Unexpected Consequences of Cannabis Legalization on Youth

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Abstract

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In 2014, Oregon became the 3rd state to legalize the local production, processing and sale of cannabis to persons 21 and older for non-medical use. The nature and direction of the impacts of this initiative on neighborhoods, underage commercial product use and juvenile justice are unknown. As more states turn to decriminalizing cannabis and opening commercial cannabis markets, it is imperative to understand the unexpected consequences of legalization on public health to inform prevention campaigns and equitable cannabis policies. Legalization of cannabis has exposed vulnerable communities, including youth, to cannabis retailers and advertisement, and has increased exposure to high potency cannabis products. There is growing concern that exposure to retailers and advertisements could have detrimental effects at both the individual and neighborhood level. This proposal will address the unexpected consequences of legalizing cannabis that impact public health and safety of youth. The primary aims of this proposal are to 1) Test the association between neighborhood deprivation and commercial cannabis retailer density in Portland, Oregon; 2) Determine if legalization of cannabis for adults has impacted cannabis allegations for youth in Oregon; and 3) Determine if underage use of high potency cannabis products is associated with proximity to commercial cannabis retailers in Oregon.

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A Dissertation

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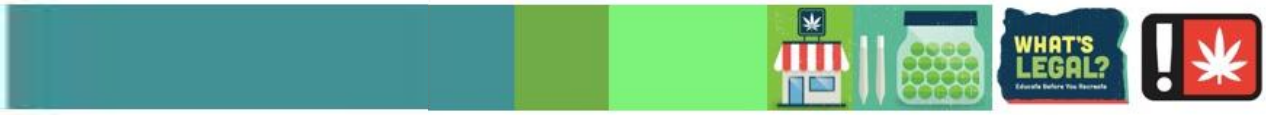

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And to my friends who have spent many long hours weighing in on my methodological dilemmas, providing hugs, distractions and lots of drinks.

Finally, I dedicate this dissertation to my fifteen-year-old self during my first few months in rehab. To have the courage and stubbornness to make my own happiness.

Table of Contents

ABSTRACT

In 2014, Oregon became the 3rd state to legalize the local production, processing and sale of cannabis to persons 21 and older for non-medical use. The nature and direction of the impacts of this initiative on neighborhoods, underage commercial product use and juvenile justice are unknown. As more states turn to decriminalizing cannabis and opening commercial cannabis markets, it is imperative to understand any unexpected consequences of legalization on public health to inform prevention campaigns and equitable cannabis policies. Legalization of cannabis has exposed vulnerable communities, including youth, to cannabis retailers and associated promotions, and has increased exposure to high potency cannabis products. There is growing concern that exposure to retailers and advertisements could have detrimental effects at both the individual and neighborhood level. This proposal will address the unexpected consequences of legalizing cannabis that impact public health and safety of youth. The primary aims of this proposal are to 1) Test the association between neighborhood deprivation and commercial cannabis retailer density in Portland, Oregon; 2) Determine if legalization of cannabis for adults has impacted cannabis allegations for youth in Oregon; and 3) Determine if underage use of high potency cannabis products is associated with proximity to commercial cannabis retailers in Oregon.

BACKGROUND

As more states turn to legalizing cannabis and opening commercial cannabis markets, it is imperative to understand any unexpected consequences of legalization on public health, social equity and criminal justice. As of August 2019, eleven U.S. states have legalized cannabis use for all adults at least 21 years of age, and most states have legalized some form of cannabis for medical use; however, cannabis use, possession and sales remain illegal at the federal level. The state-based legalization of retail cannabis has created wide variation in state regulations, including level of taxation, regulation of marketing and advertisement, cannabis product restrictions, possession and use among adults, distribution and home cultivation. Some common features across legalized states include the adoption of a market-oriented, for-profit cannabis industry that allows for the production, distribution and sale of cannabis products to adults 21+ years old.[1] Each one of these polices can be viewed as natural experiments that provide timely opportunities to assess the impacts of these population health interventions, and support collaborations between researchers and policy makers. Grounded in ecosocial theory of disease,[2]--which links social and biological processes together across levels of inference--and social cognitive theory[3]—attempts to explain how behavior is initiated and maintained and the social environment in which behavior is performed—there is concern that cannabis legalization may result in unexpected consequences for vulnerable populations.

Adult legalization of cannabis has altered the built environment, changed the way people access and consume cannabis, and exposed youth to cannabis retailers, associated promotions,[4,5] and high potency cannabis products.[6] Exposing youth to the effects of adult legalization could be harmful to public health. There is growing concern that exposure to cannabis retailers and advertisements could have detrimental effects at both the individual and neighborhood level. At the individual level, there may be unexpected consequences for youth. Youth are exposed to the effects of the commercialization of cannabis, yet cannabis use remains an illegal substance for minors that has criminal penalties.[7] Exposure to cannabis retailers and advertisement may alter social norms by reducing perceived harm of cannabis use among youth thus leading to an increase in cannabis consumption or cannabis use in public and further prosecution under the law for underage use of cannabis.[8] Further, the legalization of cannabis has

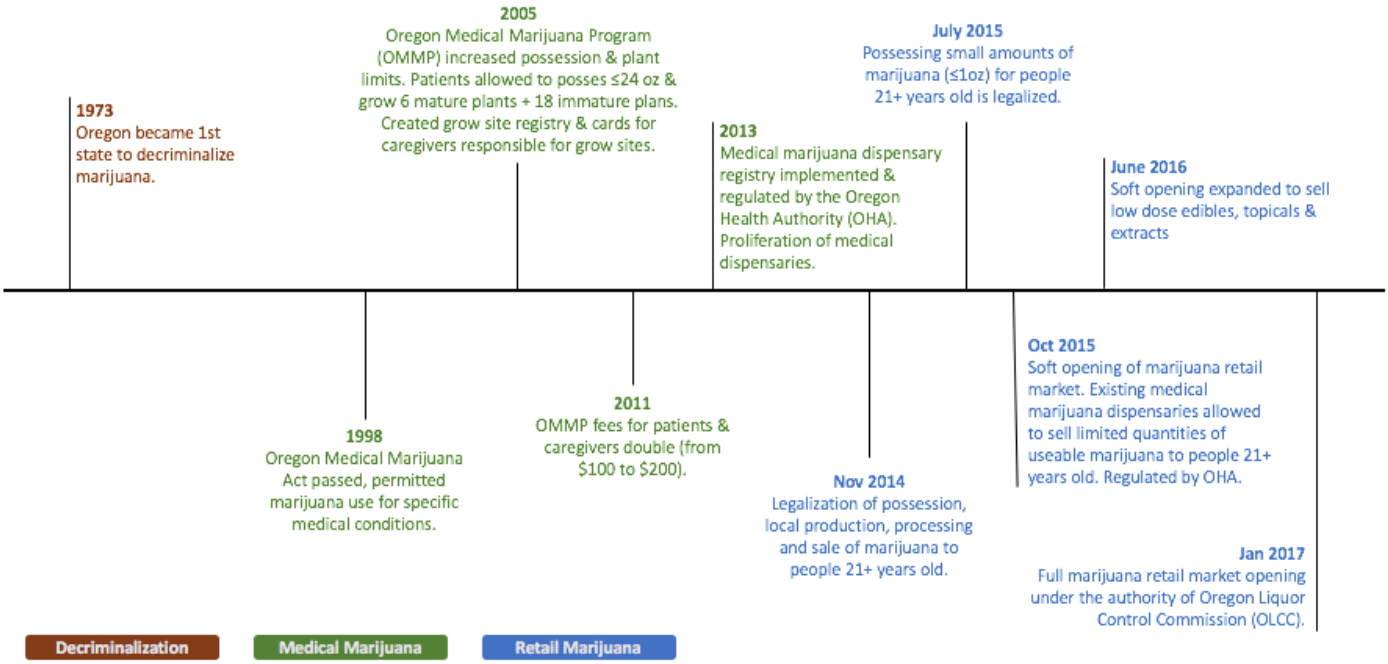
resulted in increased availability of high potency products which could lead to greater high potency product use and have negative health impacts for both youth and adults.[9] At the neighborhood level, the nature and direction of the impacts of legalization and the opening of a cannabis market on socioeconomic status, perceived safety and local economies are unknown, but could prove to have a destabilizing effect on vulnerable neighborhoods.

In 2014, Oregon became the 3rd state to legalize the local production, processing and sale of cannabis to persons 21 and older for non-medical use (Figure 1). As one of the more mature cannabis markets, Oregon's regulatory framework provides an opportunity to assess the impacts of particular cannabis policies on youth and public health. Specifically, this study will examine cannabis retailer business regulations, changes in juvenile crimes (under the age of 18) that were implemented as an effect of adult legalization and high potency products that are sold in cannabis retailers. This study will address the following aims, as depicted in the conceptual model in Figure 2. The design of the conceptual model incorporates three levels of inference (state-level, neighborhoods and individual youth) and arrows depicting associations between exposures and outcomes. The line style of the arrows denotes the significance of the association in our proposal. Solid lines indicate the association is formally tested in our analytic plan and are labeled by their corresponding aim. Dashed lines indicate a theoretical association, but these associations are not tested in our proposal. The color of boxes distinguishes between the level of data in this multi-level study, from state-level policy on the far left, neighborhood environment and local policy in the middle and individual-level factors on the right.

Results of this study will provide insights to both policy makers and researchers to support future research and evidence-based policies. First, describing commercial cannabis retailer density at the neighborhood-level will inform decisions made by the City of Portland and neighborhood coalitions to regulate commercialized cannabis markets. Specifically, this analysis will further our understanding about where cannabis retailers are located to better target public health messaging and guide local regulatory policies. Second, because there is concern that the growing commercial cannabis market will influence illegal cannabis use among youth, results from our study will elucidate high potency use among youth.

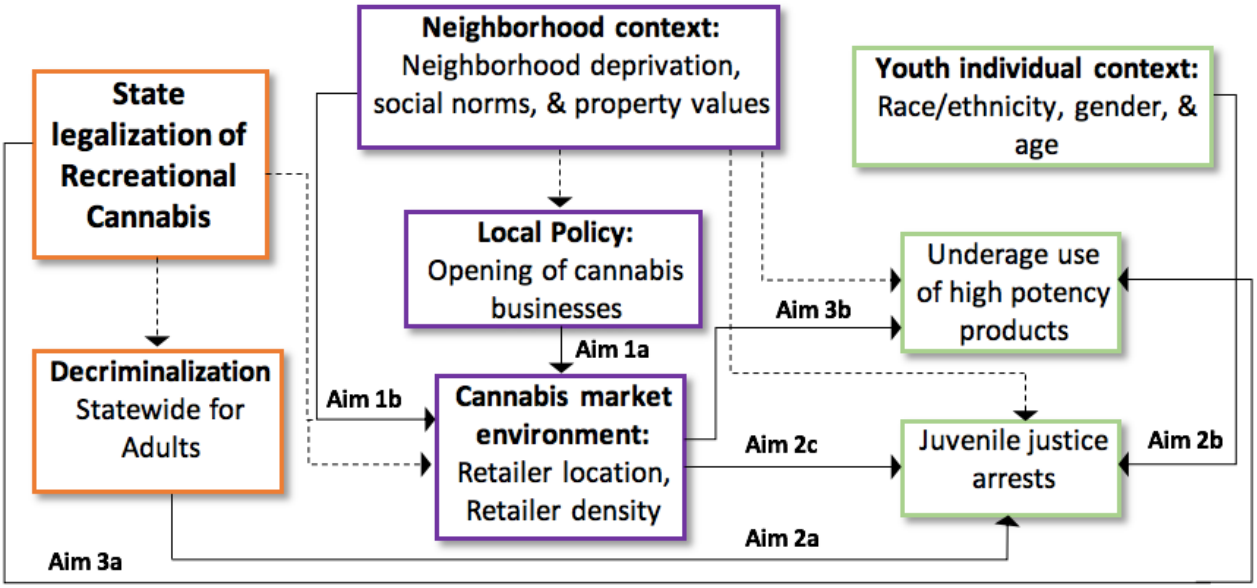
Monitoring trends of high potency use among youth can inform interventions and labeling requirements of cannabis product to reduce accidental poisonings and emergency department visits. Finally, it is imperative to examine the impacts of adult legalization on the engagement of youth with the criminal justice system for cannabis-related crimes. We will examine changes in juvenile cannabis allegations for all Oregon youth, among cannabis using youth and the impact of legalization on racial/ethnic disparities within the juvenile justice system. Results will shed light on changes in cannabis charges attributed to legalization and support the work of policy makers to advocate for decriminalization and alternatives to incarceration programs for youth.

Figure 1. Major cannabis policies enacted in Oregon



Timeline was compiled from Oregon revised statutes & the Oregon marijuana policy timeline from the Social Development Research Group at University of Washington (2016).

Figure 2. Conceptual model for unexpected consequences of cannabis legalization on youth in Oregon



Aim 1. Test the association between neighborhood deprivation and cannabis retailer density in Portland, Oregon.

1a. Estimate the number of expected marijuana retailers for each City of Portland defined neighborhood based on the number of properties eligible to operate as legitimate marijuana businesses.

1b. Test the association between neighborhood deprivation index and cannabis retailer density and assess the spatial dependence of cannabis retailer density between neighborhoods.

Aim 2. Determine if adult cannabis legalization has impacted juvenile marijuana criminal allegations while accounting for changes in cannabis use among youth in Oregon.

2a. Assess the statewide impact of adult legalization on juvenile marijuana criminal allegations.

2b. Determine whether adult legalization has impacted racial/ethnic disparities in juvenile marijuana criminal allegations.

2c. Determine whether density of commercial cannabis retailers at the county-level modifies the impact of adult legalization on juvenile marijuana criminal allegations.

Aim 3. Determine if underage use of high potency marijuana products is associated with proximity to cannabis retailers in Oregon.

3a. Describe the statewide prevalence of underage high potency cannabis product use.

3b. Determine if underage high potency use is associated with proximity to cannabis retailers.

This dissertation document is organized in chapters that contain the work of each dissertation aim as independent bodies of research complete with distinct methods, results and discussion sections. The document is arranged by level of inference, begins with the distribution of cannabis retailers by neighborhood deprivation in Portland, Oregon, followed by the impacts of adult legalization on juvenile cannabis criminal allegations, and ends with underage high potency cannabis product use by proximity to

cannabis retailers. This document concludes with a discussion of all completed work and its contribution to scientific community, policy makers and stakeholders in implementing equitable cannabis policies.

AIM ONE: Moving towards equity: Neighborhood deprivation and cannabis retailers across Portland, Oregon

INTRODUCTION

There is growing concern that exposure to cannabis retailers and storefront advertisement could have detrimental effects at both the individual and neighborhood level. Legalization of medical and retail cannabis in the U.S. has exposed vulnerable communities to storefront marketing of cannabis retailers.[10] The legalization of cannabis has also resulted in increased availability of high potency (concentrated and edible products) which could have negative health impacts for both youth and adults.[11] Specifically for youth, the impacts of legalization pose unique risks. Exposure to cannabis retailers may alter social norms by reducing perceived harm of cannabis use among youth thus leading to an increase in cannabis consumption and further criminal prosecution of minors who use cannabis.[8] In addition, youth are exposed to the effects of commercialized cannabis, yet cannabis remains an illegal substance for minors that is penalized by the criminal justice system.[7]

At the neighborhood level, the nature and direction of the impacts of legalization and the opening of a cannabis market on social cohesion, perceived safety and local economies are unknown, but could prove to have a destabilizing effect on vulnerable neighborhoods. Prior alcohol research indicates that liquor sales outlets have negative impacts on neighborhoods and health.[12,13] The opening of cannabis retailers may impact neighborhoods in a similar manner as liquor stores.[14] A study in the state of Colorado found cannabis retailers were disproportionately located in census tracts with lower household incomes and higher proportions of racial/ethnic minorities.[4] In addition, a recently published study in Washington state found that cannabis outlets were more likely to be co-located in census tracts with liquor stores and areas experiencing more poverty.[15] Consequently, early evidence from these first two states to legalize retail cannabis supports concern that the negative impacts of a commercial cannabis market will be disproportionately distributed across neighborhoods and concentrated in neighborhoods experiencing disadvantage.

The state of Oregon has legalized cannabis, along with its neighbors to the North, Washington state, and South, California. Oregon legalized the local production, processing and sale of cannabis to persons 21 and older for non-medical use by voter initiative in 2014. Early restricted retail sales of cannabis products commenced in October 2015 allowing any adult over the age of 21 to purchase up to ¼ of an ounce of cannabis flower per day. By the end of 2017, 486 retail cannabis stores were operating across Oregon;[16] 31% of these retailers (150 stores) were operating in the city of Portland, Oregon's most populous city. Given historically racist zoning practices and residential segregation in Portland,[17] the availability of commercial retail property that is eligible to operate as a cannabis retailer may predispose retailers to operate in areas of high poverty and disadvantage.

Using an interdisciplinary approach and innovative methods to address our research question, this study aims to assess the relationship between neighborhood deprivation and the distribution of cannabis retailers while accounting for features of the built environment. Findings from this study will further our understanding about where cannabis retailers are located in one urban area that has legalized cannabis and provide insight to guide equity-focused cannabis policies and target public health messaging in the U.S.

METHODS

Study design

We conducted an ecological cross-sectional spatial analysis of the association between neighborhood deprivation and distribution of cannabis retailers in Portland, Oregon.

Neighborhood definition

Areas within Portland that have registered with the Office of Neighborhood Involvement and have an established neighborhood association with clearly defined geographic boundaries are considered neighborhoods for the purposes of our study (n=92). Locally-defined neighborhood boundaries are used in our analysis as opposed to census tracts, which may not reflect neighborhood identity. In addition to the 92 registered neighborhoods, Portland has 21 areas where multiple neighborhoods share jurisdiction of an area, and 4 unclaimed areas of land.[18] Shared regions and unclaimed land were considered as

neighborhoods in our analysis in order to provide contiguous, mutually exclusive and full coverage of our study area. This resulted in 117 neighborhood areas included in analysis (Map 1).

