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Have recreational marijuana laws undermined public health progress on adult tobacco use?

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ABSTRACT

Public health experts caution that legalization of recreational marijuana may normalize smoking and undermine the decades-long achievements of tobacco control policy. However, very little is known about the impact of recreational marijuana laws (RMLs) on adult tobacco use. Using newly available data from the Population Assessment of Tobacco and Health (PATH) and dynamic difference-in-differences and discrete-time hazard approaches, we find that RML adoption increases prior-month marijuana use among adults ages 18-and-older by 2-percentage-points, driven by an increase in marijuana initiation among prior non-users. However, this increase in adult marijuana use does not extend to tobacco use. Rather, we find that RML adoption is associated with a lagged *reduction* in electronic nicotine delivery systems (ENDS) use, consistent with the hypothesis that ENDS and marijuana are substitutes. Moreover, auxiliary analyses from the National Survey on Drug Use and Health (NSDUH) show that RML adoption is associated with a reduction in adult cigarette smoking. We conclude that RMLs may generate tobacco-related health benefits.

1. Introduction

Public support for the legalization of recreational marijuana has increased substantially over the last decade and a half, rising from 25 percent in 1995 to 68 percent in 2020 (Gallup 2020). Between January 2012 and December 2022, 21 states and the District of Columbia have enacted recreational marijuana laws (RMLs), which legalize the possession, sale, and, in most cases, home cultivation of small quantities of marijuana (e.g., one or two ounces) for those ages 21 and older for any purpose, including recreational use. The first state to enact an RML was Washington on December 6, 2012, followed by Colorado four days later. Each state that has adopted an RML had previously adopted a medical marijuana law (MML) on average, 13 years prior. Unlike most MMLs, RMLs do not require registration as part of a state registry nor do they require a doctor's recommendation to treat an "allowable medical condition"

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(National Council of State Legislatures 2022). To legally obtain marijuana at an open recreational dispensary, individuals must simply show proof that they are age 21. In addition, nearly all states that legalize recreational marijuana permit home-growing of marijuana plants (Anderson et al., 2021).

While RMLs have garnered substantial support among policymakers and the public, the American Medical Association (AMA) and the American Public Health Association (APHA) have questioned their efficacy and withheld their support for recreational marijuana legalization (AMA 2021; APHA 2020). Public health experts warn that the legalization of recreational marijuana could normalize smoking among adults, leading to an increase in tobacco use (Ong 2016). One piece of evidence used to support this hypothesis is that co-use of marijuana and tobacco, often as "blunts," has increased in recent years among U.S. adults (Goodwin et al., 2018; Schauer et al., 2015; Coley et al., 2021).

Opponents of RMLs argue that frequent and heavy marijuana smoking has been linked to lung disease (American Lung Association 2021) and a host of respiratory problems, including chronic cough, bronchial episodes, and increased phlegm productivity (National Academies of Sciences, Engineering and Medicine 2017).[1] Many of the adverse respiratory health effects of marijuana smoking are shared with tobacco smoking (Tashkin 2013). Nonsmokers' rights organizations argue that secondhand marijuana smoke is as important to curb as secondhand tobacco smoke (American Nonsmokers' Rights Foundation 2021). In addition, there is evidence that frequent marijuana use (especially at younger ages) is linked to increased risk of depression (Buckner et al., 2010; Dumas et al., 2002), psychiatric problems (Guttmannova et al., 2017; Keith et al., 2015; Zvolensky et al., 2006, Zvolensky et al., 2008), and impaired cognitive function (Jager and Ramsey 2008). There is also evidence that when combined with pharmaceutical drugs or alcohol, marijuana use may generate important health risks to users (Ashton 2018; Sokolovsky et al., 2020).[2]

However, adverse health effects of marijuana use are, in part, mitigated by smoke-avoidant methods of marijuana consumption (i.e., baked goods, edibles, beverages). Moreover, relative to tobacco use, far fewer studies have linked marijuana consumption to cancers, heart disease, or stroke (National Academies of Sciences, Engineering, and Medicine 2017). To the contrary, moderate marijuana use is associated with some important health *benefits*, including reduced risks of mortality and mobility, and alleviating pain, anxiety, and many side effects of cancer and HIV treatments (Hall et al., 2005; Fiz et al., 2011; Ware et al., 2010; Anderson et al., 2014; Sabia et al., 2017; Choi et al., 2019; Anderson and Rees Forthcoming).

In contrast, tobacco use is the leading cause of preventable death in the United States (U.S.) and has been linked to nearly one-half million deaths per year (Centers for Disease Control and Prevention 2021a). In addition, its consumption leads to increased risk of emphysema, cancers of the colon, liver, head, and lung, and stroke (U.S. Department of Health and Human Services 2020). If marijuana and tobacco are complements for adults, the direct medical costs — including "internality" costs resulting from non-rational addiction (Gruber and Köszegi 2001) — and health-related externality costs of RMLs could be substantial.[3]

Recent research shows that the legalization of marijuana for medicinal purposes is associated with a small reduction in tobacco cigarette use, suggesting that medical marijuana and tobacco are substitutes for adults (Choi et al., 2019). However, the effects of RMLs could differ from MMLs for a number of reasons. First, to the extent that a non-trivial share of those who were induced to consume marijuana from MMLs were treating allowable medical conditions (i.e., pain, fibromyalgia, nausea, and side effects of cancers and HIV treatment), the marginal individual induced to consume marijuana from an RML may differ substantially on characteristics related to health production (i.e., age, health stock, depreciation rate). In this circumstance, the local average treatment effect (LATE) of RMLs on adult tobacco use may differ as well.

Second, the market for tobacco products changed dramatically from the mid-1990s, when the first MML was enacted (California in 1996). For instance, approximately one-quarter of the U.S. population lived in states with an MML before electronic cigarettes (e-cigarettes) were introduced to the U.S. market in 2006–2007 (Office of the Surgeon General 2016). While initial e-cigarette sales occurred largely via internet sales, it was during the 2009–2012 period that retail sales of e-cigarettes widely expanded (Huang et al., 2021). Moreover, the introduction of JUUL (Juice USB Lighting) in June 2015 — accompanied by a wide assortment of flavors — also greatly expanded the set of electronic nicotine delivery systems (ENDS) products (Truth Initiative 2019).

The wide availability of e-cigarette products at the time of RML-adoption may result in a very different tobacco use response. For example, vaping pens and JUUL devices used for e-cigarette consumption may be adapted to permit marijuana smoking (Miech et al., 2020), which could result in a complementary relationship between e-cigarettes and marijuana. On the other hand, if e-cigarettes and marijuana both serve to produce euphoria ("high"), generate utility from a smoking experience, or serve the ends of quitting cigarette smoking, then marijuana and e-cigarettes may be substitutes.

Third, the tobacco policy environment continued to evolve during the period when RMLs were adopted. Between 2012 and mid-2019, state excise taxes on cigarettes increased 36 times with an average increase of \$0.473 per pack, with 37 states attaining excise taxes of over \$1 per pack (Orzechowski and Walker, 2021). In addition, over this same period, 10 states and two large counties enacted taxes on ENDS (Abouk et al., 2023), clean indoor air laws were expanded in eight states (Centers for Disease Control and Prevention 2021b), and 16 states and the District of Columbia enacted a minimum legal purchasing age of 21 for all tobacco products (Hansen

[1] Moreover, there is evidence that marijuana use may impair cognitive function (Volkow et al. 2014; Wang et al. 2013).

[2] On the other hand, there is also evidence that increased legalized access to marijuana may improve mental health (Anderson et al. 2014) by inducing substitution away from alcohol (Anderson et al. 2012) and opioids (Buchhuber et al. 2014; Sabia et al. 2021).

[3] Estimates of the direct health care costs of tobacco use have been estimated to be \$200 billion per year and annual externality costs (i.e., secondhand and thirdhand tobacco smoke) to be approximately \$7 billion (U.S. Department of Health and Human Services 2014).

et al., 2020).[4] These tobacco control policies increase the shadow price of tobacco at the same time RMLs were enacted, which could dampen a complementary relationship and potentially reinforce a substitutional relationship between recreational marijuana and tobacco. Alternatively, those who continue to consume tobacco following the enactment of a wide set of tobacco control policies (i.e., taxes, informational campaigns, clean indoor air laws, minimum legal purchasing ages) may have a relatively more inelastic demand for tobacco than prior smokers who were impacted by an MML. In this case, we might expect adult tobacco consumption to be relatively unaffected by the enactment of RMLs.

Finally, in part due to the success of past tobacco control efforts, a substantial share (55.1 percent) of current smokers expresses a desire to quit cigarette consumption (Centers for Disease Control and Prevention 2021c). This may reflect time-inconsistent preferences, social pressure to respond in this manner, or a desire for the costs of rational addiction to be lower. If the former reason dominates, the availability of a new consumer product, recreational marijuana, may aid these individuals in cessation efforts.

This study is the first to comprehensively examine the impact of the legalization of recreational marijuana on adult tobacco use. In so doing, we make several important contributions. First, we make use of a newly available nationally representative panel dataset, the Population Assessment of Tobacco and Health (PATH). These longitudinal data permit the estimation of (1) dynamic difference-in-differences estimates (event-study analysis), and (2) discrete-time hazard models that partial out individual (time-invariant) unmeasured heterogeneity and model dynamic transitions across consumption margins for both marijuana and tobacco. In addition, we draw auxiliary data from the National Survey on Drug Use and Health (NSDUH) and employ difference-in-differences models using novel estimators developed by Callaway and Sant'Anna (2021) to expunge bias in two-way fixed effects (TWFE) models caused by heterogeneous and dynamic effects of RMLs on marijuana and tobacco use.

We document three key findings. First, "first-stage" results from the NSDUH and PATH show consistent evidence that RML adoption increases adult marijuana use by 2- to 5-percentage-points, including through vaping. Discrete-time hazard fixed effects estimates suggest that this increase in consumption is driven by an RML-induced increase in initiation of marijuana use among prior non-users. Event-study analyses, including those obtained using Callaway and Sant'Anna (2021) estimates, produce findings consistent with parallel pre-treatment trend. Second, we find no evidence that legalization of recreational marijuana increases adult tobacco use. The preponderance of the evidence suggests that RML adoption is associated with a small, lagged decline in tobacco use. NSDUH-based estimates suggests that two or more years after the adoption of an RML, legalization is associated with an approximately 0.5 to 2 percentage-point decline in tobacco use, including from cigarette consumption. Individual fixed effects estimates from the PATH show that RMLs are associated with a significant 1-to-2 percentage-point lagged decline in ENDS use. Third, we find that RML adoption accompanied by the opening of recreational marijuana dispensaries is associated with larger increases in ENDS use than RML adoption without open dispensaries. We conclude that the availability of recreational dispensaries is an important supply channel to explain substitution between marijuana and tobacco among adults.

2. Background

Much of the public health literature exploring the relationship between marijuana and tobacco use has been correlational in nature (Choi et al., 2019). In the main, these studies tend to find that tobacco use and marijuana use co-occur (McClure et al., 2018; Trivers et al., 2018; Goodwin et al., 2018; Ramo et al., 2013; Beenstock and Tahov 2002; Bentler et al., 2002; Agrawal et al., 2007; Leatherdale et al., 2007), or that higher marijuana use follows tobacco use (Driezen et al., 2022). While early marijuana users are more likely to initiate cigarette use (Agrawal et al., 2008; Behrendt et al., 2009) and are less likely to quit tobacco use (Richter et al., 2002) than their abstaining counterparts, this does not necessarily imply that the two substances are complements.[5] Failing to econometrically account for factors that jointly determine use — through, for example, a policy shock that affects relative costs — could mean that consumption of both goods simply reflects difficult-to-measure personal characteristics such as one's discount rate, family support system, or peer quality.

