8%	0.514
North-Central	14.9%	12.2%	10.8%	7.9%	8.7%	17.6%	13.7%	0.476
New England	13.6%	14.9%	20.8%	16.6%	11.6%	17.4%	10.5%	0.644
Pacific	21.4%	16.2%	15.2%	11.3%	10.9%	17.0%	21.4%	0.745
South Coast	11.6%	16.6%	10.7%	7.5%	7.8%	12.1%	18.3%	0.125
South	13.1%	8.1%	7.5%	7.0%	9.0%	8.1%	10.2%	0.549
				Females				
Mid-Atlantic	7.4%	10.7%	1.5%	4.7%	4.0%	6.6%	13.1%	0.144
North-Central	4.6%	5.3%	3.7%	5.1%	4.4%	8.5%	7.9%	0.034
New England	13.6%	3.3%	6.7%	8.8%	4.2%	4.7%	13.1%	0.912
Pacific	5.9%	3.8%	7.6%	8.1%	7.6%	9.2%	16.4%	0.001
South Coast	4.7%	4.4%	4.3%	5.1%	1.4%	6.7%	8.9%	0.080
South	4.1%	4.8%	5.5%	5.0%	5.0%	6.2%	8.6%	0.024

in APC models (see Table 2 and Fig. 1). For women, the estimated age pattern showed a peak in the early 20s with declining odds of use to the 60s. For men, there was an increasing, and implausible, age effect in the initial model (see Supporting information, Table S1). Despite growing prevalence of marijuana use among adults aged 50+ [3], we still expected the overall age profile of marijuana use to follow that of alcohol and other drug use, in that marijuana use declines with age. However, age patterns in the earlier NAS surveys were influenced clearly by the strong negative pre-1945 birth cohort effects. Thus, within the contrasting trends of very low prevalence among pre-1945 birth cohorts and higher prevalence among post-1945 cohorts, the shift in the age pattern of use over time (see Table 1) presented a difficult situation for the standard APC model to fit the data most accurately and produce credible estimates of APC coefficients. Therefore, we imposed a declining age effect in the APC-constraint model for men (see Fig. 1 and Supporting information, Table S1).

Overall, these APC models attribute trends in marijuana use mainly to period effects for both men and women (see Fig. 1). Previous findings of lower use among cohorts born before 1945 for men and 1950 for women were

Table 2 Estimates of socio-demographic characteristics on marijuana use by gender from age–period–cohort logistic regression models in the National Alcohol Surveys 1984–2015.

	Women (n = 21 298)			*Men (n = 16 061)*		
	OR	*95% CI*		*OR*	*95% CI*	
Less than high school	1.00			1.00		
High school	0.78	0.570	1.062	0.88	0.695	1.126
Some college	0.94	0.684	1.302	0.88	0.682	1.129
College +	0.77	0.538	1.102	0.77	0.590	1.009
Income $0–19 K	1.00			1.00		
$20–39 K	0.79	0.616	1.009	0.95	0.768	1.180
$40 K–69 K	0.72	0.550	0.950	1.02	0.806	1.284
$70 K+	0.67	0.478	0.927	0.89	0.689	1.136
Income missing	0.44	0.302	0.645	0.52	0.379	0.727
White	1.00			1.00		
Asian	0.40	0.198	0.802	0.41	0.228	0.736
Black	0.77	0.591	0.997	1.17	0.945	1.456
Hispanic	0.40	0.285	0.554	0.54	0.420	0.691
American Indian	0.85	0.419	1.716	2.00	1.196	3.335
Other	1.59	0.629	4.022	0.44	0.152	1.299
Married	1.00			1.00		
Divorced/separated	1.66	1.236	2.222	1.87	1.449	2.411
Widowed	0.87	0.507	1.480	1.93	0.935	3.985
Never married	1.62	1.260	2.088	1.56	1.291	1.881
Region mid-Atlantic	1.00			1.00		
North Central	0.86	0.639	1.161	1.22	0.948	1.559
New England	1.56	0.922	2.633	1.78	1.258	2.510
Pacific	1.54	1.138	2.094	1.74	1.341	2.257
South Coast	0.94	0.675	1.296	1.13	0.860	1.476
South	0.91	0.667	1.232	0.83	0.625	1.102
Other religion	1.00			1.00		
Jewish	4.78	2.619	8.732	1.70	1.005	2.874
Catholic	1.12	0.859	1.464	1.41	1.161	1.722
No religion	2.13	1.702	2.663	2.00	1.663	2.415
Employed	1.00			1.00		
Unemployed	1.47	1.072	2.020	1.49	1.149	1.935
Student	0.88	0.576	1.347	0.94	0.642	1.370
Retired/other	1.01	0.786	1.299	1.64	1.251	2.140
constant	0.11	0.051	0.214	0.69	0.440	1.087