Exposure: Neighborhood deprivation index

A neighborhood-level neighborhood deprivation index (NDI) was constructed from American Community Survey (ACS) 2012–2016 5-year estimates at the census block group-level. Thirty-three ACS variables were included in a principal component analysis (PCA) to calculate a Portland-specific deprivation index. Variables included in the PCA draw from the domains of income/poverty, demographics, occupation, education, housing, and assets (Supplemental Table 1). These domains represent aspects of the neighborhood context intrinsically tied to economic disadvantage, increases in health risk behaviors and poor health outcomes.[19] Variables included in the PCA are consistent with other survey-based estimations of neighborhood socioeconomic status or deprivation indices.[20] We implemented a two-step PCA approach with the *SESIndexCreator* version 1.0 statistical package in R software.[21] A two-step approach uses data mining techniques to reduce redundancy of variables and optimize the proportion of variance explained by the first dimension.

In order to estimate NDI at the neighborhood-level, each census block group was assigned to Portland neighborhoods using area-weighted estimation. This method overlays neighborhood geographic boundaries on census block groups and assigns portions of each block group contained within a particular neighborhood boundary to that neighborhood. For example, if the spatial area of a neighborhood contains 30% of block group A and 70% of block group B then the population of the neighborhood (N_p) would be the sum of area-weighted block groups estimates (N_p = 0.3(population of block group A) + 0.7(population of block group B). Therefore, every neighborhood population or prevalence estimate is the sum of area-weighted census block group estimates. Spatial weighting was conducted using the *SF* statistical package version 0.7-1 in R software.[22] The number of block groups within each Portland neighborhood varied from 1 to 28.

An NDI measure was calculated for each neighborhood from the first component of the PCA and transformed into a Z-score. The mean NDI score was 0 and 1-unit difference represented a score that was one standard deviation away from the mean.

Outcome: Count of cannabis retailers

The outcome of interest was the count of observed cannabis retailers within a defined Portland neighborhood (Map 1). To calculate the count of cannabis retailers within each neighborhood, each of the 150 active cannabis retailers registered with the Oregon Liquor Control Commission (OLCC) on December 31st 2017 were geocoded and spatially assigned to a neighborhood.

Expected Count of cannabis retailers

The expected count of cannabis retailers within each of Portland's neighborhoods was included as the offset in analytic models. Including an offset that was informed by cannabis business policies was essential to correctly model the association between neighborhood deprivation and the distribution of cannabis retailers across the city. Criteria for operating a cannabis business in the state of Oregon include several land use eligibility provisions as mandated by state legislature and the City of Portland cannabis program.[23] Requirements include: property must be zoned for commercial use, maintain a minimum 1,000 foot buffer from primary and secondary schools and at least 1,000 foot buffer between all established cannabis retailers.[23] To determine the expected count of cannabis retailers, we drew from real estate and urban planning disciplines to conduct a site suitability assessment.[24] The unit of analysis was all properties within Portland and recorded in the Multnomah County Tax Assessor data during 2017.[25] The first step assessed the suitability of each property to operate as a cannabis retailer. This determined the universe of possible locations where a cannabis retailer could legitimately open within a neighborhood. Using this geostatistical approach, the number of suitable sites for cannabis retailers within each neighborhood was reduced in a stepwise fashion. Among the 13,844 commercial properties with an existing structure in Portland, 807 were deemed eligible to open as a cannabis retailer based on the criteria described above (details on the restriction of available properties are detailed in Supplemental Table 2 at the end of this chapter). We then estimated the expected number of cannabis retailers within

each neighborhood based on the reference probability of an eligible property becoming a cannabis retailer. The reference probability was the proportion of total number of current cannabis retailers out of the total number of eligible sites in the city (150/807). The sum of expected cannabis retailers within Portland was 148 and ranged from 0 to 13 within each neighborhood, and 77 of 117 (66%) neighborhoods were expected to have least one cannabis retailer. For the 40 neighborhoods where the number of expected retailers was close to zero, the value of 0.5 was imputed to represent a 50-50 chance that a cannabis retailer would operate within that neighborhood area. All geospatial analyses were performed in ArcGIS Pro 2.1.2 (a visual guide of calculating expected number of cannabis retailers is included as Supplemental Figure 1 at the end of this chapter).

Covariates

A built environment index was constructed to account for neighborhood features that may confound the relationship between NDI and the distribution of cannabis retailers. As described in the literature, liquor store density, walkability, and commercial property value are all intertwined neighborhood features that impact the desirability of neighborhood business districts.[26,27] We hypothesized these specific neighborhood features could impact neighborhood disadvantage and the likelihood of opening a cannabis retailer. An index was created because we were interested in adjusting for the potential confounding effects of the built environment and were not interested in interpreting the individual effects of each component. The built environment index was constructed from three sources: publicly available 2017 neighborhood WalkScore™, which measures the walkability of a given area using a patented system;[28] median commercial property value from Multnomah County Tax Assessor data during 2017;[25] and count of neighborhood liquor stores (stores where spirits or “hard liquor” can be purchased for offsite consumption) as reported in the 2017 North American Industry Classification System.[29] Each component was aggregated at the neighborhood-level and values were standardized. The built environment index was calculated for each neighborhood as the sum of the three component Z-scores. Therefore, a positive index score corresponded to an overall above average combination of the three components: neighborhood WalkScore™, commercial property value, and number of hard liquor stores.

Statistical analysis

Data processing and visualization for the spatial spread of cannabis retailers and neighborhood deprivation across Portland were conducted in ArcGIS Pro 2.12. We fit statistical models with spatial smoothing for observed counts of cannabis retailers to test the association with neighborhood deprivation. This method allowed us to assess the risk surface of cannabis retailers at the neighborhood-level by neighborhood deprivation. In models, the primary **independent variable** is the neighborhood deprivation index (NDI). The **dependent variable** was the count of observed cannabis retailers within each neighborhood. We fit a series of Poisson models and used as an **offset** the natural log of the count of expected cannabis retailers within each neighborhood in order to model our dependent variable as a function of the number of eligible cannabis retailer within each neighborhood. The offset was necessary in order to estimate the number of open cannabis retailers as a function of available properties.

(Model 1)

$$\begin{cases} Y_i = \mu_i \\ variance(Y_i) = (\theta\mu_i) \\ \log(\mu_i) = \log(E_i) + \beta_0 + \beta_1 \boldsymbol{x}_i \end{cases}$$

Y_i Count of cannabis retailers within a neighborhood (outcome)
θ Overdispersion parameter
μ_i Marginal mean
E_i Expected count of eligible cannabis retailers
β_0 Intercept
β_1 Neighborhood deprivation index (exposure)
$\boldsymbol{x}_i$ Unit of analysis, measurement at the neighborhood level

First, a non-spatial quasi-Poisson model was fit to assess overdispersion (Model 1) in the data. This model directly estimated (θ) the level of non-Poisson variability, or overdispersion parameter, in the data. We estimated the log relative risk between neighborhood deprivation and the distribution of cannabis retailers.

(Model 2)

$$\begin{cases} Y_i = \mu_i \\ \log(\mu_i) = \log(E_i) + \beta_0 + \beta_1 \boldsymbol{x}_i \end{cases}$$

Y_i Count of cannabis retailers within a neighborhood (outcome)
μ_i Marginal mean
E_i Expected count of eligible cannabis retailers
β_0 Intercept
β_1 Neighborhood deprivation index (exposure)
$\boldsymbol{x}_i$ Unit of analysis, measurement at the neighborhood level

To address overdispersion in the data, a Poisson model with neighborhood random effects was fit using integrated nested Laplace approximation (INLA).[30,31] INLA is an efficient Bayesian estimation approach for areal spatial data that produces estimates of the marginal posterior distributions of the parameters.[32] We again estimated the log relative risk between neighborhood deprivation and the distribution of cannabis retailers (Model 2). A second non-spatial model was fit to the data that adjusted for the potential confounding effects of the built environment index (β_2: Built environment index).

(Model 3)

$$\begin{cases} Y_i = \mu_i \\ \log(\mu_i) = \log(E_i) + \beta_0 + \beta_1 \boldsymbol{x}_i + S_i + \varepsilon_i \end{cases}$$

Y_i Count of cannabis retailers within a neighborhood (outcome)
μ_i Marginal mean
E_i Expected count of eligible cannabis retailers
β_0 Intercept
β_1 Neighborhood deprivation index (exposure)
$\boldsymbol{x}_i$ Unit of analysis, measurement at the neighborhood level
S_i Spatial random effects
ε_i Non-spatial random effects

Next, spatial smoothing was incorporated into the Poisson model. Spatial effects were specified using a modified Besag-York-Molli´e model (BYM2) that calculated both spatial and non-spatial random effects (Model 3).[33] The BYM2 was chosen because it allows two contributions to the residuals in each area: one allows for "shocks" or random intercepts in each area that are independent of the residuals in other areas while the other allows dependence between the residuals and those in neighboring areas. The spatial contribution of the BYM2 model allows for the count of cannabis retailers within each area (neighborhood) to depend on the values of the counts in neighboring areas (defined as areas that share

boundaries). This approach allows us to examine whether there is spatial structure in the counts of cannabis retailers across neighborhoods. The regression part of the model allows examination of whether the count of retailers was associated with neighborhood deprivation. A second spatial model was fit that adjusted for the potential confounding effects of the built environment index (β_2: Built environment index).

In addition, we conducted a sensitivity analysis to ensure that individual components of the built environment index could not explain the observed association between neighborhood deprivation and distribution of cannabis retailers. The constituents of the built environment index (β_3: Walk Score™, β_4: liquor stores, and β_5: commercial property value) were included as fixed effects in a spatial model. For each spatial model, the 95% credible interval for neighborhood-area residual relative risks was reported along with the proportion of residual variability explained by spatial dependence. Credible intervals were reported to describe the interval of an unobserved parameter in Bayesian analysis as opposed to reporting confidence intervals as used in frequentist methods.

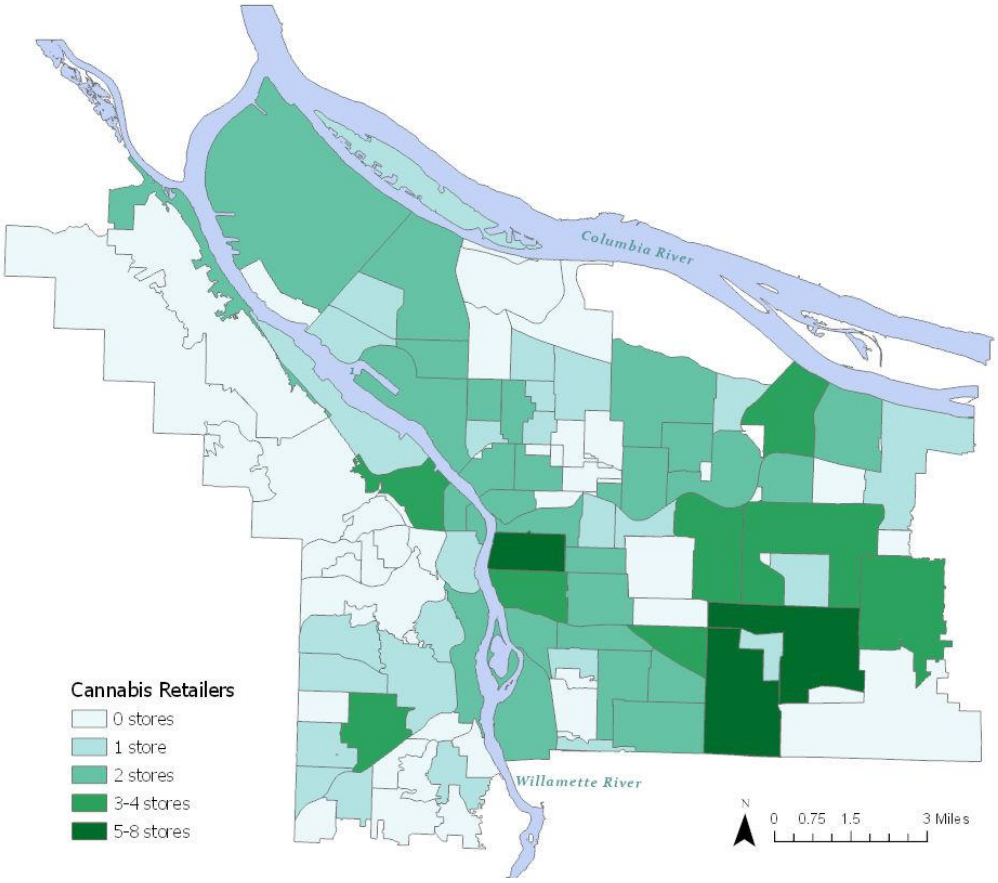
All analyses were conducted in R studio using INLA version 18.07.12 package and *SpatialEpi* version 1.2.3 package.

RESULTS

Descriptive analysis

Across the 117 neighborhood areas within Portland, 66 had at least one cannabis retailer operating by December 2017. The range of cannabis retailers within each neighborhood was 0 to 8. The city of Portland is sometimes described in terms of East or West Portland, as divided by the Willamette River. The majority of cannabis retailers (122, 81%) were located in the 79 neighborhoods in East Portland (Map 1) and the remaining 28 retailers (19%) were within the 38 neighborhoods of West Portland.

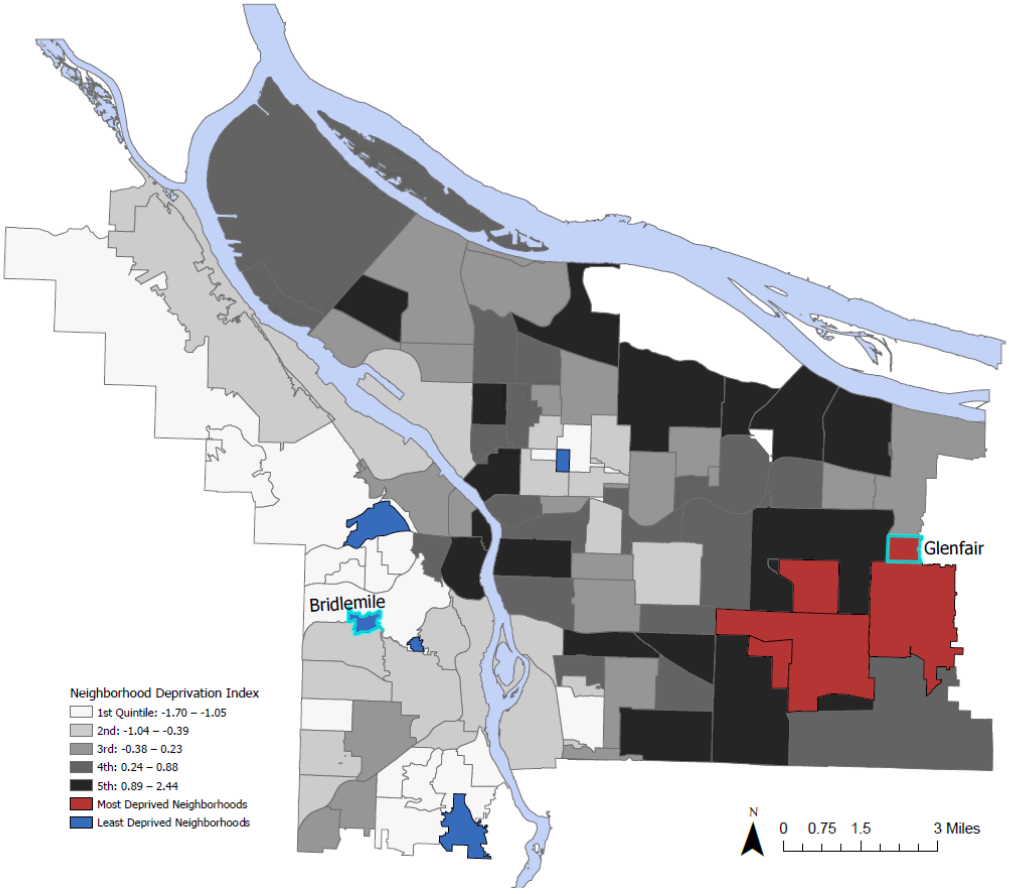
Map 1. Cannabis retailers in city of Portland, Oregon, 2017



Neighborhood deprivation varied greatly across Portland. Since it was transformed to a z-score, the mean NDI was 0 with a standard deviation of 1. Deprivation of neighborhoods was measured by a single index that incorporated the strongest indicators of neighborhood deprivation as identified from the first component of the PCA that had an eigenvalue of 8.27 and explained 69% of the variance. These indicators are summarized in Table 1 to show select characteristics of neighborhoods at either end of the NDI spectrum. The most deprived neighborhoods were predominately located in outer South East Portland and the least deprived neighborhoods were in North East and West Portland. The five most deprived neighborhoods and five least deprived neighborhoods are shown in Map 2 along with the quintile distribution of NDI (Map 2). The five most deprived neighborhoods were all within the 5th quintile of NDI whereas the five least deprived neighborhoods were in the 1st quintile. Within the most deprived neighborhood, Glenfair, over half of residents lived in households that earn less than $50,000 annually, 21% of residents lived in poverty, and the majority of residents (64%) lived in rental housing. The

educational attainment for adults at least 25 years of age in Glenfair was a high school diploma or GED for 29% of residents, 18% of residents did not have health insurance, and 12% of households spoke limited English. The least deprived neighborhood, Bridlemile, was located across the city in West Portland, Bridlemile residents earned a median household income of $167,107 annually and 14% of residents lived in households earning less than $50,000, only 1% of residents lived in poverty or received food stamps, and 3% of households lived in rental housing. Most residents received higher education, as indicative from 4% of residents having a GED or high school diploma as their highest level of education attainment, and no households had limited English proficiency.