More compelling evidence on the complementarity or substitutability of marijuana and tobacco tends to come from studies that have used state-specific policy shocks for identification (Anderson and Rees Forthcoming; Farrelly et al., 2001; Anderson et al., 2020). For instance, exploiting state changes in excise taxes on cigarettes, Farrelly et al. (2001) found that raising cigarette taxes reduced the intensity of marijuana use among individuals 12–20 years of age, suggesting that marijuana and tobacco may be complements for some youths. On the other hand, Anderson et al. (2020) found that increases in state cigarette taxes were essentially unrelated to youth marijuana use. Pesko et al. (2016) and Dave et al. (2019) found that e-cigarette minimum legal purchase age law adoption did not affect youth marijuana use. Finally, a new working paper by Hansen et al. (2020) exploits within-state variation in a new tobacco control policy —Tobacco-21 (T21) laws (which raise the minimum legal purchasing age to 21 for tobacco products) — and find some evidence that restricting access to cigarettes reduces marijuana use among 18-year-olds.[6]

[4] In December 2019, the Federal Tobacco to 21 Act was adopted by the U.S. Congress (https://www.congress.gov/bill/116th-congress/senate-bill/1258/text).

[5] In the reverse direction, public health literature has also found that 18-to-25-year-olds are almost an order of magnitude more likely to consume marijuana if they previously used tobacco products (Lai et al. 2000).

[6] Note that for outcomes at the extensive margin, symmetric cross-price effects are not a necessary property of demand functions without the imposition of requisite restrictions on parameters in the utility function. Thus, studies that have assessed the relationship between cigarette/tobacco use and marijuana use through variation in tobacco policy (i.e. variation in the full cost of tobacco use) may be of limited use in deciphering this relationship in the reverse direction, that is how tobacco use may respond if there are shifts in the full cost of marijuana use.

Four studies of which we are aware have explored the relationship between the enactment of medical marijuana laws (MMLs) and tobacco consumption (Choi et al., 2019; Andreyeva and Ukert 2019; Veligati et al., 2020; Anderson et al., 2020), three of which focus on adults.[7] Veligati et al. (2020) and Andreyeva and Ukert (2019) find that MMLs are unrelated to per capita cigarette sales and cigarette use, respectively. On the other hand, using data across three national datasets spanning two and a half decades, Choi et al. (2019) find consistent evidence that MMLs are associated with a 1 to 1.5 percentage-point decline in smoking participation, as well as a decline in cigarette use at the intensive margin (number of cigarettes consumed per day among smokers).

While results from the MML-tobacco literature are informative, particularly because we might expect that a non-trivial share of marijuana consumption that was induced by MMLs was for recreational purposes (Anderson et al., 2013), it is not clear that the treatment effects will be similar for RMLs for a number of important reasons. The explosion of the electronic cigarette market, particularly since 2010, may result in different tobacco-related behavioral responses to increased access to marijuana. In addition, the regulatory environment for tobacco, including the adoption of T-21 laws, e-cigarette taxes, and tightening of clean indoor air laws, has changed in ways that may affect how a reduction in the shadow price of marijuana affects tobacco use. Relatedly, the marginal adult smoker may have changed vis-à-vis RML adoption as compared to MML adoption, perhaps with a relatively more inelastic demand for tobacco. Finally, the medical requirements to gain access to marijuana under an MML regime (i.e., permissible to purchase for "allowable medical conditions") may have resulted in more medicinal users to be affected by MMLs relative to RMLs. Such consumers may differ in their responses to changes in relative prices of marijuana to tobacco.

The literature on RMLs and adult tobacco use is quite nascent. Alley et al. (2020) use data from the National College Health Assessment (NCHA-II) from 2008 to 2018 in conjunction with a two-way fixed effects approach and find that RMLs are unrelated to tobacco use among college students. Two other studies use data on cigarette sales. Miller and Seo (2018) use Nielsen Retail Scanner data over the period 2013–2016 to explore the impact of marijuana prices on tobacco sales in Washington state. Using county-level variation in legal access to recreational marijuana across retailers as an instrumental variable (IV) for marijuana prices, they find that tobacco sales declined in response to legalization.

Veligati et al. (2020) use state-by-year data from the 1990–2016 Alcohol Epidemiologic Data System (AEDS) to explore the relationship between recreational legalization and tobacco sales. Using a two-way fixed effects model, they find that RML adoption is associated with a statistically insignificant 0.198 decline in per capita cigarette sales. While descriptively interesting, the study (i) solely examines tobacco cigarette sales without attention to electronic cigarettes, cigars, smokeless tobacco, or pipe tobacco, (ii) relies on only four (4) states (Washington, Colorado, Alaska, Oregon) and the District of Columbia for identification, only two (Colorado and Washington) of which include post-treatment data of three years (which may be inadequate to detect medium- to long-run tobacco effects), (iii) provides no descriptive tests of parallel pre-treatment trends in tobacco use or exploration of lagged effects of RMLs, and (iv) does not employ new difference-in-differences estimators designed to expunge bias due to heterogeneous and dynamic treatment effects.[8]

3. Data

3.1. Preliminary analyses using national survey of drug use and health (NSDUH)

Our preliminary analyses use repeated cross-sectional data on marijuana and tobacco use among those ages 18-and-older from the 2002–2019 National Survey on Drug Use and Health (NSDUH), provided by the Substance Abuse and Mental Health Services Administration (SAMSHA).[9] While geocoded individual NSDUH data are not easily made available for scholars outside of the Centers for Disease Control and Prevention (CDC), two-year overlapping state-by-year averages are publicly available.

Adult prevalence rates are compiled using a survey item that asks respondents to report the number of days in the last month on which s/he "use[d] marijuana or hashish." A calculation of weighted means shows that over the 2002–2019 period, 7.5 percent of respondents ages 18 and older reported marijuana use on a positive number of days during the past month. While we would prefer to disaggregate the NSDUH data around the minimum legal purchase age (MLPA) of 21, the publicly available data only permit the disaggregation of 18-to-25-year-olds and those ages 26-and-older. An important advantage of the PATH data (described below) is that we can explore heterogeneity in the estimated treatment effect around the MLPA of 21. When we disaggregate adult marijuana

[7] Anderson et al. (2020) use data from the Youth Risk Behavior Surveys and find that MML adoption is associated with declines in marijuana use and cigarette use for U.S. high school students.

[8] With respect to youths, Vuolo, Lindsay, and Kelley (2022) use data through 2015 from the National Longitudinal Survey of Youth 1997 and find no evidence that cannabis liberalization affects youth and young adult smoking. Here, short-run treatment effects are essentially identified from the two earliest-adopting RML states (Washington and Colorado).

[9] The NSDUH is a household survey representative of the U.S. non-institutionalized population. The survey is administered in individuals' homes, which may include private homes, public housing, and non-institutional group quarters (i.e., college dorms, rooming houses, shelters). However, neither residents of hospitals and jails nor homeless individuals (who do not reside in shelters) are included in the NSDUH sample. Information on health behaviors is collected via an individual audio computer-assisted self-administered interview to increase privacy and the likelihood of a truthful response.

consumption by age using publicly available NSDUH data, we find that 18.8 percent of 18–25-year-olds and 5.5 percent of those ages 26 and older used marijuana in the prior month. Panel (a) of Appendix Fig. 1 shows trends in marijuana use for each of these age groups over the full sample period. We find that marijuana consumption rose rapidly from 6.0 percent in 2002 to a height of 11.1 percent in 2019.

Next, we measure tobacco product use, defined as prior-month consumption of the following tobacco products: cigarettes, smokeless tobacco, cigars, and pipe tobacco. In Appendix Table 1A, we show that 28.3 percent of adults ages 18-and-older — 37.8 percent of those ages 18-to-25 and 26.6 percent of those ages 26-and-older — used a tobacco product in the last month. Panel (b) of Appendix Fig. 1 shows trends in adult tobacco product use over the period 2002–2019. We find that between 2002 and 2019, tobacco product use for all adults declined dramatically from 32.9 percent to 23.0 percent. Among younger adults ages 18-to-25, the decline in use was even more rapid, from 45.1 percent in 2002 to from 25.1 percent in 2019.

In addition, publicly available NSDUH data provide information on cigarette consumption among adults. We find that 23.6 percent of adults ages 18-and-older, including 31.8 percent of those ages 18-to-25 and 22.2 percent of those ages 26-and-older, used cigarettes in the past month (Appendix Table 1A). Trends in cigarette use in Panel (c) of Appendix Fig. 1 show similar movements as those in Panel (b), with 27.2 percent of cigarette smoking participation in 2002, falling to 18.4 percent in 2019. Moreover, at least descriptively, there does not appear to be a moderation in the downward trend in cigarette use over the past decade, when marijuana use experienced a resurgence after remaining largely stable since the late-1990s.

An important drawback of the publicly available NSDUH data are they do not allow us to study dynamic consumption effects of RMLs on marijuana and tobacco use. Moreover, they do not permit us to study joint consumption effects or control for individual-level fixed effects. To complement the NSDUH, we next turn to the PATH for our primary analyses.

3.2. Main analyses using population assessment of tobacco and health (PATH)

Our primary analyses use the PATH, a nationally representative longitudinal cohort study jointly conducted by the National Institutes of Health (NIH) and the Food and Drug Administration (FDA) that ascertains patterns of tobacco product use and health among youth and adults (Hyland et al., 2017). To further supplement estimates from other datasets, we utilized all five available waves of restricted use adult survey data from the PATH study, spanning 2013 to 2019 (United States Department of Health and Human Services, 2022). A cohort of 32,320 adults was established in the first wave of the study using a four-stage stratified area probability sample design and followed at each subsequent wave. At wave 4, additional adults were sampled to replenish the cohort. Respondents from the PATH youth sample who “age up” when they reach 18 years of age also entered the adult sample at each wave. Altogether, our analytic sample consisted of 156,945 observations across all five waves of data collection for adults.[10] Weighted estimates are reflective of the U.S. adult civilian non-institutionalized population. Our primary PATH sample is comprised of adults ages 18-and-older and ages 21-and-older, the latter of which includes those aged at or above the minimum legal purchase age for recreational marijuana.[11]

The PATH dataset offers several key advantages that complement other analyses. First, the longitudinal nature of the data allows us to assess initiation and cessation of tobacco and marijuana products from wave to wave to conduct survival analysis. Second, more detailed measures of marijuana use are available than were in the NSDUH, including the number of days that survey respondents used blunts containing marijuana in the last month, as well as specific routes of consumption (e.g., vaped, smoked as a blunt). Third, the PATH provides detailed measures of tobacco use, covering the timing and amount of use for many combustible tobacco products and ENDS. The inclusion of these survey items allows us to create measures of dual use of marijuana and other tobacco products. Finally, the individual panel data allows us to include individual fixed effects in our models and capture unmeasured person-specific heterogeneity.

We created various measures of marijuana and tobacco use to capture different aspects of consumption. Marijuana measures include prior-month use of “marijuana, hash, THC, grass, pot or weed;” use of any cigar product as blunts; or use of “marijuana, marijuana concentrates, marijuana waxes, THC, or hash oils” in e-products. The PATH shows that 10.3 percent of adults ages 18-and-older consumed marijuana in the last month, 2.6 percent reported past month blunt use, 1.9 percent reported past two-day vaped marijuana use, and averaged 0.3 days of blunt use in the past month.[12] Among prior-non-users of marijuana use at baseline, 10.3 percent initiate marijuana use at some point following baseline; among marijuana users at baseline, 48.5 percent cease using marijuana at some point following baseline.

[10] We drop 11 observations due to unclear state of residence and 5 observations due to unknown age.

[11] In addition, we include additional subgroups of individuals ages 18-to-20, 21-to-25, and 26-and-older in the Appendix. For these age-specific analysis samples, participants were included in analyses when they contributed at least 2 waves of data.

[12] Some measures, such as vaped marijuana measures and number of days of blunt use, were not available across all waves. There was also variation in survey skip logic and wording for some items across waves. For instance, our past two-day vaped marijuana measure is based on an item introduced in PATH wave 3. In wave 3, the item asks, “when did you last use marijuana, marijuana concentrates, marijuana waxes, THC, or hash oils in an [EPRODTYPE1]?” in which “EPRODTYPE1” is replaced with a specific product (e.g. “e-cigarette” or “e-hookah”) based on the respondent’s previously indicated primary electronic nicotine product. In subsequent waves, the item’s dynamic text is replaced with the same set of examples for all respondents: “an electronic product such as an e-cigarette, vape, mod, personal vaporizer, e-hookah, or hookah pen.” The skip pattern is conceptually the same across waves, posing the question to all adults who have ever used marijuana in an electronic nicotine product, but waves 4 and 5 include an additional item asking about frequency of marijuana use when using ENDS, that was introduced in wave 4.