OR = odds ratios; CI = confidence intervals. Models control for age, period and cohort.

confirmed. Positive effects among recent cohorts for women were suggested, although no significant differences were found among post-1950 cohorts for either gender. Significant period effects demonstrated generally rising odds of use for men from 2000 and for women from 2005 to 2015. For men, there was also a steep decline in the odds of use from 1984 to 2000, resulting in a U-shaped trend during the 30-year period consistent with the rates presented in Table 1.

In sensitivity analysis using the IE method the results are not consistent with prior APC trends of marijuana use, in particular for women where the age and period effects appeared to be exaggerated and the cohort effects declined with birth year, the opposite of previous findings (see Supporting information, Table S2). The IE's steeply declining age effects for men seem more plausible than the increasing age effects in our unconstrained fixed effects model; however, the estimated cohort effects for some of the pre-1945 cohorts were implausibly high, similar to the most recent cohorts. Our selection of categorical models with a constrained age effect for men and a moderate age profile for women was based on informed choices, taking into account the strong pre-1945 cohort effects found in previous APC studies and retrospective measures of life-time marijuana use.

Socio-demographic variables were found to have significant influences on marijuana use during this 30-year period, as shown in Table 2. Low-income women were found to be significantly more likely to use marijuana. White men and women had the highest risk of use with