Map 2. Neighborhood Deprivation in the city of Portland, Oregon, 2012-2016[1]



[1]*Neighborhood deprivation index derived from American Community Survey Data, 2012–2016.*

Table 1. Neighborhood characteristics among the most and least deprived neighborhoods, Portland, Oregon

	Most Deprived Neighborhoods					Least Deprived Neighborhoods				
	Glenfair	Mill Park	Powellhurst-Gilbert	Centennial Community Association	Lents/ Powellhurst-Gilbert	Bridlemile/ Southwest Hills Residential League	Multnomah County, Unclaimed	Hillside	Alameda/ Irvington Community Association	Healy Heights/ Southwest Hills Residential League
Neighborhood Deprivation Index Score	2.44	2.26	2.05	1.97	1.80	-1.70	-1.63	-1.56	-1.50	-1.47
Individuals on Food Stamps	44%	39%	39%	34%	29%	1%	4%	0%	0%	1%
Individuals in Poverty	21%	26%	27%	28%	29%	1%	3%	2%	2%	5%
Educational Attainment: GED or High School Diploma	29%	29%	28%	33%	24%	4%	2%	5%	3%	3%
Female Head of Household	45%	29%	29%	26%	15%	10%	6%	5%	5%	5%
Annual income <$50,000	54%	60%	60%	59%	57%	14%	10%	16%	12%	14%
Median Income ($)	$48k	$39k	$41k	$41k	$44k	$167k	$164k	$130k	$109k	$150k
No Health Insurance	18%	17%	15%	14%	18%	2%	2%	1%	1%	3%
Rental Housing	64%	62%	46%	40%	36%	3%	8%	11%	9%	15%
Limited English Spoken in Household	12%	18%	11%	7%	14%	0%	2%	0%	2%	0%

The built environment index appeared positively associated with neighborhood deprivation. The average built environment index score was 0 with a standard deviation of 1.99 and a range of -3.30 to 9.70 (Supplemental Table 3). The average neighborhood Walk Score™ was 59 which represents a somewhat walkable neighborhood and ranged from 4 (car dependent neighborhood) to 96 (a walker's paradise neighborhood).[34] Nine neighborhoods did not have any commercial properties, and the average median commercial property value within a neighborhood was $1.4 million. There were 41 hard liquor stores in Portland operating across 27 neighborhoods. At most, neighborhoods had two hard liquor stores.

Multivariate analysis

Non-spatial Poisson models

The quasi-Poisson general linear model (Model 1), found overdispersion: the variance exceeded the marginal mean by 24%. Given the presence of overdispersion, the association between NDI and the distribution of cannabis retailers was assessed using a Poisson model with neighborhood-level random effects (Model 2). An increase of one-unit (or one standard deviation) in neighborhood deprivation was associated with 46% more cannabis retailers (RR of 1.46, 95% CI: 1.23–1.74) (Table 2). The inclusion of the built environment index did not change the association between NDI and the distribution of cannabis retailers (aRR 1.47, 95% CI: 1.23–1.76).

Spatial Poisson models

The inclusion of spatial dependence increased the effect of neighborhood deprivation on the distribution of cannabis retailers. Across neighborhoods, a one-unit increase in neighborhood deprivation was associated with 54% more cannabis retailers (RR 1.54, 95% CI: 1.23–1.98). From regression analysis, the range in fitted neighborhood area-specific relative risks was 0.31 to 2.36, i.e. advantaged neighborhoods (low values of NDI) had a lower probability of cannabis retailers compared to more disadvantaged neighborhoods. The 95% credible interval for neighborhood-area residual relative risks was 0.60 to 3.95, and over half of the residual variation was attributed to spatial dependence (63%). The inclusion of the built environment index attenuated the association between neighborhood deprivation and the distribution of cannabis retailers in the same manner as the non-spatial model (aRR 1.47, 95% CI:

1.19–1.84, Table 2). The range in fitted neighborhood area-specific relative risks was 0.19 to 3.95. Including the built environment index substantially decreased the amount of residual variability in the model (95% credible interval for neighborhood-area residual relative risks: 0.73–2.95), and 60% of the residual variability was attributed to spatial dependence. When the individual components of the built environment index were adjusted for (Walk Score™, liquor stores, and commercial property value), a one-unit increase in neighborhood deprivation was associated was 40% more cannabis retailers (aRR 1.40, 95% CI:1.13–1.74) (Table 2).

Table 2. Results from Poisson models of neighborhood deprivation on the distribution of cannabis retailers[1]

	Neighborhood Deprivation		Built Environment		WalkScore™		Hard Liquor stores		Commercial Property Value	
	RR[2]	**(95% CI)**	**RR**	**(95% CI)**	**RR**	**(95% CI)**	**RR**	**95% CI**	**RR**	**95% CI**
Model 2: Non-spatial models	1.46	(1.23–1.74)								
	1.45	(1.22–1.74)	1.22	(1.13–1.31)						
Model 3: Spatial-models	1.54	(1.23–1.98)								
	1.47	(1.19–1.84)	1.22	(1.11–1.34)						
Sensitivity analysis	1.40	(1.13–1.74)			1.71	(1.35–2.23)	1.19	(0.99–1.43)	0.71	(0.31–1.27)

[1] *All models were conducted using integrated nested Laplace approximation and incorporated neighborhood-level random effects. Spatial models incorporated both spatial effects and non-spatial random effects that were specified with a modified Besag-York-Molli´e model.*
[2] *Relative risk*

DISCUSSION

Implications of study findings

This study provides empirical evidence that neighborhoods experiencing the most disadvantage are more likely to have a higher concentration of cannabis retailers than neighborhoods who experience less disadvantage in Portland, Oregon. Specifically, a one-unit increase in neighborhood deprivation corresponded to 47% more cannabis retailers after adjusting for the effects of the built environment within a neighborhood. These results suggest that cannabis retailers are disproportionately distributed throughout the city and concentrate in more deprived neighborhoods. Our results are consistent with recent studies in other legalized states that found cannabis retailers to be more likely to be located in census tracts with greater poverty in both Washington state and Colorado.[4,15] Our analysis incorporated poverty, in addition to many other dimensions of neighborhood deprivation.

More exposure to cannabis retailers can be detrimental at both the individual and neighborhood level. Our findings support the concern that vulnerable populations, particularly youth who are living in neighborhoods experiencing disadvantage, will be exposed to more cannabis retailers and storefront advertisement than youth living in other neighborhoods. For example, greater exposure to cannabis retailers may increase illegal underage use of cannabis, particularly use of high potency products (further explored in Aim 3), that put youth at heightened risk for unexpected consequences including accidental poisoning and emergency department visits.[6,9] In addition, underage use of cannabis will increase the likelihood of school discipline and subsequent criminal justice penalties (further explored in Aim 2) which are social determinants of health that can lead to lifelong detrimental effects.[35] Youth who experience juvenile arrest have lower educational attainment and limited employment opportunities compared to their peers. At the neighborhood level, the presence of cannabis retailers may alter perceived safety of neighborhoods, replace organized crime with cannabis retailers,[36] disrupt neighborhood social cohesion, and influence local economy by perpetuating low property values.

As more states continue to liberalize cannabis-related laws, the emergence of cannabis retailers in more U.S. neighborhoods seems inevitable. Local policy efforts should prioritize mitigating negative impacts of

cannabis retailers on neighborhoods, especially the most vulnerable. In Portland, Oregon, all newly licensed cannabis businesses are required to submit Marijuana Control Plan to the city for publication on their website.[37] These control plans serve as an introduction for cannabis businesses to the neighborhoods and address concerns related to on-premise consumption, noise complaints and safety. For neighborhoods experiencing deprivation and with less social capital, they may not have the resources to advocate to local government officials or partner with cannabis business owners to place restrictions on storefront advertisement, location or the number of cannabis retailers that operate within their neighborhoods. City governments should ensure structures are in place to support open dialogue between communities and cannabis businesses prior to opening businesses.

A related issue is the lack of diversity within the emerging cannabis industry. Having retail establishments be owned and operated by community members may promote community engagement in decision making around cannabis business operations and thus mitigate the potential harms of retailers in disadvantaged areas. People of color and communities historically devastated by the war on drugs have not benefited equitably from the emerging cannabis industry.[38] Particularly in Portland, very few cannabis retailer owners are people of color.[39] Efforts are currently underway to promote the development of minority-owned cannabis businesses through small grants.[40] Though small grant programs are a step in the right direction, local government officials should implement policies that directly address the inequitable distribution of cannabis retailers in their cannabis business license applications.[23] Particularly in neighborhoods experiencing the greatest disadvantage, local officials and cannabis industry representatives should seek the input of community members. This engagement is necessary in order to ensure that the voices of communities who have been historically excluded from political decision-making, targeted by the alcohol and tobacco industry, and devastated by the war on drugs do not go unheard.

Beyond Portland, other urban centers across the U.S. have taken a proactive approach to address equitable implementation of cannabis businesses. The city of Oakland, California, has implemented a cannabis equity program that reserves at least half of all their cannabis business licenses for low income people who have been formally convicted of a cannabis crime or live in a high crime area.[41] In

Massachusetts, the Cannabis Control Commission requires prospective cannabis business owners to meet with municipality authorities to negotiate a host community agreement that outlines the terms necessary for a cannabis retailer to operate within the particular community.[42,43] Such policies help prioritize opportunities for communities disproportionately affected by previous cannabis laws from entering into the cannabis industry.

The role of the built environment

The impact of the built environment on the association between neighborhood deprivation and cannabis retailer was an important consideration. When the built environment index was included in analysis, the effect of neighborhood deprivation on the distribution of cannabis retailers was attenuated towards the null. Independently, the effects of Walk Score™ were associated with an increased presence of cannabis retailers in our sensitivity analysis. This association between walkability and cannabis retailers may suggest a separate pathway between a mutable neighborhood characteristic and distribution of cannabis retailers. Both commercial property value and hard liquor stores were not significantly associated with likelihood of cannabis retailers in our sensitivity analysis. This finding is unique from both studies in Washington state and Colorado that concluded cannabis retailers were more likely to be co-located in census tracts with more off-premise hard liquor outlets.[4,15] The absence of a geographic co-location effect among Portland retailers may be attributed to differences in alcohol sales practices between states.

Spatial confounding

Across Portland, there was no spatial confounding in the association between neighborhood deprivation and the distribution of cannabis retailers. The effect of NDI on the distribution of cannabis retailers did not change when spatial dependence was included in analysis. However, the level of aggregation used in ecological study designs could have impacted study results,[44] and the lack of confounding by location in our data could be a result of the varying size of neighborhoods within Portland. Sixty-two percent of neighborhoods in Portland are no larger than one square mile (72/117 neighborhoods) and two neighborhoods exceed 10 square miles. In addition, the lack of spatial dependence present in the data

speaks to the independence between neighborhoods, and the potential effectiveness of independent neighborhood coalitions on influencing business operations within their neighborhood.

Limitations

The ecological cross-sectional design of our study limits the ability to infer a causal relationship between neighborhood deprivation and the establishment of cannabis retailers. Our results did not assess changes in the distribution of cannabis retailers over time or establish neighborhood deprivation as a driving cause for the opening of cannabis retailers. Given that the cannabis industry is still in its infancy, it may be that retailers are first opening stores in areas perceived as “low risk” where community resistance is minimal. In the future, retailers may begin to fill into more advantaged neighborhoods and the distribution of cannabis retailers across neighborhoods may change. Longitudinal data will be needed to assess future changes.

Our ecological study was susceptible to both within-neighborhood and between-neighborhood confounding. Potential confounding factors at the neighborhood-level were formally included in multivariate analysis as the built environment index (Walk Score™, commercial property value and count of hard liquor outlets). As we observed from conducting a sensitivity analysis, Walk Score™ was strongly associated with the likelihood of cannabis retailers within a neighborhood. Additional unmeasured neighborhood features that could confound the observed association include population density (or demand), measures of neighborhood cohesion, activity of neighborhood coalitions or local ordinances that restrict the operation of cannabis businesses through augmenting land use policies. Incorporating city building permits and changes in zoning regulations may capture neighborhood gentrification and business development within particular neighborhoods. In addition, unmeasured within-area confounding could influence our study findings. This includes variability of exposure measurement within neighborhoods. For instance, using median household income as a variable in the NDI does not address income distribution and the extent of inequality experienced within a neighborhood.[45] Such inequality could further divide neighborhoods into areas of lower or higher deprivation. Therefore, the inability to control for within area confounding contributes to the ecological fallacy inherent in our study.

Our built environment index relied on the most current available data (2017). This meant that our measure of built environment was compiled from data collected after the NDI data (2012-2016). Therefore, the possibility exists that neighborhood deprivation may have influenced change in the built environment. We believe this influence is unlikely given the one-year gap between metrics and the amount of infrastructure change that would have needed to occur in order to alter the built environment index. Future research should incorporate changes in built environment over time and their influence on the establishment of cannabis retailers.

Prior to retail cannabis legalization, legitimate medical cannabis dispensaries operated across the city. Many of the cannabis retailers operating in Portland during 2017 were operating as medical dispensaries, and later converted to become retail stores.[46,47] Further, some of those medical dispensaries were originally operating as unregulated dispensaries prior to Oregon starting to license and supervise medical dispensaries in 2014.[48] If the earlier siting practices for medical dispensaries were different than current siting practices for new licensed retailers, this could introduce bias into our study results since retailers that were formally medical dispensaries were established under different regulations.

Key innovations

Our study utilizes several innovative methods. First, we drew from real estate and urban planning disciplines to conduct a site suitability assessment[24] which allows for estimation of the expected number of properties that were eligible to operate as cannabis retailers within each neighborhood. To date, no research has been published that examines the distribution of cannabis retailers as a function of properties eligible to operate as a cannabis business. This method allows for better estimation of the true denominator (eligible properties) which is an improvement upon previous research. Second, using geographic neighborhood boundaries defined by the City of Portland provides a more realistic assessment of neighborhood deprivation. Third, creating a Portland-specific neighborhood deprivation index. Providing neighborhood-specific data can directly inform neighborhood coalition policy making on cannabis business regulation. Last, study methods used several existing data sources which is a cost-effective approach to policy evaluation and paved the way for future research.

Future research

Future studies are needed to disentangle the relationship between neighborhood deprivation, local cannabis regulatory policies, and distribution of cannabis retailers. Incorporating repeated measures and time-varying analysis could assess these causal relationships. In addition, our study methods should be replicated in other urban areas that have opened commercialized cannabis markets. Variations in cannabis policies between legalized states, provinces and countries may offer insight into policies that effectively mitigate the disproportionate burden of cannabis retailers across neighborhoods.

A critical gap remains on the individual-level effects of cannabis retailer exposure on vulnerable populations. Some research has examined youth cannabis use and access to medical marijuana dispensaries, quantified by the number of miles from the school to closest dispensary.[49] New research studies should be devoted to the embodiment of cannabis retailer exposure on altering youth social norms around cannabis use, changes in underage cannabis use and underage use of commercialized high potency products.

Conclusion

This study provides empirical evidence that neighborhood disadvantage is associated with having more cannabis retailers in the city of Portland, Oregon. If not mitigated, this factor could potentially contribute to or exacerbate disparities. For residents living within neighborhoods experiencing greater disadvantage, the presence of more cannabis retailers may alter the perceived safety and social cohesion within neighborhoods. Vulnerable populations, specifically youth, who are living in neighborhoods experiencing disadvantage may be more likely to be exposed to cannabis retailers and storefront advertisement than people living in other neighborhoods. More exposure to cannabis retailers may result in increases in underage cannabis use, impact performance at school and have criminal justice implications. Replicating this work over time and in other urban areas that are implementing commercial cannabis markets will inform policies and actions around cannabis business operations and targeted cannabis prevention campaigns. As more states and municipalities move towards cannabis legalization such research will support the development of cannabis policies that prioritize equity.