Tobacco use includes all tobacco products, including combustible tobacco products, snus, smokeless tobacco, dissolvables, and ENDS. We differentiate among tobacco products by examining (1) combustible tobacco, which includes cigarettes, traditional cigars, cigarillos, filtered cigars, pipes, and hookah, (2) cigarettes, (3) cigars (including traditional cigars, filtered cigars, and cigarillos), and (4) ENDS (defined as e-cigarettes or other electronic nicotine devices). In the analysis sample comprised of adults ages 18-and-older, we find that 25.2 percent used combustible tobacco products in the last month, 21.6 percent used cigarettes in the last month, 7.0 percent consumed cigars in the last month, and 6.9 percent reported ENDS use in the last month. We further find that 6.5 percent used both marijuana and combustible tobacco products in the prior month, while 2.3 percent used marijuana and ENDS in the prior month. These means, along with the means of our dynamic dual consumption measures, are shown in Appendix Table 1A. For example, we find that 2.7 percent of baseline non-users of marijuana and combustible tobacco products initiated later use of both products, while 2.7 percent of baseline non-users of marijuana and ENDS initiated later use of both products.

4. Methods

We capitalize on the considerable variation in the adoption of RMLs across states and over time to identify their short and longer-term effects on tobacco use behaviors.

4.1. Empirical models for NSDUH

We begin by using state-by-year data from the NSDUH and estimate a two-way fixed effects (TWFE) difference-in-differences model using the following specification:

$$Y_{st} = \gamma_0 + \gamma_1 RML_{st} + \gamma_2 MML_{st} + \mathbf{X}_{st}\boldsymbol{\beta} + \alpha_s + \theta_t + \varepsilon_{st}, \tag{1}$$

where Y_{st} denotes the prevalence rate of the outcome of interest (marijuana use, tobacco use, or cigarette use) for adults in state *s* in survey wave *t*.[13] The primary independent variable of interest, RML_{st}, measures the share of the period *t* for which state *s* has an RML in effect.[14] In alternate specifications, we explore heterogeneity in the effects of recreational marijuana laws by whether recreational sales are permissible.[15] We control for whether state *s* had enacted a medical marijuana law (MML) at wave *t*. Every state that adopted an RML had previously enacted an MML. Therefore, the LATE we identify is the marginal effect of an RML over and above an MML.

The vector $\mathbf{X}_{st}$ includes a set of state-specific, time-varying controls for demographic characteristics of the state population (the share of the state population that was female, Black, Hispanic, and college educated, as well as the average age of the population), macroeconomic controls (unemployment rate, poverty rate, and the log of average pre-tax personal income), tobacco control policies (index of indoor vaping restrictions, the presence of an electronic cigarette minimum legal sales age, per pack excise tax on cigarettes, an index of indoor smoking restrictions, and the minimum age for cigarette sales), other social welfare policy controls (Earned Income Tax Credit refundable credit rate, the per hour minimum wage, whether the governor was a Democrat, whether the state had enacted a Medicaid expansion as part of the Affordable Care Act, the presence of a Prescription Drug Monitoring Program - PDMP, and the beer tax per gallon).[16] In addition, α_s is a time-invariant state effect, and θ_t is a state-invariant wave (year pair) effect. All regressions are weighted using the relevant population of adults (ages 18 and older, ages 18-to-25, or ages 26 and older) and standard errors are clustered at the state level (Bertrand et al., 2004).

Our key parameter of interest, γ_1, is the reduced-form relationship between RML enactment and adult tobacco (or marijuana use). Identifying variation comes from within-state enactment of RMLs. Appendix Table 1B lists the effective dates of RMLs for the period 2000–2019 along with the dates that recreational sales of marijuana were permitted (Anderson and Rees, Forthcoming). A total of 11 states contribute to identifying the parameter γ_1. The estimated policy impact will be unbiased if the control states capture how RML states' tobacco use would have evolved in the absence of RML adoption. While testing this assumption is not possible given the unobservability of the counterfactual, we take a number of tacks to descriptively provide evidence in support of the identifying assumption. First, we estimate event-study analyses, where we decompose the estimated treatment effect over time:

$$Y_{st} = \gamma_0 + \sum_{j=\underline{J}}^{\bar{J}} \pi^j D_{st}^j + \gamma_2 MML_{st} + \mathbf{X}_{st}\boldsymbol{\beta} + \alpha_s + \theta_t + \varepsilon_{st}, \tag{2}$$

where D_{st}^j it is a treatment indicator for an event (RML enactment) happening *j* periods away from *t*, where treatment indicators are binned at the "endpoints" (the last open-ended lead and lag variables). The vector π denotes the coefficients on the treatment effect,

[13] SAMHSA provides publicly available state-specific estimates for two-year averages (i.e., 2002-2003, 2003-2004…2018-2019). As in Sabia et al. (2021), we use overlapping state panels in the analyses, and match information on RMLs based on the month and year of enactment. The values for the controls in the vector X are also calculated as the weighted average of these measures over the two-year window that comprises each data wave.

[14] For instance, if a state enacted an RML on July 1, 2015, the value of RML_{st} for the 2013-2014 wave would be 0; for 2014-2015 ,0.25, for 2015-2016, 0.75, and for 2016-2017 and later 1.

[15] Note that nearly all RML states permit home cultivation of small quantities of marijuana, which is likely to result in some immediate effects on marijuana consumption (see Sabia et al. 2021), but lags in the opening of dispensaries for recreational sales following the adoption of RMLs may also result in delayed consumption responses and potential spillovers into other behaviors such as tobacco use.

[16] Means of state-level control variables are shown in Panel V of Table 1.

with the reference period being *j-1*, the year prior to RML enactment. If the estimates of π for the period [$\underline{J}$, *j-2*] are equal to 0, this would provide evidence in support of the parallel trends assumption.

Second, we examine the robustness of our estimates to the inclusion of state-specific linear time trends. This control may aid in reducing omitted variables bias by controlling for unobserved state trends unfolding linearly that are incidentally correlated with the enactment of an RML and with tobacco use. However, this additional control may come at a cost. If there are dynamic treatment effects of RMLs on tobacco use, then the inclusion of such time trends may obscure important treatment effects (Wolfers 2006). Moreover, it is not always the case that the policy variation that remains following the inclusion of such controls is necessarily more orthogonal to ε_{st} than the policy variation exploited when such time trends are omitted (Neumark et al., 2014). Thus, we are careful in interpreting estimates that include these trends.

Third, recent advancements in the difference-in-differences literature caution that in the presence of heterogeneous dynamic treatment effects, estimates of γ_1 from Eq. (1) and π_j from Eq. (2) may be biased (Goodman-Bacon 2021; Sun and Abraham 2021). To explore this possibility, we take two tacks. We estimate a Goodman-Bacon (GB) decomposition of γ_1 into the possible two-by-two comparisons that generate this estimate: (i) early RML adopters versus later RML adopters, (ii) later RML adopters versus early RML adopters, and (iii) ever adopters versus never adopters. If, as we might expect given that there are 40 never-adopters in our sample, the vast majority of the "weight" in the GB decomposition is given to the two-by-two comparisons described in (i) and (iii), it is less likely that our estimated treatment effects are biased due to heterogeneous treatment effects over time. In the presence of dynamic treatment effects, it is the use of early RML adopters as a counterfactual for identifying effects for later RML adopters that presents the problematic comparison.

In addition, we employ a new estimator proposed by Callaway and Sant'Anna (2021) to expunge potential biases arising in the standard TWFE estimator with staggered treatment adoption in the presence of dynamic heterogeneity in the treatment effects. Here, we explicitly select never adopters as the counterfactuals for each RML-adopting state to estimate our treatment effect and event study coefficients. A comparison of Callaway-Sant'Anna estimates to those generated via TWFE models will allow us to further assess the degree to which heterogeneous dynamic treatment effects are an important source of bias.

Finally, to more fully explore heterogeneity in the effects of RMLs across treatment states, as well as allow for longer lagged effects of RMLs on tobacco use, we turn to a synthetic control approach (Abadie et al., 2010). Specifically, we examine effects for the six earliest adopting RML states, for which we have at least 3 years of post-treatment data. Following Sabia et al. (2021), we select a donor pool comprised of states that never enacted an RML over our sample window. In addition, to ensure that our donor pool is not contaminated from the effects of post-RML MML adoption by donors, we select the donor pool from within the non-RML states that also did not enact any MML in the post-RML period. We then generate a synthetic control state for each RML state that closely approximates adult tobacco use prevalence rates in each wave (year pair) of the pre-treatment period.

We generate the counterfactual tobacco prevalence rate in pre-treatment wave *t* by $\sum_n w_n * \textit{Tobacco Use Rate}_{nt}$, where w_n is the weight assigned to donor state *n* and choose w_n^* to minimize the absolute difference between $\textit{Tobacco Use Rate}_{RML,t}$ (the tobacco use prevalence rate of the RML state at wave t) and $\sum_n w_n * \textit{Tobacco Use Rate}_{nt}$ (the tobacco use prevalence rate for the synthetic control) and for all pretreatment waves. The ATT is then the average difference in the tobacco use prevalence rate for the RML (treatment) state and its synthetic control in the post-treatment period. Permutation-based p-values from placebo tests (randomly assigning treatment to each donor state) are generated in order to conduct statistical inference.

4.2. Empirical models for PATH

This study is the first in the recreational marijuana literature to use individual-level nationally representative panel data. The longitudinal nature of PATH allows us to estimate specifications that (1) control for person-specific time-invariant unmeasured heterogeneity, and (2) capture dynamic consumption responses to the adoption of RMLs, including dual use of marijuana and tobacco products as well as initiation and cessation of marijuana and tobacco use. All regressions are weighted using survey-provided sample weights to generate a nationally representative sample of adults and standard errors are clustered at the state level.

Our PATH analysis generates estimates from the following regression equation:

$$Y_{ist} = \delta_0 + \delta_1 RML_{st} + \delta_2 MML_{st} + \boldsymbol{X}_{ist}\boldsymbol{\kappa} + \alpha_s + \theta_t + \mu_i + \varepsilon_{ist}, \tag{3}$$

where *i* indexes the individual survey respondent and θ_t is a year-by-month fixed effect. In this specification, some of the controls in the vector $\mathbf{X}_{ist}$ are now measured at the individual level, including gender, race/ethnicity, and educational attainment. One of the advantages of using the individual-level data will be our ability to explore heterogeneous treatment effects by these individual characteristics. In addition, Eq. (3) incorporates individual-level fixed effects (μ_i) to account for stable person-specific heterogeneity, such as stable risk- and time-preference and lifetime exposure to tobacco control prior to the respondents' first observation in the PATH. The outcome Y_{ist} will include current marijuana use, current use of any tobacco product, and specific tobacco products (cigarettes, cigars, e-cigarettes), as well as dual use of marijuana and tobacco products.

Analogous to our NSDUH-based analysis, we also estimate event studies in the spirit of Eq. (2), except with controls for individual fixed effects and year-by-month fixed effects. Moreover, we also explore heterogeneity in the effects of RMLs by whether recreational dispensaries were opened in the state.