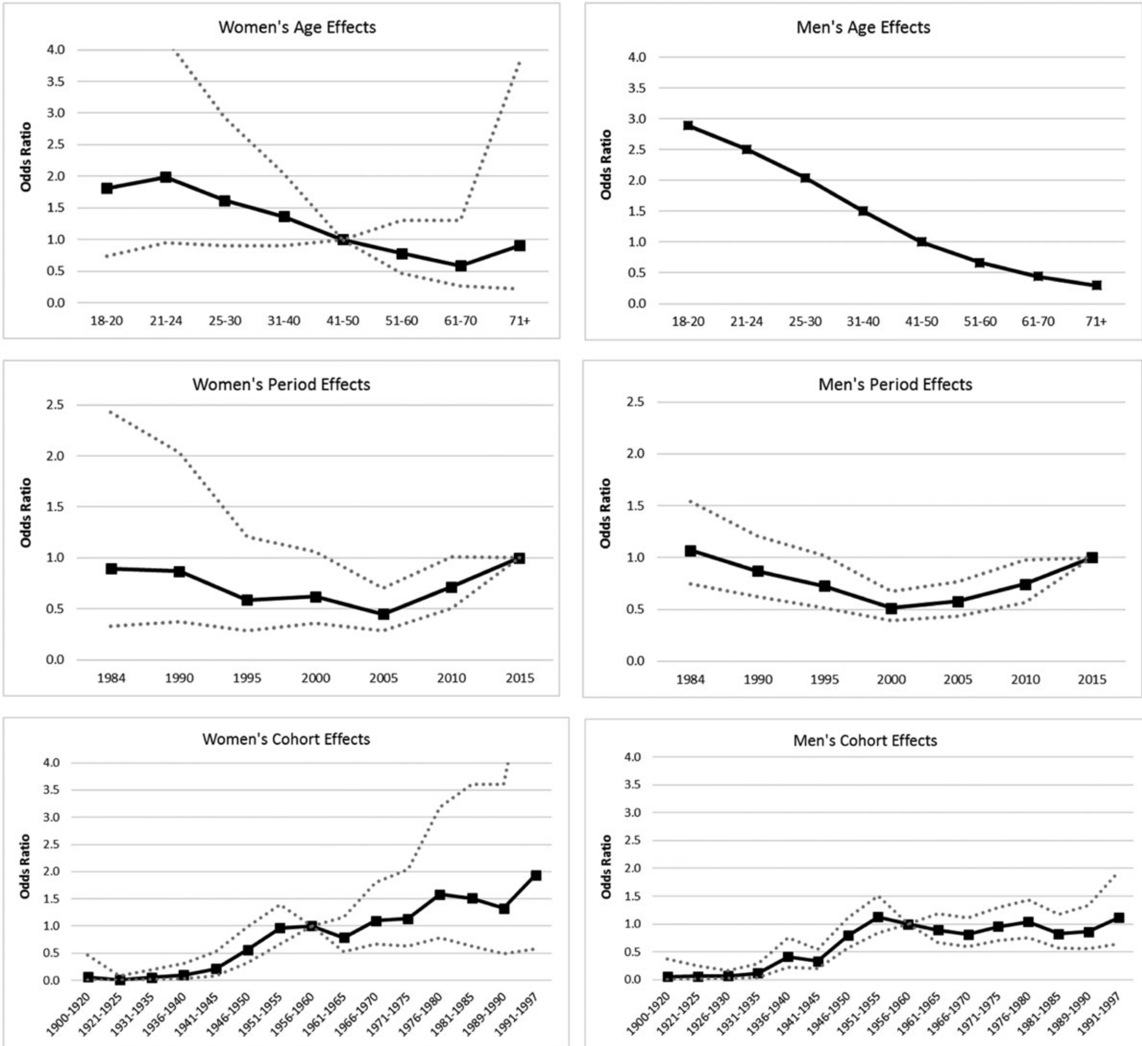

Figure 1 Age, period and cohort effects for women and men displayed as odds ratios (OR) from logistic regression models of any marijuana use from seven National Alcohol Surveys. Reference groups are the 41–50 age group, the 2015 survey and the 1956–1960 birth cohort. Dotted lines represent the estimated 95% confidence intervals. Male age effects are estimated from the age-constraint model, and thus no confidence intervals are presented

the exception of American Indian men, who had double the odds of use compared to white men. Both Asian and Hispanic men and women had substantially lower odds of use compared to their white counterparts. Black women also had lower odds than white women, but black men did not differ from white men. Having no religion was related strongly positively to the odds of marijuana use, as was Jewish religion, especially for women. Catholic religion was also related positively for men only.

Within the APC framework, results for the state policy indicators recreational legalization, medical marijuana dispensaries and home growing are shown in Table 3. We examined each policy individually and in combination to allow consideration of how the policy effects may influence marijuana use after controlling for APC. No significant effects were found for any of the measures entered individually. For men, having dispensaries selling medical marijuana was found to reduce marijuana use significantly in models including the other policies. The addition of policy measures did not change the results substantially for other variables presented in the main APC models in Table 2.

DISCUSSION

Estimates of past-year marijuana use prevalence from the NAS series illustrate a decline in use during the 1980s and 1990s, and a steep rise in marijuana use from 2005 to 2015. Differential patterns across gender, age, race/ethnicity and US region show variations in these trends, especially between younger and older age groups. Marijuana use among those born before 1945 was dramatically lower than those born after and confirms findings from earlier surveys of a cohort effect among older

Table 3 Estimates of policy effects on marijuana use by gender from age–period–cohort logistic regression models, National Alcohol Survey 1984–2015.

	Women (n = 21 298)			Men (n = 16 061)		
	OR	95% CI		OR	95% CI	
Model estimates with single policies						
1. Legalizing recreational MJ	1.36	0.878	2.111	0.93	0.623	1.398
2. Medical MJ grown at home	1.05	0.755	1.456	0.98	0.754	1.279
3. Medical MJ sold at dispensaries	1.27	0.898	1.799	0.75	0.556	1.001
Model estimates with combination of policies						
Policies 1 + 2						
1. Legalizing recreational MJ	1.39	0.901	2.142	0.93	0.623	1.381
2. Medical MJ grown at home	1.09	0.794	1.496	0.97	0.750	1.264
Policies 1 + 3						
1. Legalizing recreational MJ	1.38	0.894	2.127	0.90	0.601	1.357
3. Medical MJ sold at dispensaries	1.28	0.912	1.799	0.74	0.552	0.993
Policies 1 + 2 + 3						
1. Legalizing recreational MJ	1.36	0.878	2.097	0.94	0.630	1.416
2. Medical MJ grown at home	0.91	0.614	1.353	1.24	0.901	1.702
3. Medical MJ sold at dispensaries	1.36	0.887	2.073	0.65	0.454	0.930

OR = odds ratios; CI = confidence intervals; MJ = marijuana. Models control for age, period, cohort, demographic characteristics, religion and region.

groups [4]. In this study, our APC analyses of repeated cross-sectional surveys during the 30-year period from 1984 to 2015 found that these trends were explained primarily by period effects, consistent with a recent APC analysis showing period effects of support for marijuana legalization [11].