Supplemental Table 1. Variables included in principal component analysis of neighborhood deprivation, from American Community Survey, 2012-2016 five-year census block group estimates

Indicator	Number of variables
Income & Poverty	
Median household income[1]	1
Percent of households making <50k	1
Percentage of families in poverty with children < 18 years old[2]	1
Percentage of individuals in poverty	1
Percent use of food stamps & disability status	2
Percent of income attributed to public assistance	1
Dividends, interest, or net rental income	1
Occupation	
Percent of unemployed (in labor force, unemployed)	2
Occupation type (management/business sector, management, & food service)[3]	3
Demographics	
Population density	1
Percent of single female head of households & with children < 18 years old[2]	2
Limited English in house hold	1
Residential stability: move at least once in the past year	1
Percent covered by health insurance (any age, 18-34 yrs, 35-64 yrs)	3
Education	
Education attainment for population 25+ years (< high school; HS diploma; some college; college grad; graduate-level+)	5
Housing	
Number of housing units	1
Rental housing	1
New housing construction (2014 or newer construction)	1
More than 1 occupant per room in house	1
Assets	
No vehicle in house hold	1
Transportation to work (public transportation; bike/walk)	2

[1] *For 5 census block groups the sample size was too small for ACS to provide an estimate of median income. Estimates were imputed by assigning the corresponding census tract's median income value to the block group.*

[2] *For 3 block groups were no families lived, estimates were imputed with census tract estimates.*

[3] *Occupation type was restricted to occupations that were common in Portland, Oregon, and showed variety in type of occupation.*

Supplemental Table 2. Identifying properties that are eligible to operate as cannabis retailers, Portland, Oregon, 2017

Criteria	Count
All properties in the City of Portland and Multnomah County	235,624
Properties zoned for commercial use	13,844
Properties at least 1,000 foot buffer from any primary or secondary schools	7,727
Properties at least 1,000 foot away from each other (state laws requires 1,000 foot buffer between cannabis retailers)	807

Supplemental Figure 1. Calculating expected number of cannabis retailer by criteria to open in a cannabis retailer in the City of Portland, Oregon

Figure 1a. Criteria 1: Property must be zoned for commercial use (13,844/235,624 properties)

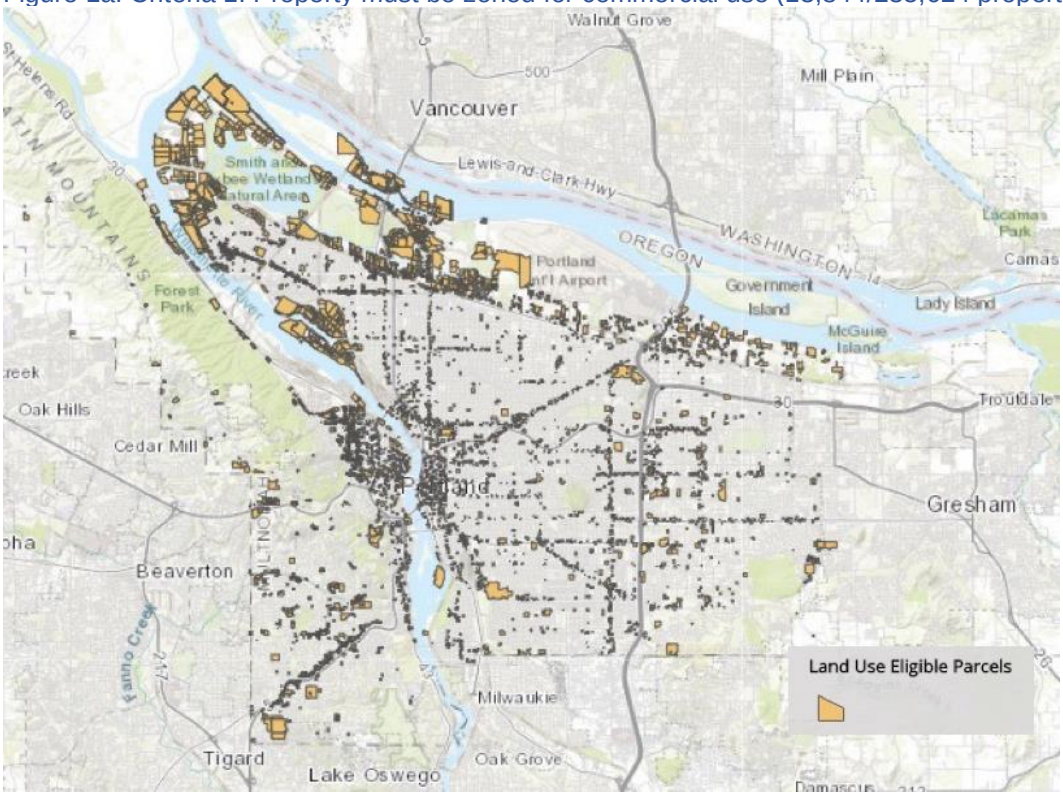


Figure 1b. Criteria 2: Must have a 1,000 foot buffer from primary and secondary schools (7,727/13,844 properties)

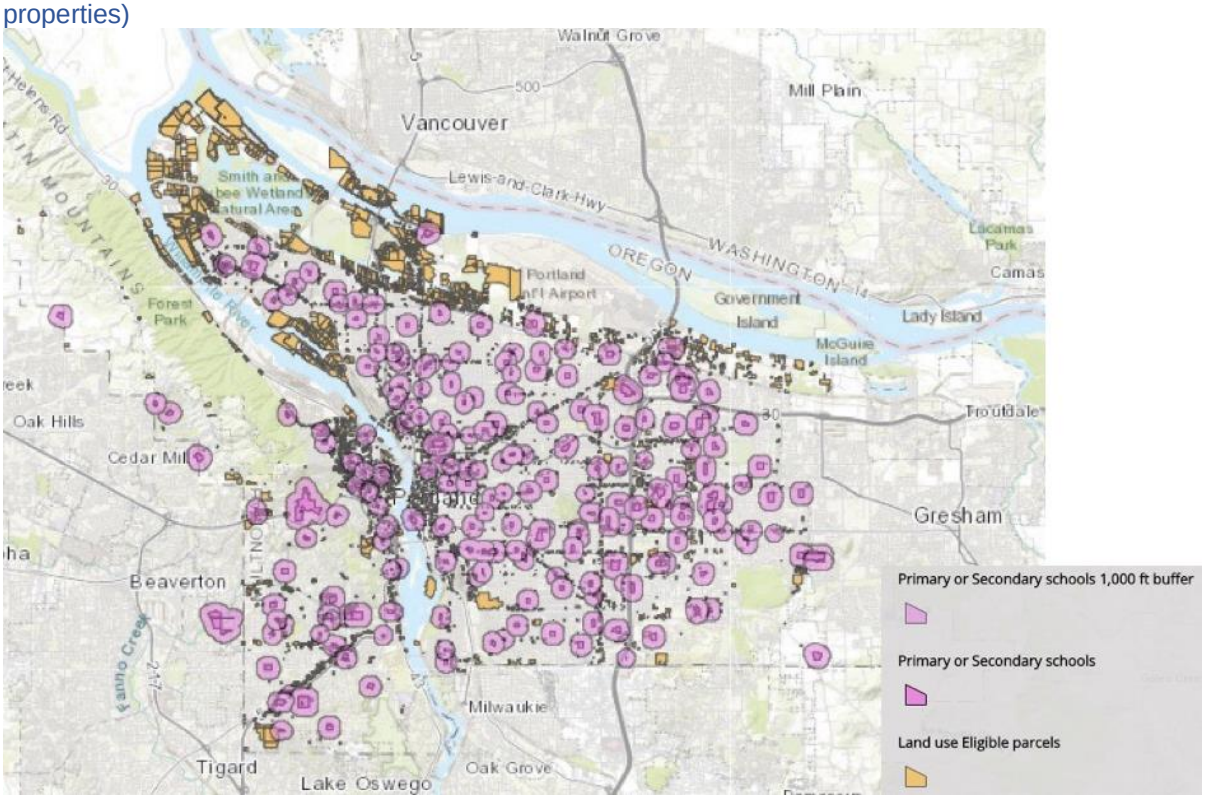


Figure 1c. Criteria 3: Must have 1,000 foot buffer between cannabis retailers (807/7,727 properties)

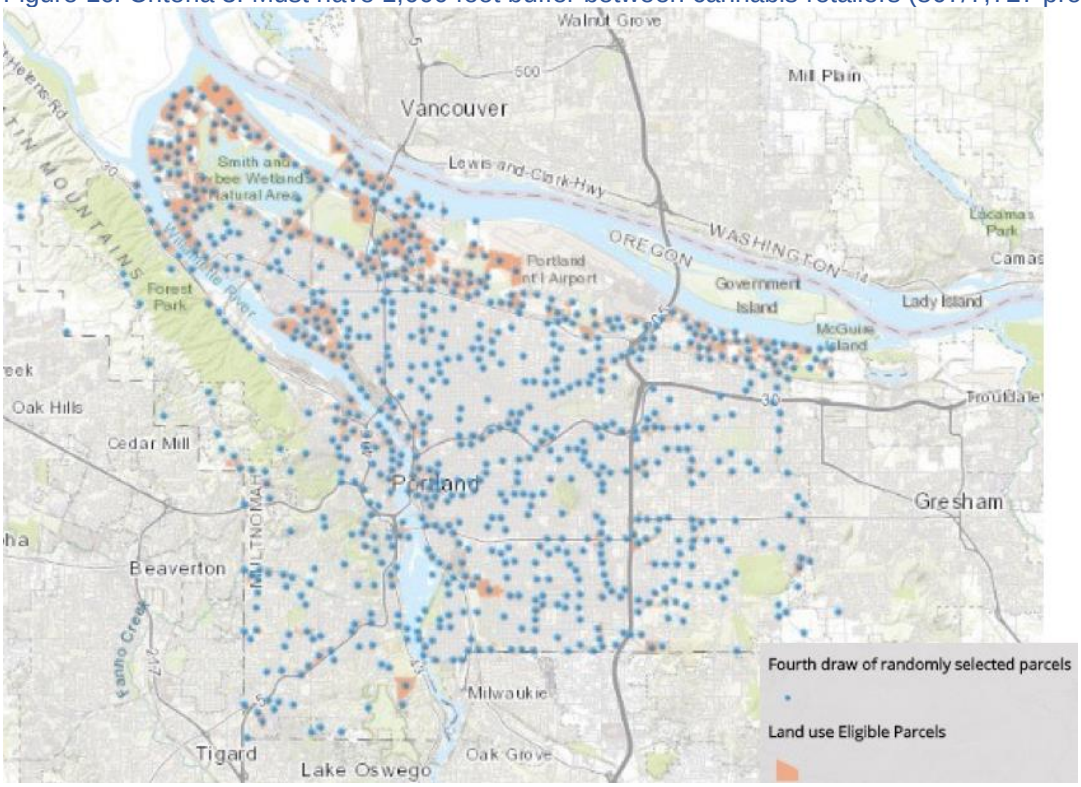
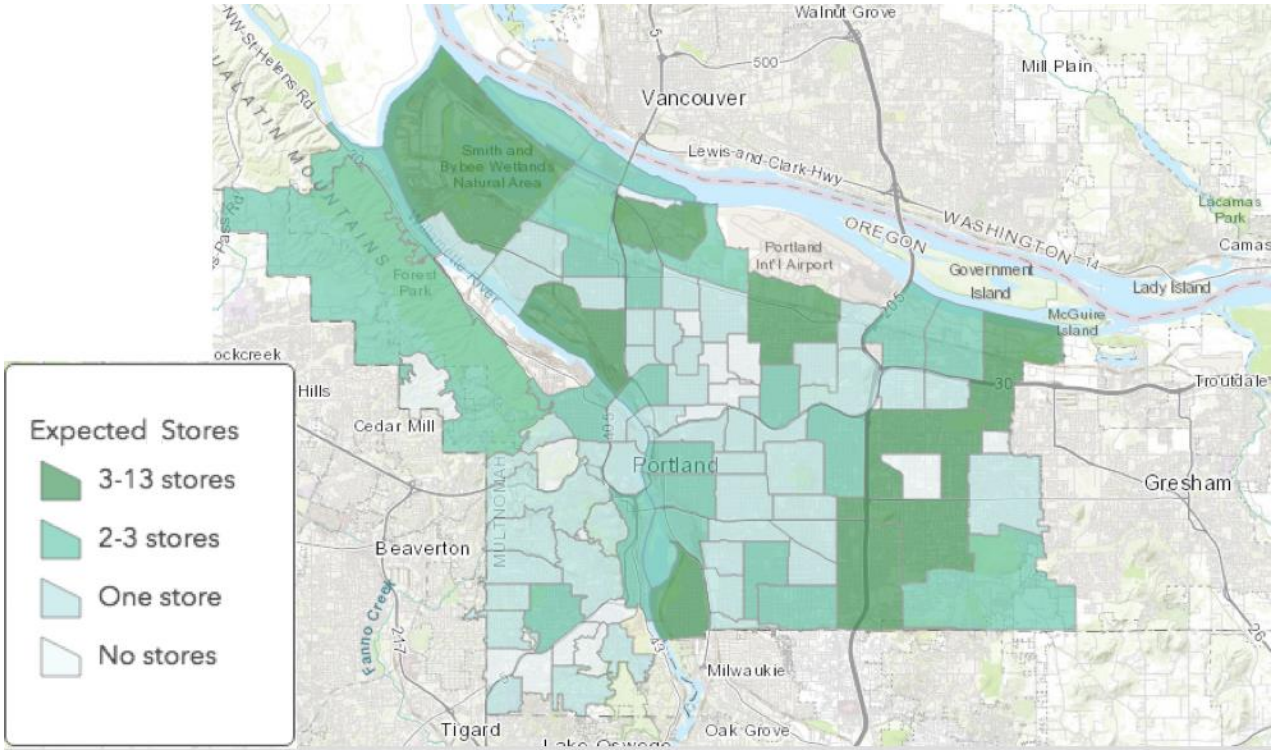


Figure 1d. Expected number of cannabis retailers within each neighborhood was based on the reference probability (150 open retailers/807 eligible properties)



Supplemental Table 3. Built Environment characteristics among select neighborhoods

Most Deprived Neighborhoods	Built Environment Index	Walkability	Number of liquor stores	Median commercial property value
GLENFAIR	-1.01	54	0	$ 706,000
MILL PARK	-0.29	69	0	$ 929,070
POWELLHURST-GILBERT	-1.12	52	0	$ 631,740
CENTENNIAL COMMUNITY ASSOCIATION	-0.39	53	0	$ 695,200
LENTS/POWELLHURST-GILBERT	-0.93	55	0	$ 847,295
Least Deprived Neighborhoods				
BRIDLEMILE/SOUTHWEST HILLS RESIDENTIAL LE	-1.67	40	0	$ 565,975
MC UNCLAIMED #13	-3.30	6	0	n/a
HILLSIDE	-0.96	47	1	$ 214,720
ALAMEDA/IRVINGTON COMMUNITY ASSN.	0.24	73	0	$ 1,902,980
HEALY HEIGHTS/SOUTHWEST HILLS RESIDENTIA	-1.96	34	0	$ 422,980

AIM TWO A & B: Impacts of adult cannabis legalization on the rates of juvenile cannabis allegations and racial/ethnic disparities

INTRODUCTION

The impact of adult cannabis legalization on juvenile justice in the United States has received little attention. Youth are exposed to commercial cannabis, yet cannabis remains an illegal substance for minors that is subject to criminal penalties. Thus, exposure to cannabis retailers may lead to an increase in underage cannabis use and further criminal prosecution of minors who use cannabis. One of the motivations for legalizing cannabis was to reduce criminal charges and incarceration attributed to cannabis among adults.[50] Proponents continue to argue that legalization would bring a significant decrease in cannabis-related crimes and reduce racial/ethnic disparities in the criminal justice system.[51] Though youth were not at the forefront of the legalization debate, the ramifications for youth could be significant. There is great concern that legalization will increase access to commercialized cannabis and reduce the perceived harm of cannabis use among youth.[8] States that have legalized cannabis have observed a substantial reduction in adult arrests of cannabis crimes,[52–54] but the effect on juvenile justice have not been well defined. It is imperative for public health agencies tasked with monitoring health and societal impacts of cannabis legalization to consider the effects that legalization has on juvenile justice. There is a growing body of evidence that youth arrests are a social determinant of health that can lead to lifelong detrimental effects.[35] Youth who experience juvenile arrest have lower educational attainment and limited employment opportunities compared to their peers. Furthermore, youth who are arrested as juveniles are at risk for recidivism which leads to more severe criminal sanctions and ultimately an increased risk of premature death.[55]

In November 2014, Oregon voters passed Measure 91 (M-91) making Oregon the third state to legalize the local production, processing and sale of cannabis to persons ages 21 and older for non-medical use. Possession of small amounts of cannabis (<1 ounce) became legal for adults on July 1, 2015. Following M-91, the Oregon legislature passed new crimes pertaining to the use of cannabis and the establishment of a commercial cannabis market.[12] After adult legalization in July 2015, cannabis crimes were

reclassified and new crimes related to legalization were defined for both adults and minors. Crimes for minors ranged in severity from violation-level status offenses, conduct that would not be a crime if committed by an adult, for <1 ounce possession or consumption of cannabis to severe felonies for transporting large quantities of cannabis.[13] A new cannabis minor in possession (MIP) status offense was enacted that included possession as well as recent consumption of cannabis that results in a fine that ranges from $135–$1000.[14,15] There is concern that the new crimes may increase the likelihood of youth being arrested for cannabis-related activities.

Inequities in the juvenile justice system may also be exacerbated by cannabis legalization. Across the country, youth of color are disproportionately in the juvenile justice system and rates of arrest are more than five times higher for Black youth compared to white youth. [16] The likelihood of juvenile arrest is also strongly associated with age and gender.[17] In Washington state, disparities for Blacks in adult cannabis arrests increased substantially after legalization.[5] In Colorado, researchers examined the overall number of juvenile cannabis arrests after legalization in 2012 and found that the number of arrests were declining and the reduction was more pronounced for white youth compared to Hispanic or Black youth; however, the lack of available data prior to legalization has made it difficult to assess the effects that adult legalization had on racial/ethnic disparities in arrests.[3] Therefore, it is crucial to be able to assess the effects that adult cannabis legalization has on existing racial/ethnic disparities in the juvenile justice system.

This study aims to 1) understand the statewide impacts of retail cannabis legalization in Oregon on the rates of cannabis-related juvenile justice allegations, and 2) assess whether legalization has impacted racial/ethnic disparities within those outcomes. Results of this study will support the work of policy makers towards equitable cannabis policies, and avoidance of unintended negative impacts for youth.

METHODS

Study Design

A population-based study was designed to determine if adult legalization of possession of small amounts of cannabis (in July 2015) has an impact on juvenile cannabis allegations. We conducted an interrupted

time series analysis to a) assess the statewide impact of legalization on the rate of criminal cannabis allegations among all youth and youth who report cannabis use in Oregon and b) evaluate whether legalization impacted relative racial and ethnic disparities in the rates of juvenile cannabis allegations.

Study Population

We obtained access to the Oregon Juvenile Justice Information System (JJIS) from the Oregon Youth Authority. The JJIS is a statewide-integrated electronic information system that captures all services administered to youth through the juvenile justice system in Oregon.[58] Our study included 18,779 allegations resulting from cannabis-related status and criminal offenses (that range in penalty from violations to felonies) in Oregon committed by youth ages 10-17 during January 2012–September 2018 and reported in JJIS with complete demographic information (Supplemental Table 2). Criminal allegations include cannabis-related offenses that are referred by law enforcement to juvenile departments prior to adjudication and disposition (before appearing in court and sentencing). Detailed information on the date, nature of crime, sentencing and demographic information of each youth was provided for each allegation in addition to the Oregon county in which the crime was committed.