Second, to assess the dynamics of how exposure to RMLs specifically affects the probability of initiating cigarette use or use of other tobacco products among tobacco abstainers (a margin that may be salient for younger adults) and affects the probability of quitting cigarette use or use of other tobacco products (a margin that may be more salient for older adults), we exploit the longitudinal structure of the PATH and estimate discrete-time hazard models.

$$Prob(S_{ist} = 1 \mid t-1 < T < t) = \delta_0 + \delta_1 RML_{st} + \delta_2 MML_{st} + X_{ist}\boldsymbol{\kappa} + \alpha_s + \theta_t + \mu_i + \varepsilon_{ist} \quad (4)$$

The discrete time hazard specification in Eq. (4) models the conditional probability of switching across margins of tobacco use (*S*) between periods *t-1* and *t*. When studying initiation, the sample is restricted to adults who had not used tobacco at baseline, and an indicator is defined for transitioning to tobacco use in period *t*, conditional on being an abstainer in period *t-1*. Similarly, when studying cessation, the sample is restricted to tobacco users at baseline, and an indicator is defined for transitioning to no reported use in period *t*, conditional on being a user in period *t-1*. The parameter of interest, δ_1, above can be interpreted as changes in the transition probability between states of consumption as affected by the RMLs. We also estimate similar models, with the PATH, for transitioning into marijuana initiation and marijuana cessation. Additionally, we explore transition into marijuana use among baseline tobacco users, and transition into dual use (of both marijuana and tobacco) among baseline abstainers. As with Eq. (3), we also explore heterogeneity in the effects of RMLs by whether recreational dispensaries had opened.

5. Results

5.1. NSDUH results

Marijuana Use. In the first three columns of Table 1, we provide "first-stage" estimates of the effect of RMLs on marijuana consumption among those ages 18-and-older (column 1), ages 18-to-25 (column 2), and ages 26-and-older (column 3). For all adults (panel I, column 1), we find that RML adoption is associated with a 4.1 percentage-point increase in prior-month marijuana consumption. A decomposition of the RML effect in the year of adoption, one year following adoption, two years following adoption, and three or more years following adoption shows effect sizes ranging from 2.5 percentage-points (year of enactment) to 4.7 percentage-points (three or more years after enactment), consistent with a consumption effect that increases over time. While self-reporting of marijuana consumption may be measured with error and could reflect, in part, RML-induced reductions in social stigma (and penalties) associated with marijuana use, evidence from marijuana arrests (Sabia et al., 2021) and emergency department (ED) visits for marijuana-related vomiting (Wang et al. 2021) suggest that the increase in reported marijuana use we detect also captures increases in consumption.

When we separately examine younger adults ages 18-to-25 (column 2) and older adults ages 26-and-older (column 3), we detect evidence of RML-induced increases in consumption for both age groups. For 18-to-25-year-olds, RML adoption is associated with a 4.5 percentage-point increase in prior-month marijuana use (column 2, panel I), while for those ages 26-and-older, the treatment effect size is 4.1 percentage-points (column 3, panel I). Both groups see larger marijuana use increases in the longer run (three or more years following adoption) as compared to the year of adoption.[17]

Appendix Fig. 1 shows event study analyses of RMLs and prior-month marijuana use among adults using TWFE estimates (panel I) and Callaway-Sant'Anna estimates (panel II). The pattern of findings is consistent with parallel pre-treatment trends, and with marijuana use increasing in the years following RML enactment. The general consistency of Calllaway and Sant'Anna (2021) and TWFE estimates is not surprising given that a Goodman-Bacon decomposition places 92.9 percent of the weight of the TWFE estimator on "ever vs. never" adopters and 5.5 percent of the weight was placed on "early vs. later" adopters. Just 1.6 percent of the weight of the TWFE estimator was comprised of the potentially problematic comparison of "later vs. earlier" adopters.

Together, these first-stage findings are consistent with those reported in Sabia et al. (2021) and Hollingsworth et al. (2022).

Tobacco Use. Establishing the first-stage effect of RMLs on marijuana consumption is important for framing what the maximal effect would potentially be if there are spillover responses into smoking and other tobacco use given that these individuals (those who shift their marijuana consumption in response to the policies) represent the affected group. The estimated effects of RMLs on tobacco use discussed below are intention-to-treat (ITT) estimates, as most adults in the population would not be affected by RMLs, and thus the estimated reduced-form tobacco use response is an average across two groups (those who are potentially affected by RMLs and those who are not). It is unlikely that RMLs would have a direct effect on tobacco use behaviors, independent of their effect on marijuana use.

In the remaining columns of Table 1, we turn to our main outcome of interest, adult tobacco use. Our findings in columns (4)-(6) of panel I show that RML adoption is associated with a (largely) statistically insignificant 0.5 to 0.7 percentage-point decline in tobacco use, a measure that encompasses cigarettes, pipe tobacco, smokeless tobacco, and cigars. However, this null effect masks small, lagged tobacco effects of RMLs. Three or more years following the adoption of an RML, we find that adult tobacco use falls by approximately 1.4 to 2.7 percentage-points (columns 3–6, panel II). The lagged effect three or more years after RML enactment is uniformly statistically different from zero at conventional levels. Importantly, the absolute magnitudes of these tobacco effects are one-fourth to

[17] Appendix Table 2 shows the sensitivity of estimates in Table 1 to the inclusion of state-specific linear time trends. The results continue show that RML adoption is associated with an increase in adult marijuana use and a lagged decline in tobacco use, though the estimated treatment effects are somewhat smaller (in absolute magnitude). In the main, these findings are also consistent with those reported by Dave et al. (2022).

Table 1
TWFE estimates of effects of recreational marijuana laws on prior-month marijuana and tobacco use, NSDUH.

	Prior-Month Marijuana Use			**Prior-Month Tobacco Use**			**Prior-Month Cigarette Use**		
	Ages 18-and-older	*Ages 18-to-25*	*Ages 26-and-older*	*Ages 18-and-older*	*Ages 18-to-25*	*Ages 26-and-older*	*Ages 18-and-older*	*Ages 18-to-25*	*Ages 26-and-older*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel I: Overall RML Effect									
RML	0.0414***	0.0454***	0.0408***	−0.00503	−0.00773	−0.00516	−0.00481	−0.00214	−0.00584
	(0.00465)	(0.00937)	(0.00435)	(0.00475)	(0.00827)	(0.00475)	(0.00444)	(0.00814)	(0.00460)
Panel II: Lagged RML Effects									
Year of RML Enactment	0.0251***	0.0321***	0.0239***	0.000536	0.000136	0.000471	−0.00226	−0.00409	−0.00210
	(0.00372)	(0.00764)	(0.00371)	(0.00359)	(0.00509)	(0.00389)	(0.00338)	(0.00510)	(0.00358)
1 Year After RML	0.0338***	0.0385***	0.0329***	0.00173	−0.000136	0.00158	−0.00112	−0.0000145	−0.00177
	(0.00594)	(0.00908)	(0.00589)	(0.00384)	(0.00687)	(0.00405)	(0.00435)	(0.00678)	(0.00474)
2 Year After RML	0.0373***	0.0406***	0.0366***	−0.00343	0.00122	−0.00457	−0.00297	0.00685	−0.00497
	(0.00788)	(0.0135)	(0.00737)	(0.00483)	(0.0113)	(0.00478)	(0.00524)	(0.0120)	(0.00514)
3 Years+ After RML	0.0471***	0.0451***	0.0477***	−0.0156**	−0.0265***	−0.0146**	−0.0108**	−0.0127**	−0.0113**
	(0.00316)	(0.00718)	(0.00278)	(0.00621)	(0.00562)	(0.00682)	(0.00450)	(0.00603)	(0.00501)
Pre-Treatment Mean DV	0.0745	0.1877	0.0554	0.2826	0.3783	0.2662	0.2358	0.3184	0.2216
N	867	867	867	867	867	867	867	867	867

***Significant at 1% level **Significant at 5% level *Significant at 10% level.
All estimates are generated via weighted least squares. Demographic controls include gender, age, educational attainment, race/ethnicity; economic controls include unemployment rate, state poverty rate, and log of ACS mean total pre-tax personal income; smoking policy controls include index of indoor vaping restrictions, any e-cig MLSA, total cig taxes, index of indoor smoking restrictions, minimum age for cig sales; other policy controls include: state EITC refundable credit rate, log of minimum wage, whether the governor is a Democrat, presence of an ACA Medicaid expansion, presence of a must access prescription drug monitoring program, and beer tax per gallon. Standard errors corrected for clustering at the state level are in parentheses. All regressions include state fixed effects and year fixed effects.

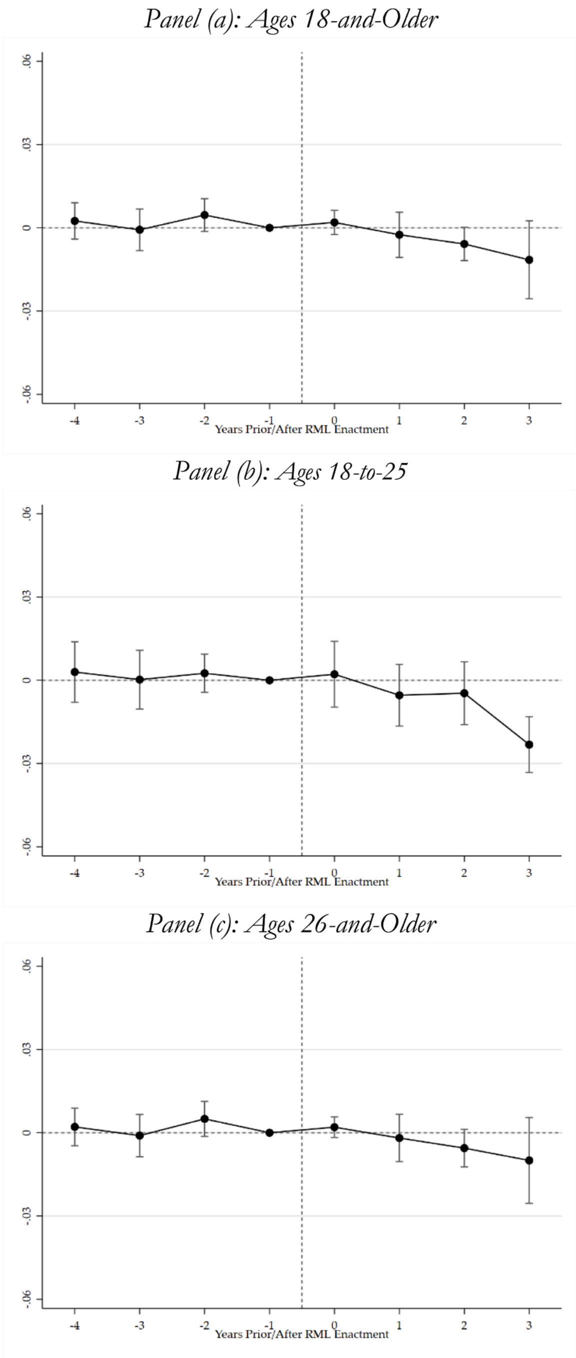

Fig. 1. Event-study analyses of RMLs and prior-month tobacco use, using TWFE estimates, NSDUH
Notes: Population weighted OLS estimates (and their 95% CIs) from an event study regression model are shown.