Modeling marijuana use in the United States through APC techniques is complicated, due to the dramatic differences in marijuana use between earlier and later birth cohorts. Because life-time use was so low in the pre-1945 cohorts, there was no opportunity to observe declines in marijuana use with aging, which are needed to inform the estimation of age effects. Marijuana use was more prevalent among the post-1945 birth cohorts, but due to the lack of available data from these cohorts at older ages until more recent survey years there were difficulties in capturing these age trends. Specifically, those born in 1950 did not reach 50 years old until 2000 and 60 years old until 2010, so that age effects utilizing earlier survey data would probably exaggerate or have difficulties with estimation, as we found in our analyses of US men. The varying APC estimates from different models demonstrate the sensitive nature of APC modeling. Models presented in Supporting information, Tables S1 and S2 provide examples of how a naive specification can go wrong. We found that utilizing age patterns of marijuana use from more recent surveys to set parameters for age effects resulted in more plausible estimates of period and cohort effects. Thus, our APC model selection of a constrained age effect for men and a moderate age profile for women was based on informed choices, taking into account the strong pre-1945 cohort effects found in previous APC studies and retrospective measures of life-time marijuana use.

Medical and recreational marijuana policies did not have any significant association with increased marijuana use in the NAS data. This does not preclude the possibility that these policies have differential effects for different subgroups or that alternative policy definitions could play a stronger role on marijuana use. While these analyses are unique in considering policy effects in an APC framework, they do not utilize policy-focused causal methods to control explicitly for state-specific trends [20]. Marijuana policy liberalization during the past 20 years has certainly been associated with increased marijuana use; however, policy changes appear to have occurred in response to changing attitudes within states and to have effects on attitudes and behaviors more generally in the United States. Legalization has been shown to increase the perceived availability of marijuana for older adults [17], but not for the heaviest-using younger groups who appear to have better access to illicit markets.

Our estimated period effects are substantial, implying a doubling of marijuana use rates from 2000 for men and 2005 for women. Importantly, marijuana use prevalence by men and women in their 40s and 50s has reached rates above those seen for the 30s in 2000, and even for men in their 60s or older the rate has reached 7%. The steep increases in use among older adults correspond with aging baby-boomers but also reflect the dwindling influence on pre-1945 birth cohorts on attitudes and public policy. The attribution of marijuana use trends primarily to period effects implies changing society-wide factors. Other studies have shown that disapproval of use has decreased [8] and support for marijuana legalization and perceptions of marijuana safety have increased [11] which have led to or changed along with increased marijuana use prevalence.

Limitations of these analyses include self-report of marijuana use, which may be affected strongly by illegality of use and social desirability bias, with the magnitude of such effects differing by state and changing over time as well as being related potentially to socio-demographic characteristics. Changing policies, including decriminalization, medical marijuana legalization and recreational legalization, could also be important factors, potentially exaggerating recent increases in marijuana use in states where policies favoring marijuana have passed. Differences in in survey mode, sampling frame, sampling method and response or cooperation rates may have affected characteristics of the respondents and their responses to sensitive questions. The outcome measure of any past-year marijuana use does not capture the frequency or intensity of use or other aspects of use, such as simultaneous use with alcohol or other drugs, which may be relevant to marijuana-related harms.

APC models offer a unique and important perspective on behavioral trends such as marijuana use. While we have identified some specific factors associated with marijuana use risk, including unemployment, low income, having no religion or belonging to certain religious groups, divorce or separation and, for men only, retirement, these factors do not explain the 30-year trends or recent increases in marijuana prevalence. Our estimates, consistent with previous studies [5,11], point to general period effects influencing the whole population towards a greater likelihood of past-year marijuana use and generally more positive attitudes towards marijuana use and legality [34]. Future studies should aim to understand this seemingly broad phenomenon in the United States and relevance to changes in other countries.

Declaration of interests

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article.

Table S1 Estimates of age, period, cohort effects on men's marijuana use from logistic regression models, National Alcohol Survey 1984–2015.
Table S2 Odds ratios (ORs) and 95% confidence intervals of age–period–cohort (APC) analysis using intrinsic estimator (IE) method past-year marijuana use.[1,2]