We chose to model changes in the rate of criminal allegations that resulted in a referral to the juvenile justice department because it allowed us to assess the earliest point of contact for all youth entering into the juvenile justice system. Any person who enters the criminal justice system is engaging in a process that is both taxing and draining of resources.[59] For youth, their future in the system is largely up to the discretion of key individuals within the juvenile justice system (police officer, juvenile department, probation officer and judge). These intermediaries make evaluating the effects of cannabis legalization on the juvenile justice system challenging because bias is introduced as the outcome of each youth's referral is up to the decision of key personnel. We believe assessing allegation-level data is subject to the **least** amount of epidemiologic bias compared to other sources of crime data.

Outcome

Our outcome of interest was the count of cannabis-related allegations for every month within each gender (male, female), Non-Latinx race (white, Black/African American, American Indian/Alaska Native and Asian/Pacific Islander) and Latinx ethnicity and age (10-14 years and 15-17 years) groups. We aggregated the occurrence date of each allegation to month and year for every demographic group. The reason for grouping allegations in this manner is to adjust for the effects of age, gender and race/ethnicity that are associated with both the likelihood of cannabis use and arrest. Since we are interested in modeling rates of criminal allegations, and not youth in the juvenile justice system, a youth could appear in our study more than once if they had more than one cannabis-related criminal incident during our follow up period from January 2012–September 2018.

Policy exposure

Our regression models centered time on the date of adult cannabis legalization (e.g., legalization of possession/use by people 21 and older, July 2015). Therefore, a one-unit change corresponded to a relative difference in the rate of allegations between two months. Our **policy** variable was the average effect of adult legalization as “1” starting in July 2015 and “0” before. To assess change in linear time trend before and after legalization, we included an interaction between time and the policy variables.

Statistical Analysis

Data processing and multivariate analysis were conducted in Stata 15.1. In models, the **primary independent variables** were the main effect of legalization on juvenile allegations and the change in time trend after legalization. The **dependent variable** was the monthly count of juvenile cannabis allegations within each demographic group (racial/ethnic, gender and age groups). We fit a series of negative binomial models in order to calculate changes in the rates of juvenile cannabis allegations. The **offset** (i.e. denominator) was the natural log of the corresponding youth population estimates or cannabis using youth estimates.

Offset

To model changes in the rates of juvenile cannabis allegations, the monthly count of allegations within each demographic group was offset by its corresponding population estimate. This produces a rate of allegations (# of allegations/population size) which improves interpretability. For analysis among all Oregon youth, we used annual Census Bureau/National Center for Health Statistics, estimates by age, unbridged race, Hispanic origin, and sex (2012–2017). Non-Hispanic multiracial estimates were not included and 2017 population estimates were imputed for 2018 allegations. We also restricted our analysis to cannabis-using youth within Oregon. Population estimates were weighted by statewide biennial prevalence estimates of current cannabis use within each demographic group. Prevalence data for current cannabis use were collected from the school-based Oregon Student Wellness Survey (2012, 2014, 2016 and 2018), a biennial study survey that is administered during even-numbered school years to ~60,000 6th, 8th and 11th graders.[60] Current use among 8th graders was used to estimate prevalence for 10-14 year olds and current use among 11th grade was used to estimate prevalence for 15-17 year olds.

(Model 1)

$$\begin{cases} Y_i = \mu_i \\ variance(Y_i) = (\theta\mu_i) \\ \log(\mu_i) = \log(E_i) + \beta_0 + \beta_1 \boldsymbol{x}_i + \beta_2 \boldsymbol{x}_i + \beta_{12} \boldsymbol{x}_i + \beta_{3\ldots j} \boldsymbol{x}_i \end{cases}$$

Y_i Count of juvenile cannabis criminal allegations (outcome)
μ_i Marginal mean
θ Overdispersion parameter
E_i Youth population (offset)
β_0 Intercept
β_1 Legalization of adult possession (July 2015) (independent variable)
$\boldsymbol{x}_i$ Unit of analysis, monthly count of cannabis allegations within each demographic group
β_2 Time Trend before legalization (in months)
β_{12} Change in time trend after legalization (in months) (independent variable)
$\beta_{3\ldots j}$ Covariates: age group, race/ethnicity, gender & month of criminal allegation (during the school year vs. summer)

First, a quasi-Poisson model was fit to assess overdispersion (Model 1) in the data. This model directly estimated (θ) the level of non-Poisson variability in the data. If data were overdispersed, an alternate modelling approach, such as a negative binomial model would be needed. We estimated the log relative risk of adult cannabis legalization on the rate of juvenile cannabis allegations and the change in time

trend after legalization compared to the time trend prior to legalization. We adjusted for age group, race/ethnicity, gender and month in which the crime occurred.

(Model 2)

$$\begin{cases} Y_i = \mu_i \\ variance(Y_i) = (\mu_i + k{\mu_i}^2) \\ \log(\mu_i) = \log(E_i) + \beta_0 + \beta_1 \boldsymbol{x}_i + \beta_2 \boldsymbol{x}_i + \beta_{12} \boldsymbol{x}_i + \beta_{3\ldots j} \boldsymbol{x}_i \end{cases}$$

Y_i Count of juvenile cannabis criminal allegations (outcome)
μ_i Marginal mean
k Overdispersion parameter
E_i Youth population (offset)
β_0 Intercept
β_1 Legalization of adult possession (July 2015) (independent variable)
$\boldsymbol{x}_i$ Unit of analysis, monthly count of cannabis allegations within each demographic group
β_2 Time Trend before legalization (in months)
β_{12} Change in time trend after legalization (in months) (independent variable)
$\beta_{3\ldots j}$ Covariates: age group, race/ethnicity, gender & month of criminal allegation (school year: September–June vs summer)

To address overdispersion in the data, we fit negative binomial models. We again estimated the log relative risk of adult cannabis legalization on the rate of juvenile cannabis allegations and the change in time trend after legalization compared to the time trend prior to legalization (Model 2). We represented a counterfactual plot, alongside model results, to characterize the absolute number of juvenile cannabis allegations that could have been prevented in the absence of legalization. The number of allegations that would have occurred over time were estimated from the linear time trend parameter estimate prior to legalization (β_2). This assumed that the linear time trend before legalization held constant over time and the difference between the counterfactual and the observed number of allegations after legalization represented the number of allegations that could have been prevented if Oregon had not legalization cannabis for adults. In order to better characterize the impacts of adult legalization on juvenile cannabis allegations, it was essential to consider the impacts of legalization within racial and ethnic groups and account for changes in cannabis use over time within demographic groups. We fit separate models for each race/ethnicity to assess the impacts adult legalization within each racial/ethnic group.

To understand the effects that changes in youth cannabis use may have on the impacts of legalization, an additional model was fit that used cannabis using youth as an **offset.** This approach assumed that cannabis criminal allegations occurred among youth who use cannabis and accounted for changes in cannabis use within demographic groups over time. All models were adjusted for age group, race/ethnicity, gender and month in which the crime occurred.

(Model 3)

$$\begin{cases} Y_i = \mu_i \\ variance(Y_i) = (\mu_i + k{\mu_i}^2) \\ \log(\mu_i) = \log(E_i) + \beta_0 + \beta_1 \boldsymbol{x}_i + \beta_2 \boldsymbol{x}_i + \beta_3 \boldsymbol{x}_i + \beta_{31} \boldsymbol{x}_i + \beta_4 \boldsymbol{x}_i + \beta_{41} \boldsymbol{x}_i + \beta_5 \boldsymbol{x}_i + \beta_{51} \boldsymbol{x}_i + \beta_6 \boldsymbol{x}_i + \beta_{61} \boldsymbol{x}_i \end{cases}$$

Y_i Count of youth cannabis allegations (outcome)
μ_i Marginal mean
k Overdispersion parameter
E_i Population of current cannabis users (offset)
$\boldsymbol{x}_i$ Unit of analysis, monthly count of cannabis allegations
β_1 Legalization policy (main effect)
β_2 Time (centered at legalization: July 2015) (main effect)
β_3 Allegations among Black/African Americans before legalization (< July 2015)
β_{31} Allegations among Black/African Americans after legalization (≥ July 2015)
β_4 Allegations among American Indians/Alaska Natives before legalization (< July 2015)
β_{41} Allegations among American Indians/Alaska Natives after legalization (≥ July 2015)
β_5 Allegations among Latinx before legalization (< July 2015)
β_{51} Allegations among Latinx after legalization (≥ July 2015)
β_6 Allegations among Asian/Pacific Islanders before legalization (< July 2015)
β_{61} Allegations among Asian/Pacific Islanders races after legalization (≥ July 2015)
$\beta_{7\ldots j}$ Covariates: age group, gender & month of criminal allegation (school year: September–June vs summer)

In order to assess the impacts of adult legalization on racial/ethnic disparities in juvenile cannabis allegations, we reparametrized the negative binomial models to include the effects of legalization for specific racial/ethnic groups (Model 3). In this way, we could directly estimate the relative disparities between communities of color and white youth (the referent group) before and after legalization. We also conducted post estimation linear contrast statements to determine if disparities had changed after legalization compared to before legalization for each racial/ethnic group.

To extend the analysis of racial/ethnic disparities in juvenile cannabis allegations, we fit a second model that used cannabis using youth as an **offset.** Both models were also adjusted for age group, gender and month in which the allegation occurred.

In addition, we conducted a sensitivity analysis to examine the effect of geography on the statewide impacts of adult legalization on juvenile cannabis allegations and on racial/ethnic disparities. We did so by stratifying Models 2 and 3 by county-level urbanicity among all Oregon youth.

RESULTS

Descriptive

Before legalization, the number of juvenile cannabis allegations was declining from 3,762 in 2012 to 2,631 in 2014. After cannabis legalization passed in November 2014 and adult possession (21+ years) of small quantities of cannabis became legalized in July 2015, the reduction in juvenile cannabis allegations seen before legalization was no longer apparent and 2,709 allegations were reported in 2016. During the study period, 72% of youth with cannabis-related crimes were white; white youth make up 68% of the state of Oregon population.

The majority of juvenile cannabis allegations were for possession of small amounts of cannabis (<1 oz of useable flower). Prior to legalization 88% of allegations (9190/10488) were for possession compared to 92% of allegations after legalization (7621/8290) (p-value: <0.05). More severe crimes like cannabis delivery and manufacturing made up the remaining allegation types. The proportion of allegations attributed to delivery crimes went from 11% (1209/10488) prior to legalization to 7% (629/8290) after legalization (p-value: <0.05), and the proportion of manufacturing crimes remained unchanged after legalization (<1%) (Supplemental Table 3).

The rate of juvenile cannabis allegations varied greatly by race/ethnicity over time. Prior to legalization, the highest rates of cannabis allegations were reported among American Indian/Alaska Native youth followed by Black/African American youth and white youth (Figure 1b). In addition, youth cannabis use

prior to legalization was also highest among Black/African American and American Indian/Alaska Native youth (Figure 1a). Adult legalization of cannabis (July 2015) has not appeared to have a substantial impact on statewide cannabis use estimates among youth. Among American Indian/Alaska Native 11th graders, current cannabis use increased from 28% in 2014 before legalization to 31% in 2018 after legalization. Whereas, 32% of Black/African American 11th graders reported cannabis use before legalization in 2014 and 24% reported cannabis use in 2016 and 28% in 2018 after legalization. Other racial and ethnic groups have observed little change in underage cannabis use over our six-year observation period.

Figure 1a. Cannabis use among Oregon youth, 2012–2018

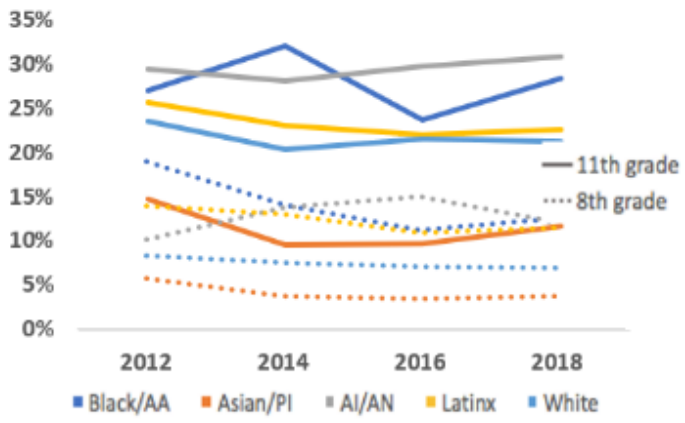
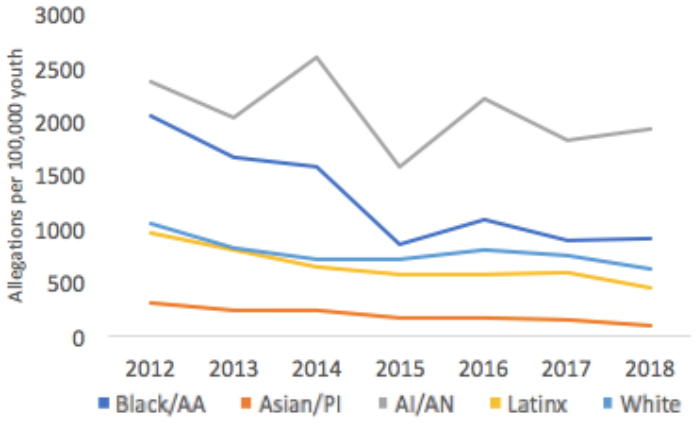


Figure 1b. Juvenile cannabis allegation rates, 2012–2018



Model results: Statewide impacts

The quasi-Poisson general linear model (Model 1), found overdispersion: the variance was 2.25 times larger than the marginal mean. Given the presence of overdispersion, we used a negative binomial model to evaluate our study question (Model 2). Statewide, the average monthly rate of juvenile cannabis allegations among all Oregon youth (10-17 years) increased by 28% (RR:1.28, CI: 1.14–1.44) (Table 1) after adult legalization of cannabis adjusting for age, race/ethnicity, gender and month that crime was committed. In addition, the decline in allegations over time seen before legalization had flattened (RR 1.01, CI: 1.01–1.02). When our models were restricted to cannabis-using youth, the average rate of allegations increased by 32% (RR:1.32, CI: 1.18–1.48) after adult legalization. Again, the decline in allegations seen before legalization had flattened after legalization because of significantly positive

interaction term between time and legalization policy (RR 1.01, CI: 1.00–1.01). If Oregon had not legalized cannabis for adults in July of 2015, we would have expected to see an average of 541 fewer cannabis allegations among cannabis-using youth each year if the decline in allegations observed prior to legalization remained constant over time; or a reduction of 1622 allegations in the first three years since legalization (July 2015–June 2018) (Figure 2).

Table 1. Model results of statewide impacts of adult cannabis legalization on juvenile cannabis allegations rates by racial and ethnic groups and youth who report cannabis use

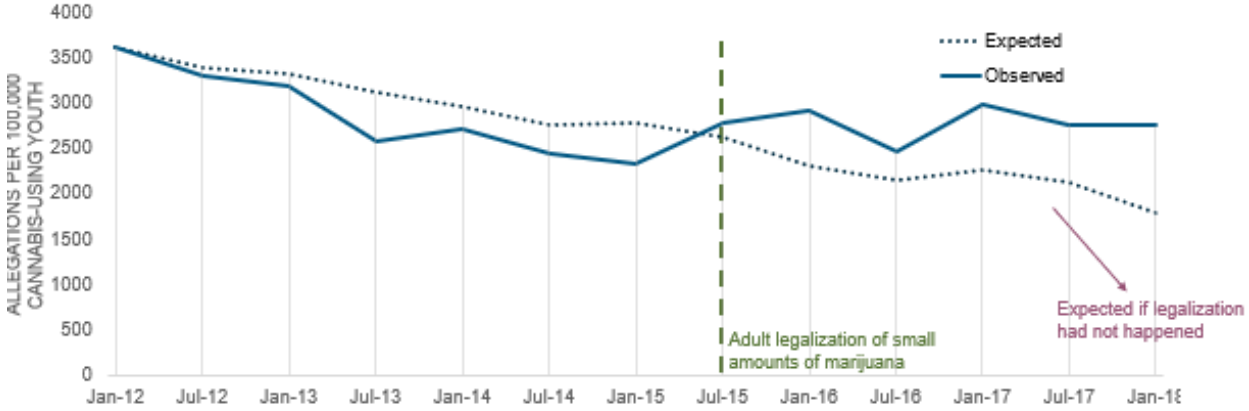
**p-value <0.05; [1]Non-Latinx race was reported*

	Rate Ratio (95% CI) among all youth (10-17 years old)[2]						Rate Ratio among all Cannabis using youth (10-17 years old)[3]
Parameters	All youth	Black/African American youth[1]	Asian/Pacific Islander youth	American Indian/Alaska Native youth	Latinx youth	White youth	
Legalization of adult possession (July 2015)	1.28 (1.14–1.44)*	1.04 (0.78–1.49)	1.25 (0.71–2.20)	0.79 (0.51–1.22)	1.33 (1.09–1.61)*	1.46 (1.26–1.70)*	1.32 (1.18–1.48)*
Time Trend before legalization (in months)	0.99 (0.98–0.99)*	0.98 (0.97–0.99)*	0.99 (0.97–1.00)	1 (0.99–1.01)	0.98 (0.98–0.99)*	0.99 (0.98–0.99)*	0.99 (0.99–0.99)*
Change in time trend after legalization (in mo	1.01 (1.01–1.02)*	1.02 (1.00–1.03)*	0.99 (0.97–1.02)	1.01 (0.99–1.03)	1.01 (1.00–1.02)*	1.01 (1.00–1.02)*	1.01 (1.00–1.01)*

[2]The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates. The effects of age, race/ethnicity, gender and month that crime was committed were adjusted for.