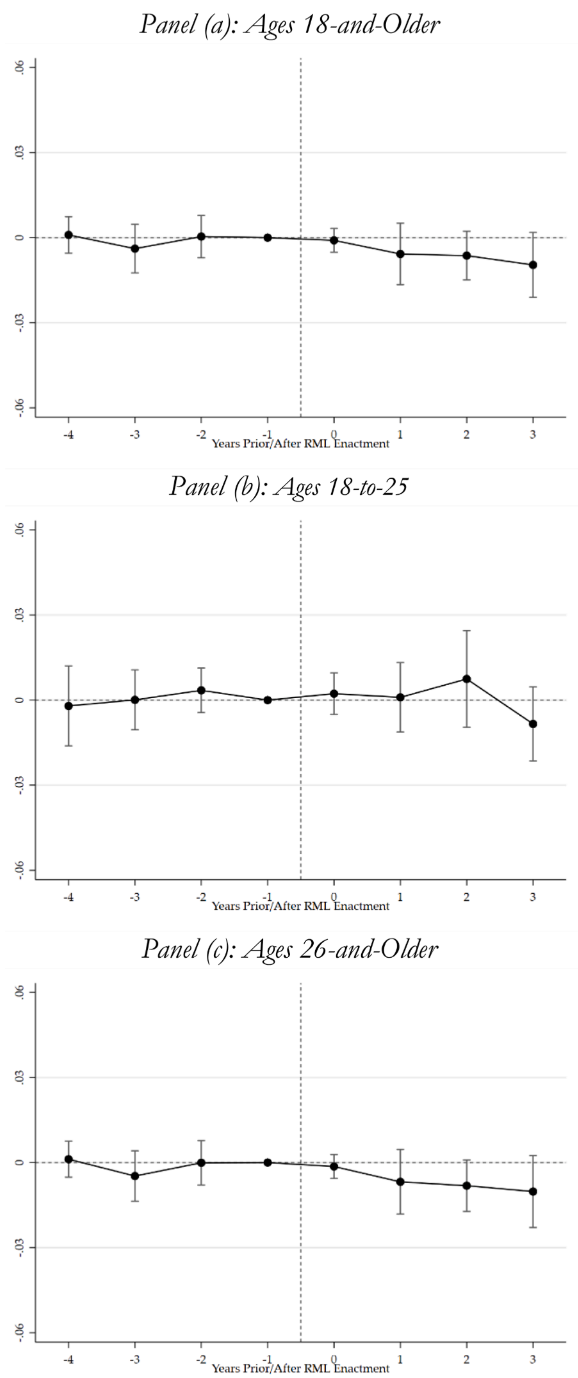

Fig. 2. Event-study analyses of RMLs and prior-month cigarette use, using TWFE estimates, NSDUH
Notes: Population weighted OLS estimates (and their 95% CIs) from an event study regression model are shown.

one-third the size of the first-stage marijuana results in standard TWFE models, which suggests the effect sizes are plausible.

Event-study analyses based on TWFE estimates (Fig. 1) and Callaway and Sant'Anna estimates (Appendix Fig. 2) show evidence of parallel pre-treatment trends in tobacco use, as well as a lagged decline in tobacco use following RML adoption. Together, these results suggest that recreational marijuana and tobacco are substitutes for the average marginally affected individual.

Columns (7)-(9) repeat the above exercise for cigarette consumption. Again, while the overall treatment effect is relatively small (0.2 to 0.6 percentage-points in panel I), three or more years following RML enactment, we find evidence of a statistically significant 1.1 to 1.3 percentage-point decline in cigarette use among adults (panel II). These patterns for cigarette use largely and expectedly mirror the results for tobacco use and suggest that cigarettes and recreational marijuana are substitutes. Event-study analyses using TWFE (Fig. 2) and Callaway-Sant'Anna (Appendix Fig. 3) estimators continue to show that cigarette use was trending similarly in RML and non-RML states prior to RML adoption. Cigarette use declines — with about a 2- to 3-year lag — in RML as compared to non-RML states.[18]

One concern with the estimates presented thus far is that the RML effects could be conflated with the long-run effects of MMLs, as every state that adopted an RML had previously adopted an MML. This long-run effect of MMLs could be driven by the opening of medical marijuana dispensaries, which often occur with a lag following MML adoption. Appendix Table 3 shows the estimated effects of RMLs from an adapted version of Eq. (1) in which we replace the MML_{st} with a set of dummies for the year of MML adoption, one, two, three, four, and five or more years following adoption to capture longer-run MML effects. The findings are quantitatively similar to our main results.[19] Appendix Table 4 shows estimated RML effects from an adapted version of Eq. (1) in which we add an additional control for when medical marijuana dispensaries were permitted to open in the state (Sabia and Nguyen, 2018; Dave et al., 2022; Anderson and Rees, Forthcoming). Again, the findings are quantitatively similar to our main results.

As an additional robustness exercise that allows us to capture longer-run tobacco effects of RML enactment, we explore synthetic control estimates of the effect of RML enactment on tobacco use for the six earliest adopting states. The results, shown in Fig. 3, provide some support for the hypothesis that tobacco use declined in several of the earliest adopting states, most notably in Colorado and Washington, which are also those states that saw the largest increases in marijuana use following RML enactment. This pattern of results is confirmed in Appendix Table 5, which restricts the analysis sample to the four earliest adopting RML states and never adopters and is consistent with the hypothesis that RML-induced increases in recreational marijuana partly substitute for tobacco use for the average marginally affected adult.[20,21]

5.2. PATH results

Next, we turn to longitudinal evidence from the PATH. Table 2 shows results from Eq. (3), which includes individual and year-by-month fixed effects. Among all adults ages 18-and-older (panel I), we find that RML adoption is associated with a 2.0 percentage-point increase in past 12-month marijuana use (column 1) and a 1.9-percentage-point increase in past month use (column 2). The latter effect represents an increase of approximately 17.8 percent relative to the pre-treatment mean in RML states.

[18] The Callaway and Sant'Anna (2021) estimates use observable covariates to generate a propensity score of weighted counterfactuals (never--adopters of RMLs in our case). The "doubly robust" strategy of generating propensity scores does not computationally permit a substantial number of time-varying observables to contribute to the generation of the weighted counterfactual. The use of ordinary least squares as opposed to propensity score weighting permits the use of additional time-varying Xs, but often creates very imprecisely estimated event study coefficients. The event studies using Callaway and Sant'Anna (2021) estimates presented in the appendix use the doubly robust approach with limited covariates. In unreported results, we find that (1) using OLS to estimate propensity scores with additional time-varying controls produces similar Callaway and Sant'Anna (2021) estimates as shown in the appendix, (2) the use of Sun and Abraham (2021) estimates to generate our event study also produces estimates that are qualitatively similar to those obtained using Callaway and Sant'Anna (2021) estimates.

[19] In unreported results available upon request, we estimate RML effects for those states that enacted an MML ten (10) or more years prior to RML adoption. (The average number of years between MML and RML adoption is 12.6 years.) Difference-in-difference estimates on a sample of treatment states that adopted RMLs at least 10 years after MML adoption and control states that did not adopt an RML during the 2000-2019 period generate a quantitatively similar pattern of findings as our main regression results.

[20] We note that if we use the Goodman-Bacon decomposition, we find that the weight for Colorado is 0.11, the weight for Washington is 0.15, and the weight for Oregon is 0.26. Appendix Figure 4 shows the results of a leave-one-state-out at a time analysis. The findings show that while the earliest adopting RML states were important drivers of increases in adult marijuana use and declines in adult tobacco use, the pattern of findings can be detected (albeit with less precision) when the earliest four adopting RML states are excluded from the analysis sample.

[21] Appendix Table 6 shows results from auxiliary analysis from the Behavioral Risk Factor Surveillance System (BRFSS) survey and the Current Population Survey-Tobacco Use Supplements (CPS-TUS). The results provide some evidence of RML-induced declines in cigarette and ENDS use in the BRFSS, but no consistent evidence of cigarette declines in the CPS-TUS.

In the remaining columns of Table 2, we focus on the method by which adults consume marijuana. Our findings in columns (3) and (4) suggest that RMLs are not associated with significant increases in the probability of prior-month blunt use or in the number of days in the past month that an individual uses a blunt. There is stronger evidence that RML adoption is associated with an increase in the probability that an adult vaped marijuana. Specifically, we find that RML adoption is associated with a 0.8 percentage-point (47.1 percent) increase in the probability of vaping marijuana in the prior two (2) days (column 5) and a 1.9 percentage-point (27.1 percent) increase in the probability that an individual had ever vaped marijuana (column 6).[22] Together, given that changes in individuals' reports of "ever vaping" likely capture the initiation margin of consumption, we interpret these estimates as evidence that RMLs likely increase take-up of vaping, a hypothesis that we will directly explore below.[23]

In panel II of Table 2, we focus on individuals above the minimum legal purchasing age for recreational marijuana (age 21). We find that the "first stage" marijuana results in Panel I are largely driven by individuals who are of legal purchasing age.[24]

In column (1) of Table 3, we report lagged effects of RML adoption on prior-month marijuana use. In the main, the results point to significant increases in adult marijuana use in the year of adoption and in the post-treatment period, with the largest significant coefficient observed for two years following RML adoption for those ages 18-and-older (panel I) and 21-and-older (panel II). The event-study analysis shown in panel (a) of Fig. 4 shows that in the pre-treatment period, adult marijuana consumption trends were similar in RML and non-RML states. The increase in reported marijuana consumption following RML adoption occurred immediately and peaked two years later.

The remaining columns of Table 3 show tobacco consumption effects of RML adoption. Consistent with the NSDUH, we find no evidence that RML adoption significantly increased prior-month combustible tobacco use or ENDS use. While estimated lagged effects are positive in most cases for cigarette use (column 2), cigar use (column 4), and all combustible tobacco products (column 5), the effects are uniformly below a percentage-point — often under 0.5 percentage-points — and not statistically distinguishable from zero at conventional levels. Thus, we detect no evidence that RML adoption over the sample period caused a large renormalization of combustible tobacco product use. This is also true at the more intensive margins of behavior (see Appendix Table 8), when we find null effects on everyday cigarette smoking and number of cigarettes consumed per day.

When we turn to ENDS use (column 3), we find evidence consistent with the hypothesis that e-cigarettes and marijuana are substitutes for adults. For adults ages 18-and-older or 21-and-older, we find that RML adoption is associated with a lagged 1.2-to-1.6 percentage-point decline in prior-month ENDS use (panels I and II, column 3). This finding is consistent with auxiliary analysis from a short window (2016–2018) in the BRFSS (column 3, Appendix Table 6). Given recent evidence that ENDS and combustible tobacco products are substitutes (Abouk et al., 2023; Cotti et al., 2022; Pesko 2023), this could also be a factor in understanding the small, positively signed coefficients on cigarettes in column (2).[25,26]

In panels (b) and (c) of Fig. 4, we show event-study analyses of RMLs and adult (1) ENDS use (panel (a), and (2) cigarette use (panel b). The findings in both panels suggest that prior to RML adoption, e-cigarette and cigarette trends were similar in RML and non-RML states. We find strong evidence that ENDS use declines in RML states relative to non-RML states in the post-treatment period, with the effect size somewhat larger (in absolute magnitude) in the longer run. For combustible tobacco, we find little evidence that RMLs are related to combustible tobacco use.[27,28]

In Table 4, we turn to dynamic consumption effects of RMLs on initiation and cessation of marijuana and tobacco products using the

[22] The PATH data do not include information on prior-month marijuana vaping behavior; thus, we are only able to measure *prior 2-day* and *ever* marijuana vaping behavior.

[23] The PATH data also do not include information on consumption of edibles over the analysis period, precluding an empirical examination of this consumption mode.

[24] Appendix Table 7 provides age-specific first-stage estimates of the overall treatment effect and shows that RML adoption is associated with statistically significant increases in marijuana use among those ages 18-to-20 (panel I), ages 18-to-25 (panel II), and ages 26-and-older (panel III). Compared to the NSDUH analyses (Table 1), the effect magnitude is similar for young adults (ages 18-25) and smaller for older adults (ages 26+). This variance may be partly driven by the different sampling frames between the NSDUH (pooled cross-section of nationally representative samples of individuals ages 12+ in each survey year) and the PATH (prospective longitudinal cohort, representative of individuals who were ages 9+ in the first interview wave in 2013-2014). Moreover, given that the PATH study commenced in late-2013, the precise states identifying the treatment effect differ (slightly) across the datasets, which could also contribute to differences. It is notable that this difference in the sample period and the sampling frame also explain the higher marijuana use rates in the PATH, both overall and at baseline (Appendix Table 1A); relative to these higher baseline prevalence rates, the magnitude of the effect size for marijuana use for both younger and older adults is consistently smaller in the PATH analyses than in our NSDUH analyses.

[25] In columns (4) through (6) of Appendix Tables 3 and 4, we explore the robustness of the estimates in Table 3 to the inclusion of controls for lagged MML effects (Appendix Table 3) and the timing of the opening of medical marijuana dispensaries (Appendix Table 4). The results from these specifications are similar to those reported in Tables 2 and 3.

[26] This finding appears to be driven by the extensive margin of prior-month ENDS use as there are much smaller effects on everyday ENDS use (see Appendix Table 8).

[27] In columns (4) through (9) of Appendix Table 5, we restrict the sample to individual-by-month observations from residents of states that were the four earliest RML adopters and non-adopters of RMLs. While the estimated ENDS effects are similar, we detect (among later adopting RML states) some evidence that RMLs are negatively related to cigarette use, consistent with evidence in the NSDUH that marijuana and cigarettes are substitutes for some adults.

[28] In Appendix Table 9, we explore whether the effects on ENDS use are driven by any specific age group. We find evidence of negative effects of RMLs on ENDS use for those ages 18-to-25 and ages 26-and-older, though effects are more precisely estimated for the larger sample of those ages 26-and-older.

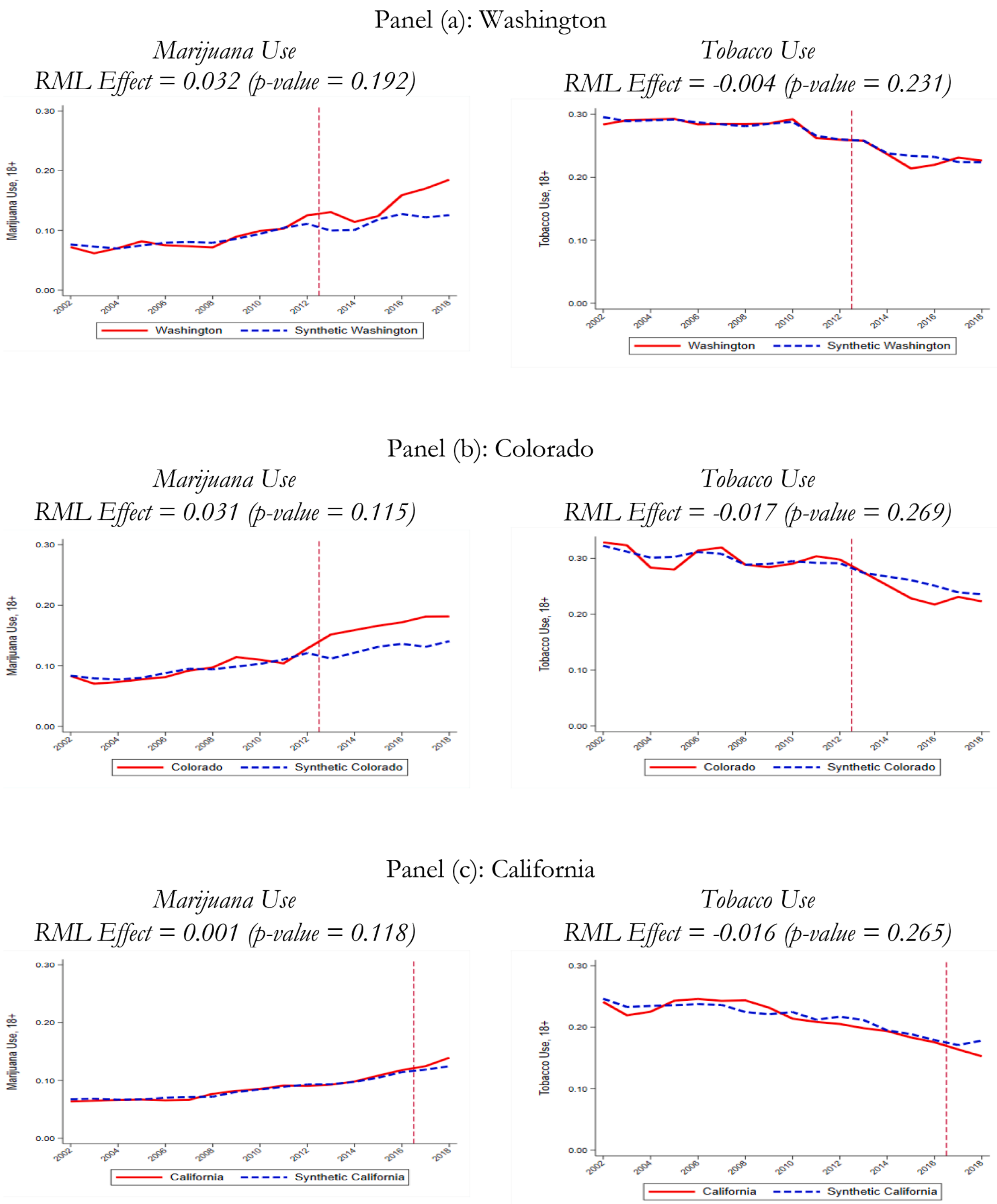

Fig. 3. Synthetic Control Estimates for Early Adopting States
Notes: Synthetic control estimates are obtained by matching on pre-treatment values of the outcome variable in all pre-treatment years. The donor pool is comprised of never-adopting RML states (over the sample period) that also did not enact any MML in the post-RML period.

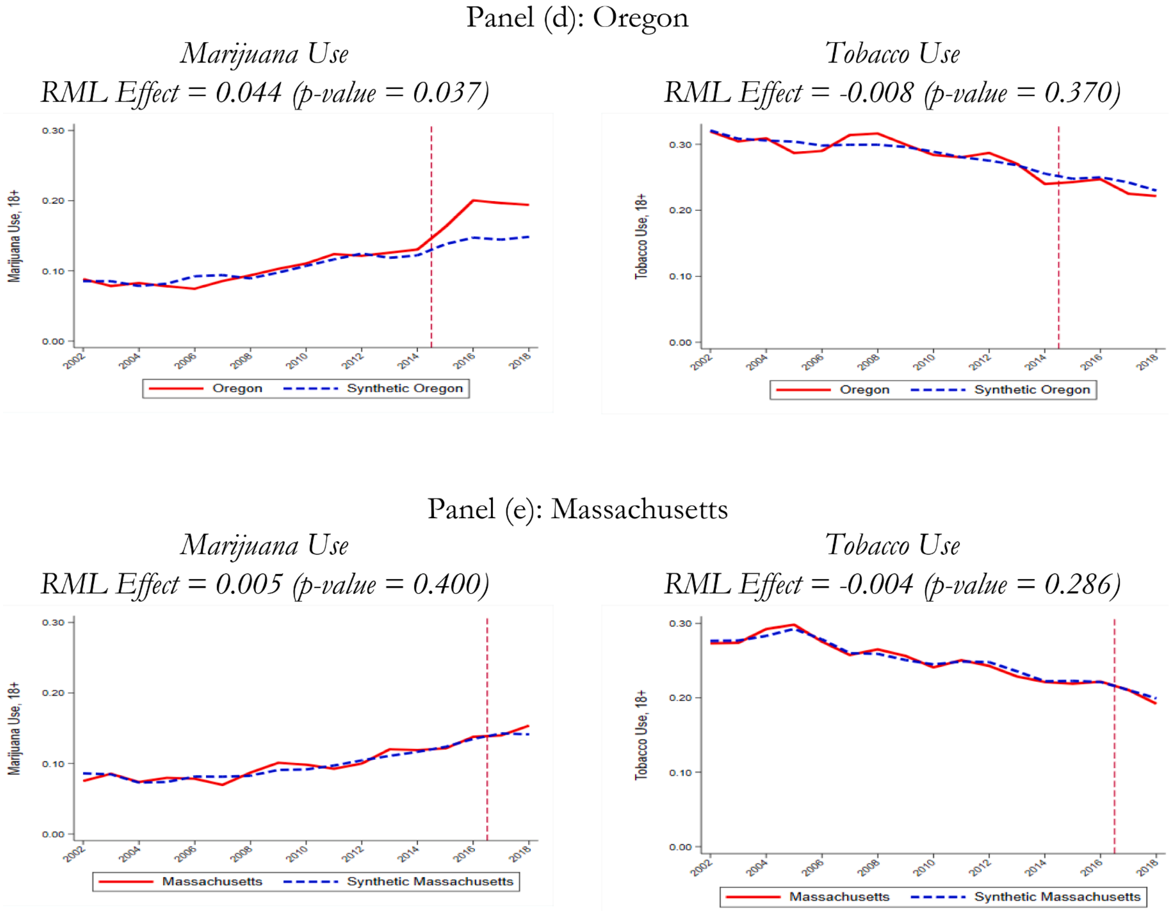

Fig. 3. (*continued*).

discrete-time hazard model described in Eq. (4). This will allow us to uncover whether any of the largely null effects on tobacco use are masking important dynamics in consumption decisions. Our results provide strong evidence that RML adoption is associated with an increase in marijuana initiation among baseline non-users (column 7).[29] RML adoption is estimated to increase the transition probability on the initiation margin by 1.3 percentage-points (50-to-57 percent). There is also evidence that RML adoption is negatively related to the likelihood that baseline marijuana users cease consuming marijuana (column 8), with an estimated reduced transition probability of 1.9-to-2.5 percentage-points (13-to-17 percent). However, these estimated treatment effects are not statistically significantly different from zero, in part because they are underpowered due to a relatively small sample of baseline marijuana users.

Turning to tobacco-related outcomes in columns (1) through (6), we find no evidence that RML adoption significantly increases initiation of tobacco products among baseline non-users or decreases cessation among baseline tobacco users. The negative relationship between RML adoption and ENDS use shown in Table 3 appear to be explained by a combined (though individually insignificant) increase in the probability of cessation and decline in the probability of initiation (columns 5 and 6). Interestingly, we detect evidence that RML adoption is associated with a large (though underpowered) increase in cessation of cigars among baseline cigar users (column 4).[30]

In Table 5, we explore how RML enactment may have impacted dual use of tobacco and marijuana products. The findings in column (1) show that RML adoption is significantly associated with a 1.2-to-1.3 percentage-point (nearly 18 percent) increase in joint use of

[29] Initiation was defined as the first instance of past month use among baseline non-users, while cessation was defined as the first instance of past month non-use among baseline users. For initiation models, only baseline non-users are included, and the individual remains in the sample until use occurs (if ever), and opposite for cessation models.

[30] Appendix Tables 10 to 12 explore the robustness of our PATH-based dynamic consumption estimates to (1) controlling for lagged MML effects, (2) controlling for medical marijuana dispensary openings, and (3) restricting the set of treatment states to the four earliest adopters. In the main these findings are qualitatively similar to those shown in Table 4. Some of the dynamic effects are different when focusing on the earliest adopters, indicative of heterogeneous treatment effects over time (longer post-adoption window) and/or heterogeneity across the earliest vs. later treated states; in Appendix Table 12, there is stronger evidence for RML-induced reductions in ENDS initiation and smaller, less precise estimated effects on marijuana initiation.

Table 2
Individual Fixed Effects Estimates of Effect of Recreational Marijuana Laws on Marijuana Use, PATH.

	Prior-Year Marijuana Use	Prior-Month Marijuana Use	Prior-Month Blunt Use	Prior-Month Number of Days of Blunt Use	Prior-2 Day Vaped Marijuana	Ever Vaped Marijuana
	(1)	(2)	(3)	(4)	(5)	(6)
Panel I: Ages 18 and Older						
RML	0.020*** (0.005)	0.019*** (0.004)	0.001 (0.002)	0.031 (0.048)	0.008*** (0.003)	0.019*** (0.005)
N	156,804	156,671	101,489	83,414	87,457	87,754
Pre-Treatment Mean DV	0.150	0.107	0.026	0.272	0.017	0.070
Panel II: Ages 21 and Older						
RML	0.020*** (0.005)	0.018*** (0.005)	0.002 (0.002)	0.041 (0.053)	0.008*** (0.003)	0.017*** (0.005)
N	132,002	131,898	85,106	68,697	71,226	71,464
Pre-Treatment Mean DV	0.139	0.100	0.021	0.233	0.016	0.065
Years	2013–2019	2013–2019	2014–2019	2015–2019	2015–2019	2015–2019

***Significant at 1% level **Significant at 5% level *Significant at 10% level.
All estimates are weighted. All regressions include individual fixed effects, state fixed effects, year-by-month fixed effects, wave fixed effects, and medical marijuana laws. Demographic controls include gender, age, educational attainment, race/ethnicity; economic controls include unemployment rate, state poverty rate, and log of ACS mean total pre-tax personal income; smoking policy controls include index of indoor vaping restrictions, total e-cigarette taxes, any e-cigarette MLSA, total cigarette taxes, index of indoor smoking restrictions, minimum age for cigarette sales; other policy controls include: state EITC refundable credit rate, log of minimum wage, whether the governor is a Democrat, presence of an ACA Medicaid expansion, presence of a must access prescription drug monitoring program, and beer tax per gallon. Standard errors, in parentheses, are clustered within 156 primary sampling units that are nested within states (except in one instance).

tobacco and marijuana. Conceptually, this increase in dual use could be driven by an (1) increase in marijuana use among baseline current tobacco users; and/or (2) increase in both marijuana and tobacco use among baseline abstainers of both substances.[31] The longitudinal nature of the PATH data allows us to distinguish between these hypotheses in a dynamic consumption framework.