[3] The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates of cannabis users. The effects of age, race/ethnicity, gender and month that crime was committed were adjusted for.

Figure 2. Impact of adult cannabis legalization on juvenile cannabis allegations among cannabis-using youth, Oregon

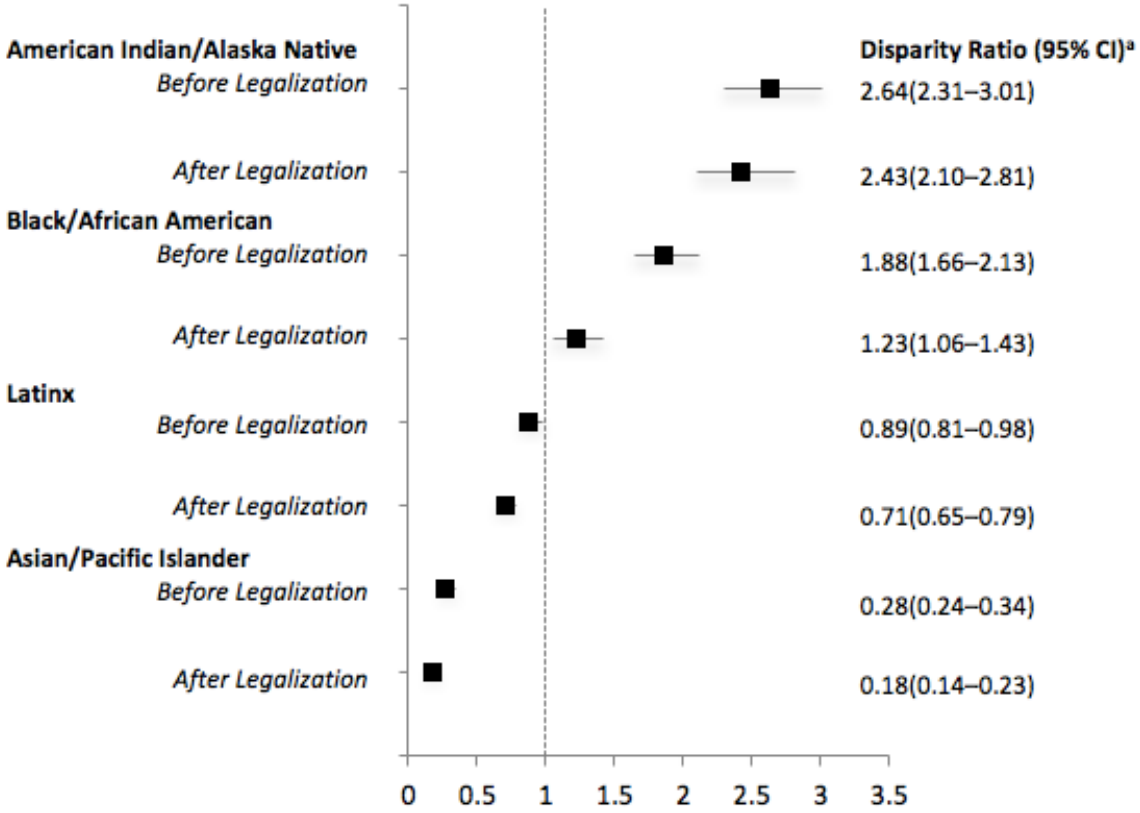


The impact of adult legalization on juvenile cannabis allegations was not consistent across racial and ethnic groups. Legalization significantly increased the rate of allegations among all white and Latinx youth, but legalization did not significantly increase the rate of allegations among Black/African American, Asian/Pacific Islander or American Indian/Alaska Native youth (Table 1). This pattern was consistent when models were restricted to cannabis-using youth (Supplemental Table 4).

Model results: Racial and ethnic disparities

To address whether adult legalization of cannabis impacted racial and ethnic disparities in juvenile cannabis allegations, our models were reparametrized to estimate the relative disparity in allegations for each community of color compared to white youth (Model 3). Among all Oregon youth, Black/African American youth were nearly twice as likely to receive a cannabis related criminal allegation than white youth before legalization (RR: 1.88, CI: 1.66–2.13) and this disparity significantly decreased after legalization (RR: 1.23, CI: 1.06–1.43) (Figure 2a). For American Indian/Alaska Native youth, the likelihood of receiving a cannabis criminal allegation was 2.6 times that of whites before legalization (RR: 2.64, CI: 2.31–3.01) and this disparity did not significantly change after legalization (RR: 2.43, CI: 2.10–2.81). Both Latinx and Asian/Pacific Islander youth had rates of cannabis allegations that were lower than non-Latino whites before and after legalization.

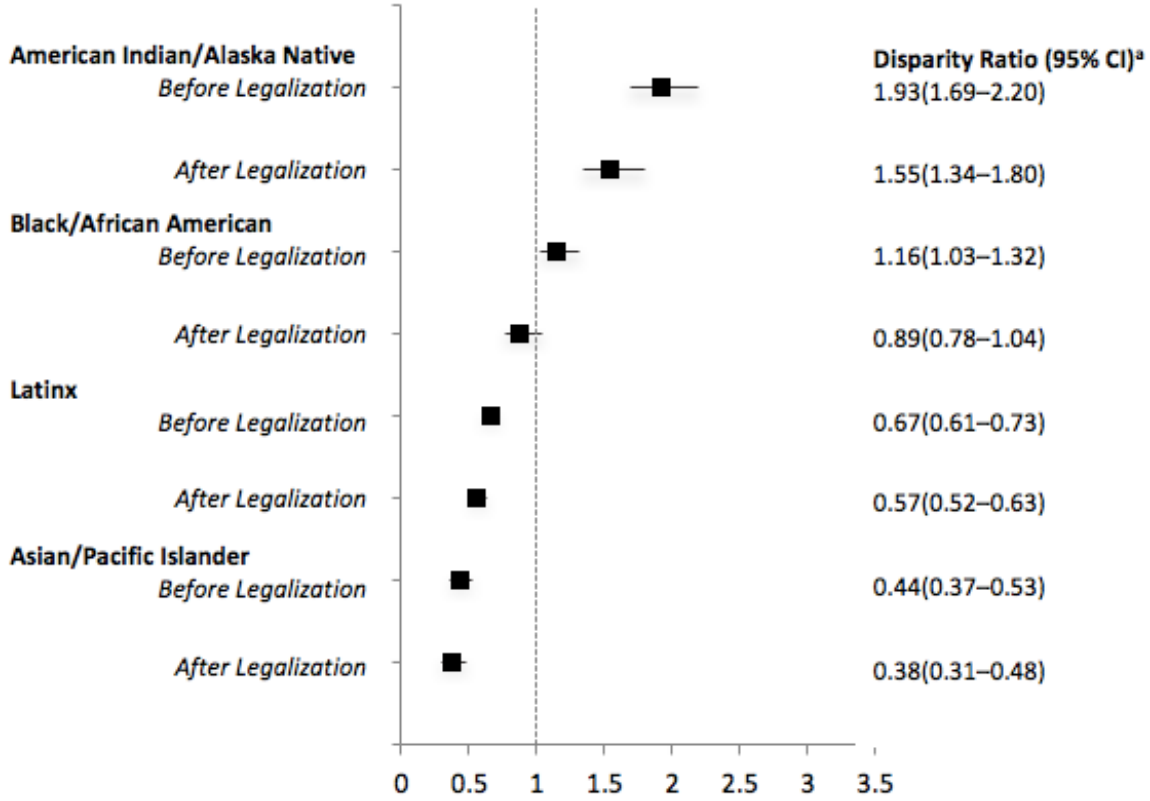
Figure 2a. Disparities in juvenile cannabis allegations before and after legalization among all youth



**Significant reduction in disparity after legalization, p-value <0.05;*
[1] The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates of cannabis users. The effects of age, gender and month that crime was committed were adjusted for.

When our study population was restricted to cannabis-using youth, racial disparities in juvenile cannabis allegations were less pronounced. Before legalization, cannabis-using Black/African American youth were 16% more likely to be receive a cannabis criminal allegation than white youth (RR: 1.16, CI: 1.03–1.32) and after legalization the disparity reduced such that there was no significant increase in the risk of allegations among Black/African American relative to whites (RR: 0.89, CI: 0.78–1.04). For American Indian/Alaska Native cannabis-using youth, the risk of receiving an allegation prior to legalization was twice that of white youth (RR: 1.93, CI: 1.69–2.20) and this disparity did not significantly reduce after legalization. After legalization American Indian/Alaska Native cannabis using youth were still 55% more likely to receive a cannabis criminal allegation than white youth (RR: 1.55, CI: 1.34–1.80). Both Latinx and Asian/Pacific Islander cannabis-using youth were less likely to receive a cannabis allegation relative to white youth, and legalization had no significant impact on these relative differences (Figure 2b).

Figure 2b. Disparities in juvenile cannabis allegations before and after legalization among cannabis-using youth



**Significant reduction in disparity after legalization, p-value <0.05;*
[1] The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates of cannabis users. The effects of age, gender and month that crime was committed were adjusted for.

Sensitivity analysis

We were interested in understanding how geography, specifically urban and rural environments, may affect the impacts of adult cannabis legalization on juvenile cannabis allegations overall and racial and ethnic disparities within these allegations. From stratified analysis by urbanicity of Oregon county, the increase in cannabis allegations after legalization was more pronounced in rural areas (RR: 1.45, CI: 1.22–1.72) compared to the impact of legalization in urban areas (RR: 1.26, CI: 1.11–1.43). Both rural and urban areas saw a flattening in the decline of cannabis allegations that was previously observed prior to legalization (Supplemental Table 5).

Racial disparities varied by Oregon county urbanicity. For Black/African American youth, relative disparities in cannabis criminal allegations decreased in both urban and rural areas after legalization, but the magnitude of the disparity varied from 2.6 times the risk of whites in rural areas before legalization to 1.3 times the risk of whites in urban areas after legalization. Within urban areas, the disparity for American Indian/Alaska Native youth was 2.8 times that of whites prior to legalization and no significant change was observed after legalization. Though, the disparity for American Indian/Alaska Native youth in rural areas significantly decreased from 2.3 times the risk of white youth before legalization to 1.3 times the risk after legalization (Supplemental Table 6a&b).

DISCUSSION

This study is the first to assess the impacts of adult cannabis legalization among youth who report cannabis use and on racial disparities in juvenile justice outcomes. Results indicate that the rate of juvenile cannabis allegations increased after legalization, including after adjustment for cannabis use prevalence trends among youth. The largest disparity in allegations before legalization was among AI/AN youth relative to white youth, and this disparity remained unchanged after legalization. For Black youth disparities were reduced following legalization, but rates remained greater than for white youth. The magnitude of disparities was less pronounced among youth who reported using cannabis, but patterns were similar.

Statewide impacts

This study provides empirical evidence that adult legalization of cannabis in Oregon has contributed to a rise in juvenile cannabis allegations. Youth are being exposed to cannabis retailers and advertisements,[20,21] and some have argued this may alter social norms by reducing perceived risks of cannabis use, increasing cannabis consumption and resulting in more juvenile justice penalties for youth who use cannabis.[7] However, if legalization resulted in increased youth use, an increase in the total population rate of allegations after legalization and no change in the rate of cannabis allegations among youth reporting cannabis use would have been expected. Instead the rate of cannabis allegations increased, and that increase was even greater among the estimated population of youth using cannabis.

These findings contradict the results of the only other study to examine changes in juvenile justice outcomes–that legalization had no effect on rates of cannabis possession arrests for youth among seven states using Uniform Crime Reporting data (2000–2016).[6] Plunk et al's analysis examined only one type of crime (arrests where cannabis possession was implicated as the most severe offense), their analysis pooled the effects of seven legalized states together, and they did not consider the effects that variations in criminal justice policies between states had on arrest outcomes.

One possible explanation for this increase in Oregon's youth allegation rates may be new cannabis crimes targeting underage use (people <21 years) that were enacted after adult legalization.[12–14] Specifically, the cannabis MIP status offense was enacted in July 2015 and includes both underage possession and consumption of cannabis in the past 24 hours. Including consumption into the definition of the offense may have increased the likelihood of youth being arrested. Therefore, the increase in juvenile cannabis allegations could be partly driven by changes in how crimes are defined, policies and enforcement practices, and if youth are more likely to use cannabis in public or in areas where they could be more easily caught by law enforcement.

Racial disparities

Differences in cannabis use by racial and ethnic groups affected the magnitude of disparities within juvenile cannabis allegations. The prevalence of underage cannabis use was highest among Black/African American and American Indian/Alaska Native youth for the entirety of the study period (Figure 1a). This attenuated the relative disparities in allegations among cannabis users. For Black/African American youth, disparities in allegations reduced after legalization in models of all youth and among cannabis using youth. For American Indian/Alaska Native youth, disparities in allegations were more prominent and legalization did not reduce disparities. The lack of reduction in disparities may be confined to urban areas given that rural counties saw a significant reduction in the disparities among American Indian/Alaska Native youth after legalization. Statewide, the majority of Oregon residents identify as non-Latinx white as do 68% of Oregon youth. The diversity within the state is not distributed evenly across space, and the majority of Black/African American and Asian/Pacific Islander residents live

in urban areas compared to the majority of Latinx and American Indian/Alaska Native residents live in rural areas.[61] The geographical differences in diversity coupled with socio-cultural norms may contribute to the different patterns in racial disparities between urban and rural areas.

Beyond cannabis-related crimes, disparities within the Oregon juvenile justice system have been well documented.[62] The Oregon Youth Authority has invested in training juvenile justice professionals in cultural competency, developing local transition programming services and has supported work to identify underlying mechanisms and risk factors for youth being committed to a correctional institution.[63,64] Our findings further support need for community-specific targeted prevention efforts to decrease underage cannabis use in tandem with addressing school disciplinary polices and police racial bias to decrease disparities. Regardless of the impacts of adult legalization, the number of youth entering the juvenile justice system in Oregon for cannabis-related crimes are still disproportionately Black/African American or American Indian/Alaska Native.

Alternative explanations

There are unmeasured contextual factors that could have influenced our study results. At the school district-level, school disciplinary policies around cannabis use may have become more severe after adult legalization along with an increase in the presence of police officers (e.g., school resource officers) within schools and disciplinary referrals to juvenile justice departments. These factors could account for increases in cannabis-related allegations that are unrelated to adult legalization. Disproportionate disciplinary actions by race/ethnicity[65] play a role in exacerbating the school-to-prison pipeline that contribute to the sustained disparities seen in juvenile cannabis allegations after legalization.

Similar to school disciplinary programs, law enforcement and public safety resources are not allocated equally across the state. For youth living in rural counties, there was one sworn police officers for every 43 youth compared to one officer for every 63 youth in urban counties during 2018.[66] The passage of Measure 91 (adult legalization of cannabis) designated 15% of collected cannabis sales tax for law enforcement agencies, but it is unclear how law enforcement agencies invested their funds.[67] As evident

from our exploratory analysis, the impact of legalization in urban counties was less pronounced than in rural environments (RR: 1.26 vs. 1.45). This may be indicative of fewer police officers and law enforcement agencies prioritizing other public safety concerns in more urban environments while agencies in rural areas will continue to target juvenile cannabis crimes.

Call for policy change

While adults are less likely to be arrested for cannabis-related crimes after legalization in Oregon,[54] youth are entering the juvenile justice system for cannabis-related offenses at an increasing rate. In order to impact this unforeseen increase in juvenile cannabis allegations, an interdisciplinary approach is likely needed to address the underlying causes of substance use and enact policies and enforcement practices that advocate for the health of all Oregon youth. A recent study among California teens found that after decriminalization of cannabis possession for all ages in 2011, the rate of teens arrested for cannabis plummeted along with violent crime and school dropout.[68] This finding supports the interconnectedness of social systems and the mutual benefit that criminal justice policy reforms can have. Since the majority of juvenile cannabis allegations in Oregon are for possession or consumption violations, a coordinated effort between law enforcement and school discipline will be needed in the absence of decriminalization. The goal would be to implement community-based interventions for youth who use cannabis and are at risk of substance abuse without engaging the juvenile justice system which has been shown to have negative health consequences for youth.[69,70] Using an interdisciplinary community-based approach would move substance use out of the purview of criminal justice and acknowledge that substance use is a matter of public health.

Limitations

Key limitations of our study that affect the generalizability of our results include: use of an ecologic study design, cannabis use estimated from school-based survey data, and race/ethnicity misclassification in juvenile justice data. An ecological design was used to assess the impacts of adult cannabis legalization and our results represent the average increase in juvenile cannabis allegations. Our results should not be inferred as change in the risk of allegations at the individual-level because individual-level factors related

to the susceptibility of arrest beyond gender, race/ethnicity and age could not be accounted for in our study design. Instead we were able to assess changes in allegations within groups of people over time for all Oregon youth.

We used school-based survey data (Student Wellness Survey) to estimate the biennial prevalence of cannabis use with each demographic group.[60] Using school-based survey data was a particular concern given that the survey sampling frame does not fully represent our study population. Namely, students who did not attend school on the day that the survey was administered, students who were institutionalized, or students who had dropped out of school were categorically excluded from receiving the survey. Youth who are not in school are at higher risk of substance use and incarceration.[71,72] Additionally, survey data only reflects the experiences of 8th and 11th graders. We used 8th grade estimates for cannabis use among 10-14 year olds and 11th grade for 15-17 year olds which likely overestimated cannabis use among students who took the survey given that most 8th graders are 13–14 years old and 11th graders are 16–17 years old. Though, overestimating student cannabis use probably better represented cannabis use patterns among all youth—including youth not captured on school-based surveys.