In columns (2) and (3), we present estimates from discrete-time hazard models to parse out which of these margins may be driving the observed increase in dual use. These analyses show a substantial and significant increase in the probability of transitioning from marijuana abstention to marijuana initiation (3.0 to 3.2 percentage points; or nearly 50 percent relative to the baseline mean) among baseline tobacco users (column 2). On the other hand, there is no statistically or economically significant impact on the probability of transitioning to both tobacco and marijuana use among prior abstainers of both substances (column 3). Together, these findings indicate that the RML-induced increase in dual use we observe in column (1) is driven by an increase in marijuana initiation among the sub-population of individuals who were already using tobacco prior to the policy shift. And as such, these results are consistent with the previously discussed findings on the impacts of RMLs on net marijuana use (positive) and tobacco use (null or negative). Lastly, results in column (4) show that RML adoption had no effect on dual use of marijuana and ENDS products.

5.3. Heterogeneity by demographic characteristics and recreational dispensary openings

Fig. 5 describes heterogeneity in the lagged effects of RMLs by demographic characteristics of individuals surveyed in the PATH. Our results show that RML adoption has a larger positive effect on prior-month marijuana use of males than of females (lagged effects of 1.8 to 3.2 percentage-points and generally statistically different from zero for males vs 0.3 to 2.2 percentage-points and not generally statistically different from zero for females). Expectedly, we also find that the decline in ENDS use following RML adoption is larger (in absolute magnitude) for males than females (lagged effects of 1.4 to 2.8 percentage-point decline for males vs 0.4 to 1.2 percentage-point decline for females).

We find little evidence that the effects of RMLs on adults differs by race/ethnicity, though the estimated effects are somewhat larger for non-Hispanic whites relative to racial/ethnic minorities. There are also no pronounced differences in estimated effects by educational attainment of individuals (< high school diploma/GED, high school diploma, college or more).

Finally, in Tables 6 and 7, we explore whether the effects of RMLs on marijuana and tobacco use differ by whether an RML was

[31] Note that the latter transition does not preclude a sequencing of use from abstention to marijuana (tobacco) use to subsequent tobacco (marijuana) use over the longitudinal window. Also, note that (i) is consistent with no net increase in tobacco use, whereas (ii) would imply net increases in both marijuana and tobacco use.

Table 3
Lagged effects of recreational marijuana laws on marijuana and tobacco use by age, PATH.

	Prior-Month Marijuana Use	Prior-Month Cigarette Use	Prior-Month ENDS Use	Prior-Month Cigar Use	Prior-Month Combustible Tobacco Use
	(1)	(2)	(3)	(4)	(5)
Panel I: Ages 18 and Older					
Year of RML Enactment	0.016***	0.004	−0.005	−0.005	−0.001
	(0.004)	(0.005)	(0.004)	(0.004)	(0.007)
1 Year After RML	0.011	0.010	−0.013**	0.003	0.006
	(0.008)	(0.008)	(0.006)	(0.008)	(0.011)
2 Year After RML	0.028***	0.009	−0.015**	0.005	0.003
	(0.006)	(0.007)	(0.006)	(0.006)	(0.009)
3 Years+ After RML	0.015	0.004	−0.016**	0.009	0.002
	(0.009)	(0.008)	(0.007)	(0.008)	(0.010)
N	156,671	156,866	156,732	156,765	156,898
Pre-Treatment Mean DV	0.107	0.209	0.064	0.064	0.246
Panel II: Ages 21 and Older					
Year of RML Enactment	0.015***	0.005	−0.005	−0.004	0.000
	(0.005)	(0.006)	(0.004)	(0.004)	(0.007)
1 Year After RML	0.008	0.012	−0.012*	0.002	0.007
	(0.009)	(0.008)	(0.006)	(0.009)	(0.012)
2 Year After RML	0.026***	0.010	−0.015**	0.004	0.003
	(0.007)	(0.008)	(0.006)	(0.007)	(0.010)
3 Years+ After RML	0.011	0.005	−0.016**	0.007	0.002
	(0.010)	(0.008)	(0.007)	(0.008)	(0.011)
N	131,898	132,047	131,930	131,954	132,077
Pre-Treatment Mean DV	0.100	0.210	0.060	0.061	0.243

***Significant at 1% level **Significant at 5% level *Significant at 10% level.
All estimates are weighted. All regressions include individual fixed effects, state fixed effects, year-by-month fixed effects, wave fixed effects, and medical marijuana laws. Demographic controls include gender, age, educational attainment, race/ethnicity; economic controls include unemployment rate, state poverty rate, and log of ACS mean total pre-tax personal income; smoking policy controls include index of indoor vaping restrictions, total e-cigarette taxes, any e-cigarette MLSA, total cigarette taxes, index of indoor smoking restrictions, minimum age for cigarette sales; other policy controls include: state EITC refundable credit rate, log of minimum wage, whether the governor is a Democrat, presence of an ACA Medicaid expansion, presence of a must access prescription drug monitoring program, and beer tax per gallon. Standard errors, in parentheses, are clustered within 156 primary sampling units that are nested within states (except in one instance).

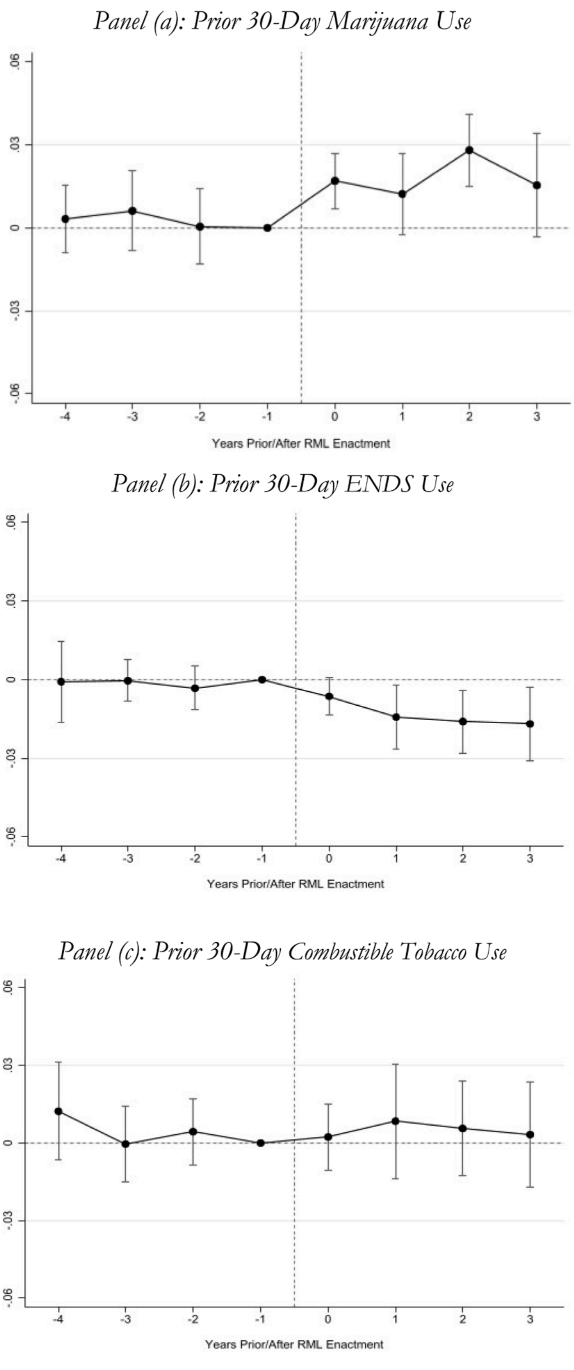

Fig. 4. Event-Study Analyses of RMLs and Marijuana and Tobacco Use, Using Individual Fixed Effects Estimates, Adults Ages 18-and-Older, PATH
Notes: Population weighted OLS estimates (and their 95% CIs) from an event study regression model are shown.

Table 4
Exploring dynamics: initiation and cessation by age, PATH.

	Initiation of Cigarettes Among Non-Users (Survival)	Cessation of Cigarettes Among Users (Survival)	Initiation of Cigars Among Non-Users (Survival)	Cessation of Cigars Among Users (Survival)	Initiation of ENDS Among Non-Users (Survival)	Cessation of ENDS Among Users (Survival)	Initiation of Marijuana Among Non-Users (Survival)	Cessation of Marijuana Among Users (Survival)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel I: Ages 18 and Older								
RML	0.002	−0.008	−0.002	0.057	−0.002	0.007	0.013***	−0.019
	(0.005)	(0.012)	(0.002)	(0.041)	(0.003)	(0.049)	(0.004)	(0.020)
N	82,455	53,162	118,258	14,661	118,174	13,399	116,108	18,214
Pre-Treatment Mean DV	0.024	0.081	0.020	0.283	0.022	0.330	0.026	0.147
Panel II: Ages 21 and Older								
RML	0.004	−0.011	−0.002	0.040	−0.002	0.012	0.013***	−0.025
	(0.005)	(0.013)	(0.002)	(0.045)	(0.003)	(0.053)	(0.004)	(0.021)
N	65,747	48,980	100,682	11,832	100,452	10,676	99,467	14,411
Pre-Treatment Mean DV	0.021	0.078	0.019	0.275	0.020	0.331	0.023	0.148
Years	2013–2019	2013–2019	2013–2019	2013–2019	2013–2019	2013–2019	2013–2019	2013–2019

***Significant at 1% level **Significant at 5% level *Significant at 10% level.
All estimates are weighted. All regressions include individual fixed effects, state fixed effects, year-by-month fixed effects, wave fixed effects, and medical marijuana laws. Demographic controls include gender, age, educational attainment, race/ethnicity; economic controls include unemployment rate, state poverty rate, and log of ACS mean total pre-tax personal income; smoking policy controls include index of indoor vaping restrictions, total e-cigarette taxes, any e-cigarette MLSA, total cigarette taxes, index of indoor smoking restrictions, minimum age for cigarette sales; other policy controls include: state EITC refundable credit rate, log of minimum wage, whether the governor is a Democrat, presence of an ACA Medicaid expansion, presence of a must access prescription drug monitoring program, and beer tax per gallon. Standard errors, in parentheses, are clustered within 156 primary sampling units that are nested within states (except in one instance).

Table 5
Exploring dynamics: dual use by age, PATH.