Misclassification of race/ethnicity among youth in the Juvenile Justice Information System likely underestimated the true disparities in criminal allegations between youth of color and whites. Race and ethnicity are recorded by the juvenile department based on police report or youth self-report. All races are reported as non-Latinx and any youth recorded as Latinx regardless of race is classified as Latinx. A consistent data collection form is not used across law enforcement agencies and has resulted in an underreporting of Latinx youth.[73] Misclassification of race/ethnicity are a result of inadequate data systems and reliance on perception of race. Particularly in Oregon, where the majority of the population identifies as non-Latinx white, misclassifying Hispanics as white will surely mask meaningful differences and disparities. Given that the extent of misclassification cannot be quantified, it is assumed that our findings are likely a conservative estimate of the true racial/ethnic disparities within juvenile cannabis allegations in Oregon.

Future studies

Expanding on our results, future studies should be dedicated to understanding the direct effects of school-based disciplinary policies and law enforcement practices on cannabis-related juvenile justice involvement. Conducting policy evaluations for specific programs could identify interventions that successfully divert youth who use cannabis from entering the juvenile justice system. To address the limitations of our ecologic design, new research should consider multi-level models to account for individual-level covariates that may impact a youth's likelihood of arrest. It may be that the largest effects of adult legalization on juvenile cannabis allegations are among youth who were engaged in the juvenile justice system before legalization. Finally, this work should be conducted in other states that have legalized cannabis in order to compare the impacts of different cannabis policies on juvenile justice outcomes.

Conclusion

As more states turn to legalizing cannabis and opening commercial cannabis markets, it is imperative to understand the unintended consequences of legalization on youth. Our study found that the average rate of juvenile cannabis allegations among Oregon youth increased after adult legalization of cannabis, and this increase could not be explained by changes in youth use of cannabis that may also be attributed to adult legalization. Furthermore, racial/ethnic disparities in juvenile cannabis allegations declined but remained present after legalization for American Indian/Alaska Native and Black/African American youth compared to white youth. Results of this study shed light on the impacts of adult cannabis legalization on juvenile justice that supports the work of policy makers to advocate for cannabis decriminalization and enact equitable cannabis policies.

Supplemental Table 1: Reclassifying cannabis crimes in Oregon by adult cannabis legalization, 2017 legislative session

< 21 years			
Before		After	
Crime	**Penalty**	**Crime**	**Penalty**
Manufacture of marijuana	Class B Felony	no change	Class C Felony
Possession <1 oz	A Violation	Marijuana MIP	B Violation
Possession 1–4 oz	B Misdemeanor	Possession 1–8 oz	B Misdemeanor
Possession >4 oz	C Felony	Possession >8 oz	A Misdemeanor
Attemt to possess >4 oz	A Misdemeanor	Attemt to possess >8 oz	B Misdemeanor
Possession >1/4 oz marijuana product	C Felony	Possession of marijuana product >16oz solid or >72 oz liquid	A Misdemeanor
Possession <1/4 oz marijuana product	B Misdemeanor	Possession of marijuana product <16oz solid or <72 oz liquid	B Misdemeanor
Unlawful delivery--No Consideration	C Felony	no change	A Violation
Unlawful delivery--For Consideration	B Felony	no change	A Misdemeanor
Attempt unlawful delivery--For Consideration	C Felony	no change	B Misdemeanor
		Use of marijuana in public place	B Violation
		Providing to visably intoxicated person	A Misdemeanor
		Allowing consumption by minor on property	A Misdemeanor
		Homegrown or homemade in public view	B Violation
		Producing or storing homemade extract	A Misdemeanor
		Giving marijuana as a prize	A Misdemeanor
		Use of marijuana while driving	B Violation

Note: "No change" indicates that the name of the crime did not changer after legalization compared to before legalization.

Supplemental Table 2: Study eligibility

Study Eligibility Criteria	**Sample size**
All cannabis-related allegations that occurred between Jan 2012–Sep 2018	20,180
Allegations reported from Oregon law enforcement agencies (federal, tribal, & out of state jurisdictions were excluded)	20,150
Youth had complete demographic information (age, race/ethnicity & gender)	18,826
Youth was 10–17 years of age at the time of the crime.	18,779

Supplemental Table 3: Juvenile cannabis allegations by crime type

Crime Type	Before Legalization (Jan 2012–Jun 2015)		After Legalization (July 2015–Sept 2018)	
Delivery	1209	12%	629	8%
Manufacturing	89	1%	35	0%
Possession/Use	9190	88%	7621	92%
Other	0	0%	5	0%
Total	10488		8290	

Supplemental Table 4: Model results of statewide impacts of adult cannabis legalization by racial & ethnic groups among cannabis-using youth

	Rate Ratio (95% CI) among cannabis using youth (10-17 years old)[2]											
Parameters	All Cannabis-using youth		Black/African American youth[1]		Asian/Pacific Islander youth		American Indian/Alaska Native youth		Latinx youth		White youth	
Legalization of adult possession (July 2015)	1.319	(1.175–1.481)*	1.268	(0.883–1.823)	1.295	(0.737–2.276)	0.784	(0.508–1.208)	1.421	(1.166–1.731)*	1.429	(1.236–1.653)*
Time Trend before legalization (in months)	0.989	(0.986–0.992)*	0.981	(0.972–0.990)*	1	(0.986–1.015)	0.997	(0.985–1.009)	0.985	(0.980–0.990)*	0.991	(0.987–0.995)*
Change in time trend after legalization (in months)	1.008	(1.003–1.013)*	1.018	(1.004–1.034)*	0.981	(0.957–1.006)	1.011	(0.992–1.030)	1.011	(1.002–1.019)*	1.005	(0.999–1.011)

**p-value <0.05; [1]Non-Latinx race was reported*
[2]The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates. The effects of age, race/ethnicity, gender and month of allegation were adjusted for.
[3]The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates of cannabis users. The effects of age, race/ethnicity, gender and month that crime was committed were adjusted for.

Supplemental Table 5: Model results of statewide impacts of adult cannabis legalization by geography

	Rate Ratio (95% CI) among all youth (10-17 years old)[1]			
Parameters	Urban Counties		Rural Counties	
Legalization of adult possession (July 2015)	1.264	(1.113–1.434)*	1.447	(1.220–1.716)*
Time Trend before legalization (in months)	0.984	(0.981–0.988)*	0.989	(0.984–0.994)*
Change in time trend after legalization (in months)	1.01	(1.003–1.014)*	1.01	(1.004–1.018)*

**p-value <0.05.*
[1]The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates. The effects of age, race/ethnicity, gender and month that crime was committed were adjusted for.

Supplemental Table 6a. Racial disparities in juvenile cannabis criminal allegations among urban counties

	Disparity Ratio (95% CI) among youth (10-17 years old) in Urban Counties[2]			
	Before Legalization		After Legalization	
Black/African American[1]	1.826	(1.601–2.083)	1.337	(1.141–1.566)*
Asian/Pacific Islander	0.288	(0.238–0.349)	0.195	(0.153–0.248)*
American Indian/Alaska Native	2.844	(2.421–3.340)	3.343	(2.810–3.978)
Hispanic	0.912	(0.826–1.007)	0.768	(0.689–0.857)*
White	-	-	-	-

**Significant reduction in disparity after legalization, p-value <0.05; [1]Non-Latinx race was reported.*
[2] The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates. The effects of age, gender and month that crime was committed were adjusted for.

Supplemental Table 6b. Racial disparities in juvenile cannabis criminal allegations among rural counties

	Disparity Ratio (95% CI) among youth (10-17 years old) in Rural Counties[2]			
	Before Legalization		After Legalization	
Black/African American[1]	2.598	(1.932–3.493)	1.576	(1.126–2.204)*
Asian/Pacific Islander	0.263	(0.136–0.509)	0.263	(0.144–0.478)
American Indian/Alaska Native	2.301	(1.912–2.770)	1.334	(1.075–1.655)*
Hispanic	0.892	(0.779–1.021)	0.672	(0.585–0.772)*
White	-	-	-	-

**Significant reduction in disparity after legalization, p-value <0.05; [1]Non-Latinx race was reported.*
[2] The negative binomial models included an offset for age, gender and race/ethnicity-specific annual population estimates. The effects of age, gender and month that crime was committed were adjusted for.

AIM TWO C: Cannabis retailer access and changes in the rates of juvenile cannabis allegations

OBJECTIVE

The objective of our analysis was to assess whether access to cannabis retailers at the county-level impacted changes in juvenile cannabis allegations. Given that local access to retailers may influence the likelihood of underage cannabis use and committing cannabis-related crimes, it was imperative to assess whether differences in access could explain the changes in the rates of juvenile cannabis allegations after adult legalization of cannabis.

METHODS

Study population

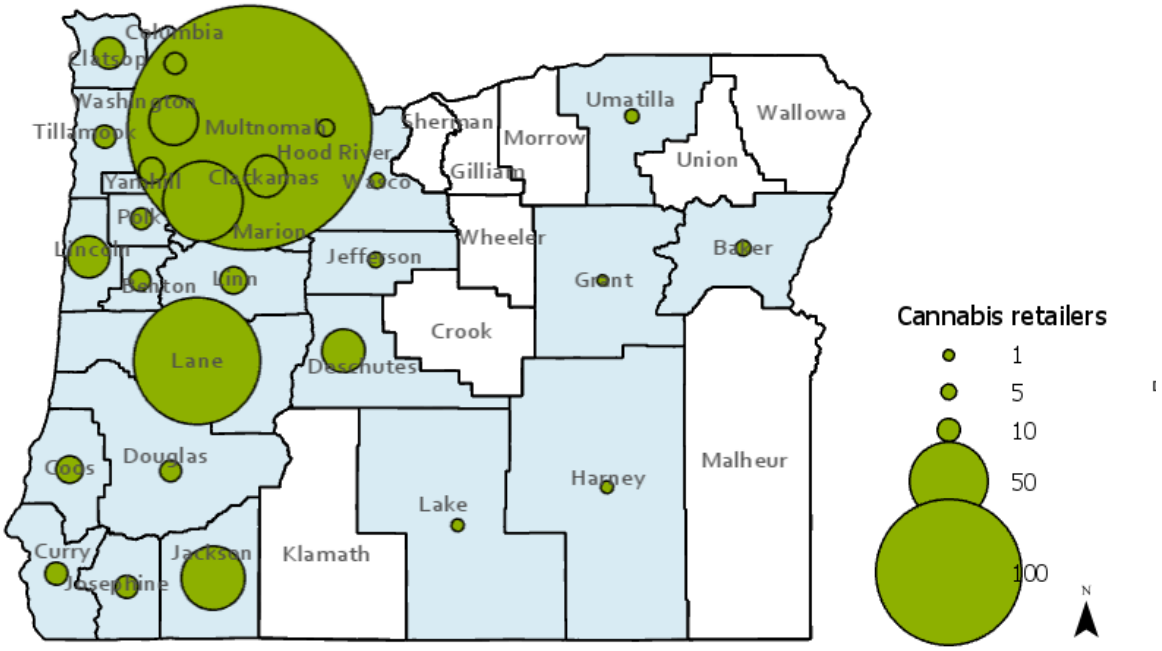
In order to account for local access to cannabis retailers, the study population was aggregated at a smaller geographic scale. Given that JJIS provided the Oregon county in which the crime was committed, we were able to assess county-level access to cannabis retailers and juvenile cannabis allegations. This restructured our **study outcome** to the count of juvenile cannabis allegations within county-specific demographic groups for each month and year (January 2012–September 2018). Corresponding population data relied on annual county-specific estimates for the same age group, gender and race/ethnicity demographic groups used in the previous analysis and obtained from Census Bureau/National Center for Health Statistics, estimates by county, age, unbridged race, Hispanic origin, and sex (2012–2017). Aggregating our data at the county-level led to a large number of 0 observations because of few allegations occurring every month and year within each demographic group of each county (47,913/55,122 observations were zero).

Exposure: Access to cannabis retailers

Unlike previous models, we were interested in understanding the impact of access to cannabis retailers beyond the effect of statewide legalization. In Oregon, legalization of adult possession of cannabis occurred July 1st 2015 (this is the primary predictor in our previous models) and restricted sale of cannabis products in medical dispensaries began in October 2015 within 22 of 36 Oregon counties. The retail cannabis market continued to grow and 599 retailers were licensed in Oregon by September 2018

within 27 Oregon counties. By the end of our study period (September 2018), the number of cannabis stores ranged from 1 to 171 within each county (Map 1). Data on the location of cannabis retailers from October 1st 2015–September 30th 2018 were obtained from archived Oregon Liquor Control Commission (OLCC) active retailer registries.[74] Because of the wide range in number of cannabis retailers (0 to 171 retailers in each county), our retailer exposure variable was the quintile distribution of stores (0 stores, 1st quintile: 1-4 stores, 2nd quintile: 5-6 stores, 3rd quintile 7-10 stores, 4th quintile 11-21 stores, 5th quintile 22-171 stores). Our cannabis retailer access variables were "0" for all month before October 2015, and indicator variables were created for each of the six retailer categories after cannabis retailers opened: no stores, 1-4 stores, 5-6 stores, 7-10 stores, 11-21 stores and 22-171 stores.

Map 1. Cannabis retailers in Oregon counties, September 2018



Note: A blue county represents cannabis businesses are allowed to operate there while a white county indicates that the area has implemented local policies that prohibit cannabis businesses from operating there.

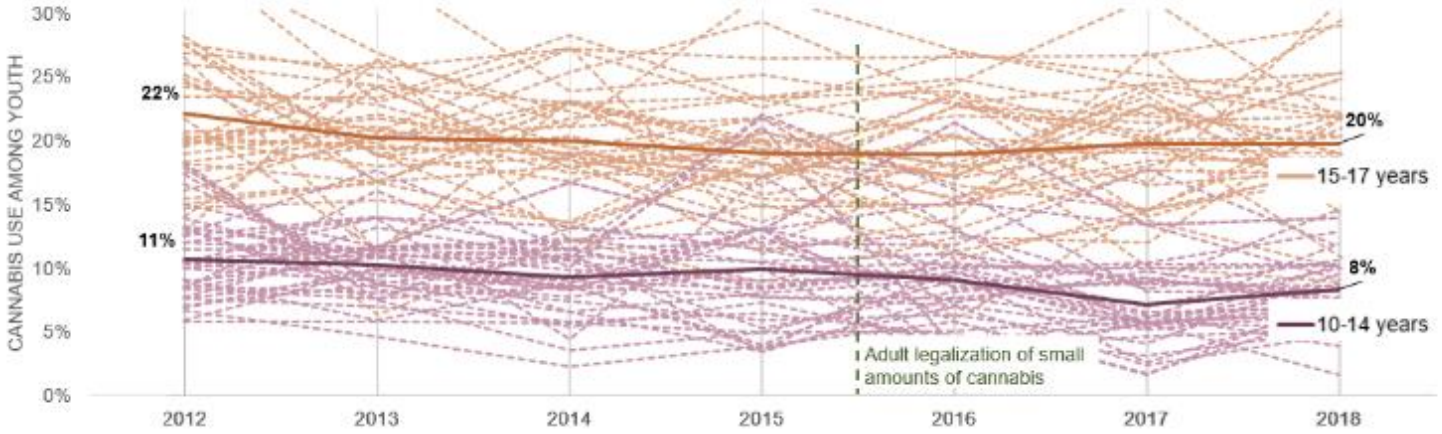
Considering underage cannabis use

Similar to prior study objectives, models were fit for all Oregon youth and separate models restricted to cannabis-using youth. Because of the lack of reliability of demographic-specific cannabis use estimates

within each Oregon county, we relied upon age-specific current cannabis use estimates within each county. Annual cannabis use estimates for 8th and 11th graders within each Oregon county were obtained from Student Wellness Survey (SWS) for even-numbered school years (2012, 2014, 2016, 2018) and Oregon Health Teens Survey (OHT) for odd-numbered school years (2013, 2015, 2017).[75] The sampling and weighting methodology varies between surveys and students did not participate from every Oregon county each year. The OHT survey reports multi-county estimates for some of Oregon's smaller counties. Specifically, North Central Health District was comprised of Sherman/Gilliam/Wasco counties and Grant/Lake/Harney counties were often combined. In this case, the multi-county estimate was assigned to each county within the grouping. For counties that did not have a reliable estimate of cannabis users, we took the average prevalence of all the neighborhood counties. For instance, Wallowa and Wheeler counties were never sufficiently sampled during 2012–2018 so we used the average of Umatilla, Union and Baker counties which all share a border with Wallowa and Wheeler counties. We imputed 32 county estimates over the 7-year period (or 6%, 32/504 estimates).

Again, annual population estimates within demographic and county groups were adjusted by their corresponding age-specific cannabis use estimates. Therefore, both genders and all racial/ethnic groups within a particular age category received the same cannabis use prevalence estimate. Using county-specific cannabis use estimates were important because of the variability in underage age cannabis use (Figure 1) and access to cannabis retailers between Oregon counties. For some counties the prevalence of cannabis use among 8th graders exceeds that of 11th graders in other counties.

Figure 1. Cannabis use by grade among Oregon counties, 2012–2018



Source: Data from Student Wellness Survey and Oregon Healthy Teen survey, 2012–2018

Policy exposure

Our regression models centered time on the date of adult cannabis legalization (e.g., legalization of possession/use by people 21 and older, July 2015). Therefore, a one-unit change corresponded to a relative difference in the rate of allegations between two months. Our **policy** variable was the average effect of adult legalization as "1" starting in July 2015 and "0" before. To assess change in linear time trend before and after legalization, we included an interaction between time and the policy variables.