	Dual Marijuana and Tobacco Use	Initiation of Marijuana among Baseline Tobacco Users	Initiation of Tobacco and Marijuana among Baseline Non-users	Dual Marijuana and ENDS Use
	(1)	(2)	(3)	(4)
Panel I: Ages 18 and Older				
RML	0.013*** (0.003)	0.032*** (0.012)	0.002 (0.002)	0.003 (0.002)
N	156,707	52,427	64,787	156,805
Pre-Treatment Mean DV	0.073	0.065	0.006	0.022
Panel II: Ages 21 and Older				
RML	0.012*** (0.004)	0.030** (0.012)	0.002 (0.002)	0.003 (0.002)
N	131,927	47,993	51,672	132,009
Pre-Treatment Mean DV	0.068	0.061	0.004	0.019
Years	2013–2019	2013–2019	2013–2019	2013–2019

***Significant at 1% level **Significant at 5% level *Significant at 10% level.
All estimates are weighted. All regressions include individual fixed effects, state fixed effects, year-by-month fixed effects, wave fixed effects, and medical marijuana laws. Demographic controls include gender, age, educational attainment, race/ethnicity; economic controls include unemployment rate, state poverty rate, and log of ACS mean total pre-tax personal income; smoking policy controls include index of indoor vaping restrictions, total e-cigarette taxes, any e-cigarette MLSA, total cigarette taxes, index of indoor smoking restrictions, minimum age for cigarette sales; other policy controls include: state EITC refundable credit rate, log of minimum wage, whether the governor is a Democrat, presence of an ACA Medicaid expansion, presence of a must access prescription drug monitoring program, and beer tax per gallon. Standard errors, in parentheses, are clustered within 156 primary sampling units that are nested within states (except in one instance).

accompanied by permissible open recreational marijuana dispensaries. The findings in Table 6 show that RML adoption with and without open recreational dispensaries is associated with an increase in adult marijuana use (column 1) and marijuana vaping (column 2).[32] This is consistent with the hypothesis that dispensaries represent only one channel through which RMLs increase consumption. For instance, nearly all states that adopted RMLs permitted home cultivation of marijuana (i.e., allow for growing marijuana plants). Turning to tobacco use, we find no evidence that RMLs, with or without open recreational dispensaries, lead to an increase in combustible tobacco use (column 6), cigarette use (column 3), ENDS use (column 4), or cigar use (column 5). Instead, we find that the RML-induced reduction in ENDS use is driven by open recreational dispensaries. The absolute magnitude of the RML effect is four times larger (in absolute magnitude) for RMLs with open dispensaries as compared to RMLs without dispensaries (−0.013 vs −0.003).

An examination of the initiation and cessation of behavior in Table 7 shows that RML adoption (with and without dispensaries) is associated with significant increases in marijuana initiation among prior non-users (column 5). However, the initiation effect is nearly three times as large when the RML is accompanied by a recreational dispensary (0.025 vs 0.09). We further find that the RML dispensary-induced reduction in ENDS use observed in Table 6 can be largely explained by a reduction in the probability that a non-ENDS user transitions to ENDS use (column 3). We find no evidence that recreational marijuana dispensaries significantly affect initiation or cessation of combustible tobacco products.[33]

6. Conclusions

While public support for recreational marijuana has sharply risen in recent decades, public health experts have taken a more cautious approach, urging more research to assess the health benefits and costs of marijuana use, as well as to understand potentially unintended consequences on other health behaviors (American Medical Association 2021). One important unintended consequence could be the renormalization of smoking, which could undermine the achievements of tobacco control policies over the last two decades.

Indeed, since 1964 when the first Surgeon General report was released, cigarette smoking rates among male adults have declined from 55 percent to 16 percent and female smoking rates have declined from 35 percent to 12 percent (Centers for Disease Control and Prevention 2021c; Holford et al., 2014). While the causes of these declines are the subject of much debate, most public health experts seek to preserve the health gains related to anti-smoking efforts of the previous half-decade.

[32] In NSDUH-based results available upon request, we find that RML adoption with and without recreational dispensaries is associated with increases in adult marijuana use, with slightly larger effects when open dispensaries are permitted.

[33] In Appendix Tables 13 and 14, we show the robustness of our estimated null results to controlling for border state RMLs. If there are spillover effects to neighboring jurisdictions, then our estimated treatment effects could be biased toward zero. Our central NSDUH-based findings (Appendix Table 13) and PATH-based findings (Appendix Table 14) are largely unchanged after controlling for cross-jurisdiction spillovers.

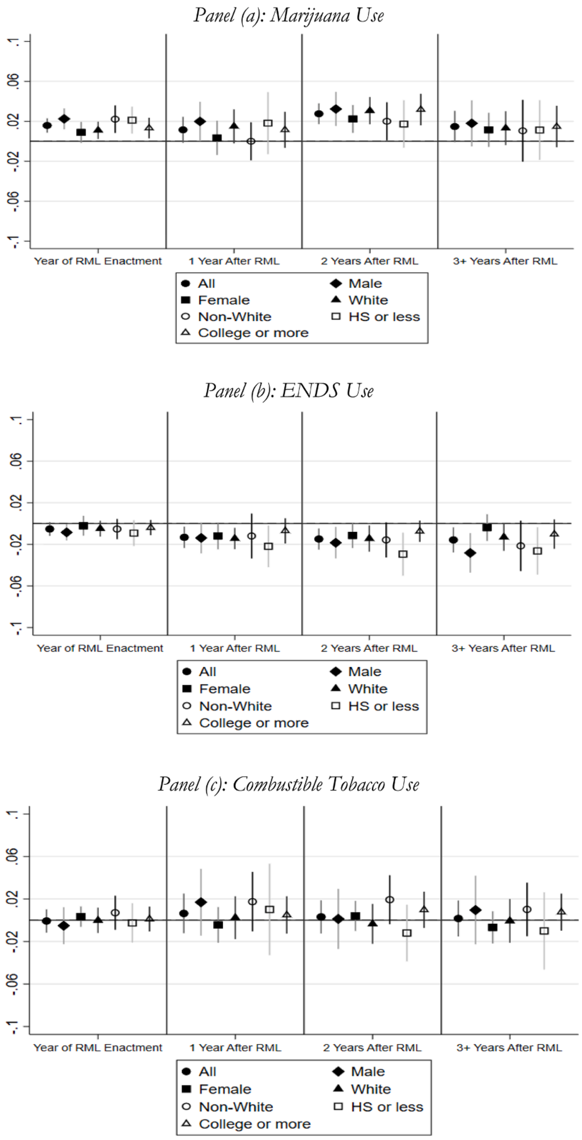

Fig. 5. Heterogeneity in RML Effects by Gender, Race, and Education, PATH
Notes: Estimated RML effects and their 95% confidence intervals from lagged regression models are shown.

Table 6
Heterogeneity in effects of RMLs by whether open recreational dispensary, PATH, adults ages 18 and older.

	Prior-Month MJ Use (1)	Prior-2 Day Vaped MJ (2)	Prior-Month Cigarette Use (3)	Prior-Month ENDS Use (4)	Prior-Month Cigar Use (5)	Prior-Month Combustible Tobacco Use (6)
RML with Open Recreational Dispensary	0.022***	0.007*	0.008	−0.013**	0.003	0.003
	(0.007)	(0.004)	(0.007)	(0.005)	(0.006)	(0.008)
RML without Open Recreational Dispensary	0.016***	0.008***	0.004	−0.003	−0.007	−0.001
	(0.005)	(0.002)	(0.006)	(0.004)	(0.004)	(0.007)
State FE, Year-Month FE & MML?	Yes	Yes	Yes	Yes	Yes	Yes
Individual and State Controls?	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE?	Yes	Yes	Yes	Yes	Yes	Yes
N	156,671	87,457	156,866	156,732	156,765	156,898
Pre-Treatment Mean DV	0.107	0.017	0.209	0.064	0.064	0.246

***Significant at 1% level **Significant at 5% level *Significant at 10% level.
All estimates are weighted. Demographic controls include gender, age, educational attainment, race/ethnicity; economic controls include unemployment rate, state poverty rate, and log of ACS mean total pre-tax personal income; smoking policy controls include index of indoor vaping restrictions, any e-cig MLSA, total cig taxes, index of indoor smoking restrictions, minimum age for cig sales; other policy controls include: state EITC refundable credit rate, log of minimum wage, whether the governor is a Democrat, presence of an ACA Medicaid expansion, presence of a must access prescription drug monitoring program, and beer tax per gallon. Standard errors corrected for clustering at the state level are in parentheses. All regressions include state fixed effects, year-by-month fixed effects, and medical marijuana laws. PATH-based estimates include individual fixed effects.

This study is the first to comprehensively examine the impact of recreational marijuana legalization on tobacco use. In doing so, we introduce a novel nationally representative longitudinal dataset —the Population Assessment of Tobacco and Health — to the recreational marijuana legalization literature. Using data from the PATH and the NSDUH, and a generalized difference-in-differences approach, we find consistent evidence that RML adoption led to an increase in adult marijuana use. However, we find little empirical support for the hypothesis that RMLs increase the net consumption of tobacco, as measured across a wide set of combustible tobacco products as well as ENDS, either at the extensive or intensive margin. Rather, the preponderance of the evidence points to small, occasionally significant longer-run declines in adult tobacco use (cigarette use in the NSDUH, ENDS use in the PATH). Reductions in ENDS use are primarily concentrated among men and for RMLs that are accompanied by open recreational dispensaries. These findings are consistent with the hypothesis that recreational marijuana and tobacco may be substitutes for some adults.

The findings from this study complement the results from Sabia et al. (2021), which found that RML-induced increases in marijuana use also did not encourage harder drug use, which is associated with larger adverse public health consequences relative to marijuana use. The potential health care cost savings from substitution away from cigarette consumption, which estimates from the NSDUH point to, could be substantial. Scaling these estimates to the national level, our estimates suggest a reduction in smoking prevalence by as many as 5.1 million, translating into tobacco-related healthcare cost savings of about $10.2 billion per year.[34] These cost-savings, of course, need to be balanced against the public health costs and benefits associated with increased marijuana use and reduced ENDS use, and against effects on marijuana use and tobacco use realized for youth (Anderson et al., 2021). Our study underscores the importance of quantifying and incorporating policy-driven spillovers when attempting to evaluate the benefits and costs of liberalized access to recreational marijuana.

CRediT authorship contribution statement

Dhaval Dave: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **Yang Liang:** Software, Formal analysis, Investigation, Data curation. **Michael F. Pesko:** Software, Formal analysis, Investigation, Data curation. **Serena Phillips:** Project administration, Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Joseph J. Sabia:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

[34] These estimates are based on the approximate two percentage points longer-term decline in smoking prevalence, based on the NSDUH results. Xu et al. (2015) estimated annual health care costs related to cigarette smoking of $170 billion, which imply $1995 (deflated to 2019 dollars) in added health care costs per year per smoker.

Table 7
Sensitivity of dynamic effects of RMLs by whether open recreational dispensary, PATH, adults ages 18 and older.

	Initiation of Cigarettes Among Non-Users (Survival) (1)	Cessation of Cigarettes Among Users (Survival) (2)	Initiation of ENDS Among Non-Users (Survival) (3)	Cessation of ENDS Among Users (Survival) (4)	Initiation of Marijuana Among Non-Users (Survival) (5)	Cessation of Marijuana Among Users (Survival) (6)	Initiation of Tobacco and Marijuana among Baseline Non-users (7)	Dual Marijuana and ENDS Use (8)
RML with Open Dispensary	0.005	0.017	−0.007*	0.021	0.025***	0.026	0.004	0.001
	(0.006)	(0.017)	(0.004)	(0.056)	(0.007)	(0.032)	(0.004)	(0.003)
RML with No Open Dispensary	0.002	−0.004	−0.000	−0.003	0.009**	−0.023	0.000	0.003
	(0.005)	(0.014)	(0.003)	(0.044)	(0.004)	(0.020)	(0.002)	(0.002)
N	82,455	53,162	118,174	13,399	116,108	18,214	64,787	156,805
Pre-Treatment Mean DV	0.024	0.081	0.022	0.330	0.026	0.147	0.006	0.022
Years	2013–2019	2013–2019	2013–2019	2013–2019	2013–2019	2013–2019	2013–2019	2013–2019

***Significant at 1% level **Significant at 5% level *Significant at 10% level.
All estimates are weighted. All regressions include individual fixed effects, state fixed effects, year-by-month fixed effects, wave fixed effects, and medical marijuana laws. Demographic controls include gender, age, educational attainment, race/ethnicity; economic controls include unemployment rate, state poverty rate, and log of ACS mean total pre-tax personal income; smoking policy controls include index of indoor vaping restrictions, total e-cigarette taxes, any e-cigarette MLSA, total cigarette taxes, index of indoor smoking restrictions, minimum age for cigarette sales; other policy controls include: state EITC refundable credit rate, log of minimum wage, whether the governor is a Democrat, presence of an ACA Medicaid expansion, presence of a must access prescription drug monitoring program, and beer tax per gallon. Standard errors, in parentheses, are clustered within 156 primary sampling units that are nested within states (except in one instance).

Declaration of Competing Interest

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jhealeco.2023.102756.

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