Covariates

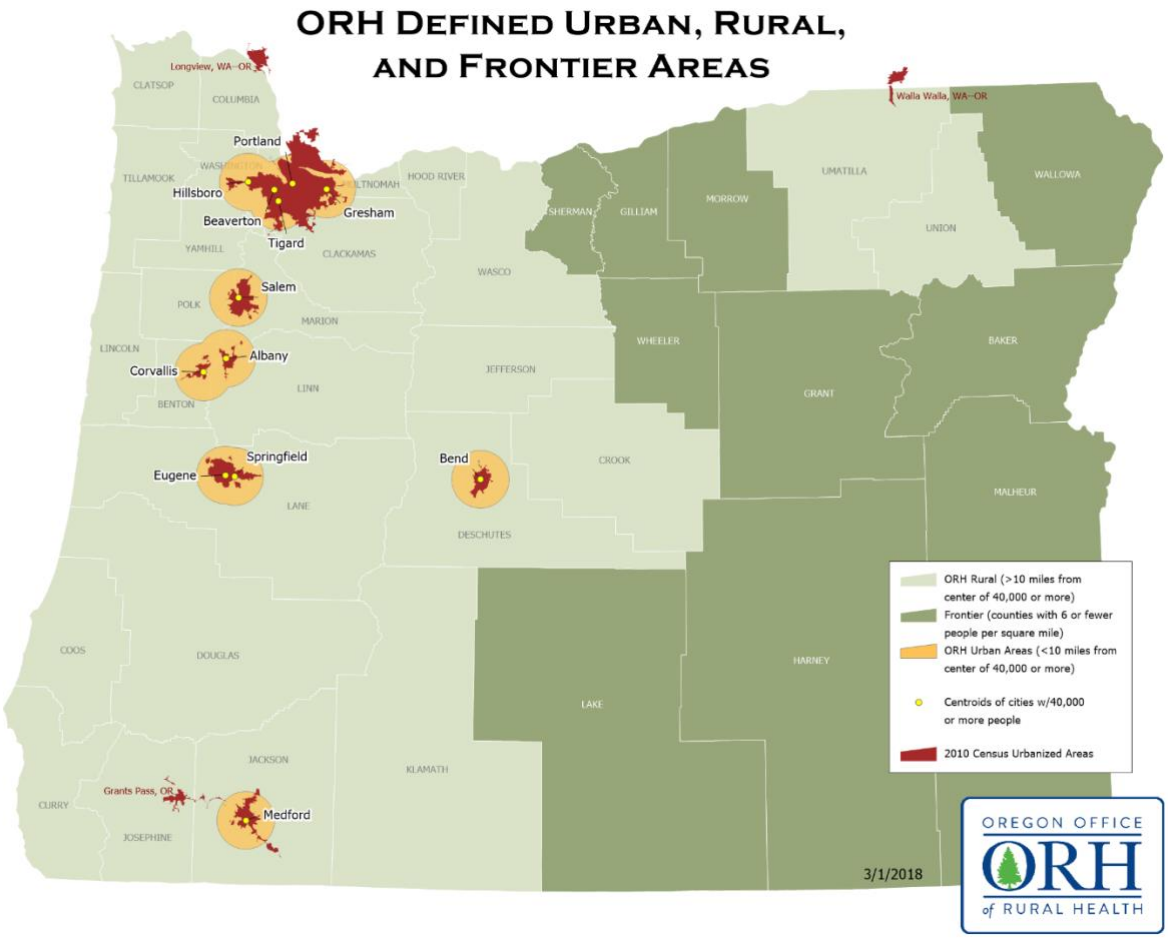
Conducting a county-level analysis allowed us to incorporate the effects of potential county-level confounding factors. Specifically, we were interested in adjusting for the effects of law enforcement resources and the urbanicity of the county.

Law enforcement resources were operationalized as the annual count of sworn police officers within each county. We obtained information on sworn police officers from the from Oregon Uniform Crime Reporting (UCR) annual crimes reports, 2013-2017[76] and the police employee data on law enforcement officers killed or assaulted (LEOKA) in the line of duty, 2012.[66] The LEOKA data set had more agencies reported in 2012 than the annual crime reports from Oregon UCR (2013–2017). Because I did not have UCR

available for 2012, LEOKA data was used and restricted to law enforcements agencies that subsequently reported to UCR to avoid introducing bias attributed to differential reporting by data source. In 2018, the number of sworn officers varied from 4 in Wheeler county to 1224 in Multnomah county.

County urbanicity was derived from the Oregon Office of Rural Health that designates the urbanicity of each zip code in Oregon.[77] Rural zip codes were defined as any geographic area at least 10 miles from the centroid of a population center of at least 40,000 residents, and frontier zip codes were defined as areas with six or fewer people per square mile. Zip code-level urbanicity was aggregated to the county level for analysis using four mutually exclusive categories: frontier, rural, urban/rural and urban. Counties were categorized as urban if at least 60% of zip codes were designated as urban and counties containing fewer urban areas were categorized as urban/rural. Ten of Oregon's 36 counties are designated as frontier counties (Map 2); 16 are rural counties, seven are urban/rural counties and three counties are urban.

Map 2. Oregon Rural Health urban, rural and frontier areas



Source: The Oregon Office of Rural Health, Oregon Health & Science University, Accessed: April 30th 2019. Available at: https://www.ohsu.edu/xd/outreach/oregon-rural-health/about-rural-frontier/index.cfm

Statistical analysis

We assessed the impacts of cannabis retailer access on juvenile cannabis allegations using a similar approach to that of models which assessed the statewide impacts of adult cannabis legalization. We fit a negative binomial model to the data and incorporated county-level random intercepts to allow for baseline differences in cannabis allegations between counties. Our primary predictor was access to cannabis retailers and was parameterized by the quintile distribution of cannabis retailers and counties with no cannabis retailers after the market opened in October 2015. This parameterization allowed for the rate of allegations in areas with a particular quantity of cannabis retailers to be compared to the statewide rate of allegations before adult legalization. Time was centered on market opening (October 2015) to account for

a linear time trend and the effects of adult legalization as an indicator variable “1” for allegations occurring July 2015 or after and “0” for allegations occurring before was adjusted for. In addition, we adjusted for the county-level covariates of urbanicity and law enforcement resources.

RESULTS

The majority of Oregon counties had at least one cannabis retailer by September of 2018. For 9 of the 36 counties, local restrictions still prohibited the establishment of cannabis retail businesses within their county. Only 4.3% of Oregon youth live in counties where cannabis retailers are prohibited (16,020/372,286). During the three-month interim period after adult cannabis legalization and before the market opened (July 1st 2015–September 30th 2015), the rate of juvenile cannabis allegations decreased by 26% statewide in the unadjusted model (Table 1). After the cannabis market opened, the rates of juvenile cannabis allegations doubled in counties that prohibited cannabis retailers and counties with fewer than 22 cannabis retailers in the unadjusted model. The rates of juvenile allegations increased by 45% in areas with at least 22 cannabis retailers in the unadjusted model. Regardless of the number of cannabis retailers, allegation rates increased in all areas compared to rates before legalization in the crude model.

The contribution of the cannabis market on juvenile cannabis allegations was attenuated when demographic covariates were adjusted for in analysis. For counties with fewer than 22 cannabis retailers, a significant increased rate in juvenile cannabis allegations remained in the demographic adjusted model (Table 1). Such that counties with few or no cannabis retailers increased their rates of allegations by 45% to 74% after cannabis retailers opened compared to rates prior to legalization. For counties with the greatest number of retailers, there was no longer an increase in rates of cannabis juvenile allegations after cannabis retailers had opened. Further, there was no longer a significant reduction in the rate of allegations during the three-month interim period between legalization and retailer opening in the adjusted model. Adding county-level covariates of urbanicity and count of police officers had minimal impact on our cannabis market parameters (Table 1. Demographic + County-level covariates).

Table 1. Multi-level negative binomial models of juvenile cannabis allegations and access to cannabis retailers among all youth

	Rate Ratio (95% CI) among all youth (10-17 years old)						Rate Ratio among all Cannabis using youth (10-17 years old)[3]	
Cannabis market parameters (Oct 2015)	Unadjusted		Demographic adjusted[1]		Demographic + County-level covariates[2]			
No stores after market opened	2.08	(1.69–2.56)*	1.54	(1.29–1.83)*	1.54	(1.29–1.83)*	1.47	(1.23–1.75)*
1-4 stores	2.38	(1.96–2.89)*	1.74	(1.48–2.05)*	1.74	(1.48–2.05)*	1.62	(1.38–1.91)*
5-6 stores	2.07	(1.69–2.54)*	1.46	(1.23–1.73)*	1.46	(1.23–1.73)*	1.33	(1.12–1.58)*
7-10 stores	2.17	(1.76–2.66)*	1.57	(1.32–1.86)*	1.57	(1.32–1.86)*	1.37	(1.15–1.62)*
11-21 stores	2.03	(1.69–2.44)*	1.45	(1.25–1.69)*	1.46	(1.25–1.70)*	1.40	(1.21–1.63)*
22-171 stores	1.45	(1.20–1.75)*	1.12	(0.97–1.31)	1.13	(0.97–1.31)	1.02	(0.87–1.19)
Time trend	0.99	(0.99–0.99)*	0.99	(0.99–0.99)*	0.99	(0.99–0.99)*	0.99	(0.99–0.99)*
Legalization of adult possession (July 2015)	0.74	(0.62–0.88)*	1.00	(0.87–1.15)	1	(0.87–1.15)	1.06	(0.92–1.22)

**p-value <0.05. [1]The negative binomial model included an offset for age, gender and race/ethnicity-specific annual population estimates within each county, a random intercept by county effect, and age, race/ethnicity, gender and month of allegation were adjusted for in the model. [2]In addition to the demographic model, sworn police officers and urbanicity at the county-level were adjusted for in the model. [3]The negative binomial model adjusted for demographic and county-level covariates and included an offset for age, gender and race/ethnicity-specific estimates of cannabis users within each county.*

Among youth who reported cannabis use, the effects of the cannabis market on the rates of juvenile cannabis allegations were further attenuated compared to results from models among all youth (Table 1, column titled “Rate Ratio among all Cannabis using youth (10-17 years old)”). Assuming that cannabis crimes were committed among cannabis using youth, access to cannabis retailers could greatly impact their likelihood of committing cannabis associated crimes. Significantly increased rates of juvenile cannabis allegations were only observed among cannabis using youth living in areas with fewer than 22 cannabis retailers. By the end of our study period (September 2018), 8 counties had more than 22 cannabis retailers.

In addition, demographic and county-level characteristics were associated with juvenile cannabis allegations among youth who reported cannabis use (Table 2), particularly, race/ethnicity, gender and age of youth. The association of both race/ethnicity and gender with the rates of allegations was logical given that our model was offset (or the model denominator) by grade-specific cannabis use estimates for each county. Our analysis did not account for variations in cannabis use between race/ethnicity and gender groups. From our statewide analysis (see page 45), we knew that cannabis use estimates were

highest among Black/African American and American Indian/Alaska Native youth which corresponded with higher rates of juvenile cannabis arrests. At the county-level, urban/rural counties were significantly more likely to have higher rates of cannabis allegations compared to urban counties. Again, these findings were consistent with our previous analysis that found the impacts of adult legalization on juvenile cannabis allegations varied by urbanicity (see page 56-57).

Table 2. Negative binomial model results for cannabis using youth

	Rate Ratio among all Cannabis using youth (10-17 years old)	
Cannabis market parameters (Oct 2015)	**Demographic + County-level covariates[1]**	
No stores after market opened	1.47	(1.23–1.75)*
1-4 stores	1.62	(1.38–1.91)*
5-6 stores	1.33	(1.12–1.58)*
7-10 stores	1.37	(1.15–1.62)*
11-21 stores	1.40	(1.21–1.63)*
22-171 stores	1.02	(0.87–1.19)
Time trend	0.99	(0.99–0.99)*
Legalization of adult possession (July 2015)	1.06	(0.92–1.22)
Non-Latinx race & Latinx		
Black/African American	2.53	(2.32–2.77)*
Asian/Pacific Islander	0.31	(0.27–0.36)*
American Indian/Alaska Native	2.26	(2.08–2.47)*
Latinx	0.83	(0.79–0.88)*
White	ref	
Age group		
15–17 years	1.80	(1.73–1.89)*
10–14 years	ref	
Gender		
Male	2.63	(2.51–2.74)*
Female	ref	
Crime occurred during school year	2.08	(1.95–2.23)*
Urbanicity		
Frontier	1.51	(0.91–2.53)
Rural	1.52	(0.95–2.42)
Urban/Rural	1.83	(1.14–2.94)*
Urban	ref	
Sworn police officers	1.00	(1.00–1.00)
County-level random effect (SD)	0.11 (0.03)	

**p-value <0.05.*

[1] This negative binomial model was adjusted for demographic and county-level covariates and offset for age, gender and race/ethnicity-specific estimates of cannabis users within each county.

DISCUSSION

Implication of study findings

Our study found that access to cannabis retailers, as measured by the number of cannabis retailers within each county, was not positively associated with increased rates of juvenile cannabis allegations. Our hypothesis was that the rates of juvenile cannabis allegations would increase with the number of cannabis retailers. But in fact, our results suggest increases in allegations in areas with few or no cannabis retailers. Results suggest that environments with the most cannabis retailers did not experience increased rates of juvenile cannabis allegations after cannabis markets opened. This finding was contradictory to our hypothesis. Regardless, our study results highlighted the importance of examining local variations in cannabis policies and the implementation of retail markets on changes in the rates of juvenile cannabis allegations. Using different measures of cannabis retail environment exposure and at different spatial scales will be crucial to understanding the relationship between adult cannabis legalization and impacts on juvenile cannabis allegations.

Limitations

Inherent limitations in our study could have greatly biased our results. Namely, our exposure variable, cannabis retailer access, could have inadequately captured youth exposure to cannabis retail markets. Our method of measuring access relied on a naïve approach of the time-varying count of cannabis retailers within each Oregon county. We were restricted to measuring access to cannabis retailers at the county-level–which was a relatively large spatial scale–given that our juvenile cannabis allegation data were aggregated at the county-level. The count of cannabis retailers within a large geographic area may have little utility in characterizing cannabis retailer markets because it does not capture clustering, density or proximity to retailers in neighboring counties (or states). In addition, aggregating cannabis markets to the county-level may miss variability between cities and unincorporated communities within counties. This misalignment between policy implementation (at the city and unincorporated county-level) and aggregation of juvenile justice data may introduce residual confounding in our analysis. Specifically, policies related to the cannabis market and juvenile justice that are implemented at the sub-county level could have introduced bias into our results. For instance, a county with 3 cannabis retailers and high rates

of juvenile allegations may have all 3 cannabis retailers within a small city that has lower rates of juvenile allegations than surrounding areas into the county without cannabis retailers.

Our hypothesis assumed that opening cannabis retailers would both directly and indirectly increase underage use and committing cannabis-related crimes. For instance, the presence of cannabis retailers could directly impact the likelihood of arrest if youth were able to illegally obtain cannabis from retailers which subsequently increase their susceptibility for being caught committing cannabis-related crimes. Cannabis retailers are heavily fined for selling to minors, yet decoy operations across Oregon found that retailers in cities were 60-100% compliant in not selling to minors.[78] Cannabis retailers could indirectly impact rates of juvenile cannabis allegations if the presence of a retailer reduced stigma around cannabis use, increased public consumption among youth, and increased the likelihood of youth being arrested for underage public consumption of cannabis. In addition, Oregon law permits home grow for adults which could be an additional source of youth access to cannabis. In areas of the state where cannabis retailers are sparse or prohibited, adults may choose to grow their own cannabis instead. We were unable to assess these direct and indirect effects of cannabis retailers on juvenile cannabis allegations. Future studies should invest in unpacking the mechanisms that tie access to cannabis retailers, underage cannabis use and juvenile cannabis allegations together.

AIM THREE: Underage high potency cannabis use, does proximity to cannabis retailers matter?

BACKGROUND

In the era of adult cannabis legalization, youth are reporting underage use of high potency cannabis products. Use of high potency cannabis products, particularly among naïve users and youth, can elicit strong intoxicating effects that can lead to unwanted experiences like intractable vomiting or psychosis.[79] Cases of emergency department visits attributed to consuming high potency edibles have been well documented in the media and literature.[79,80] In addition, states that have legalized cannabis have seen an increase in poison center calls and emergency department visits attributed to ingesting edible cannabis products.[81]

There is reason to speculate that underage high potency cannabis will be higher in areas with greater access to cannabis retailers. High potency products are accounting for a substantial share of cannabis product sales.[11,82] Of the nearly 600,000 cannabis purchases made in the City of Portland, Oregon, during July 2017, 12% were extracts and 10% were edibles (Communication with Julia Dilley, PhD on October 10th 2017 in regards to cannabis market data for the City of Portland cannabis market sales data for July 2017). In addition, we know that liquor store density is associated with excessive underage alcohol consumption.[83] If cannabis retailers operate similarly to liquor stores in providing increased access to illicit cannabis products, then there is reason to speculate that underage use of high potency products will be associated with proximity to cannabis retailers. This finding is particularly important given the concern among advocates and policymakers in preventing increased youth use and accidental poisonings attributed to high potency products.[6,9]

Study Objective

This study is the first to assess whether proximity to cannabis retailers in a U.S. state with an established retail cannabis market is associated with more underage high potency cannabis use. We hypothesize that students attending schools near cannabis retailers would be more likely to use high potency cannabis products than students attending schools farther from cannabis retailers or living in areas where the average proximity to cannabis retailers was farther away.

METHODS

Study design

We conducted a multi-level cross-sectional study to examine the association between underage high potency cannabis use among 8th and 11th graders and proximity to cannabis retailers. Our study drew from three existing data sources: Oregon Healthy Teen (OHT) survey, Oregon Liquor Control Commission (OLCC) and Oregon Department of Education data.

Sampling frame

We used the 2017 OHT survey of 8th an 11th graders. The OHT is an anonymous, school-based survey conducted among middle and high schools in Oregon during odd-numbered years.[75] Surveys are intended to monitor the health and well-being of Oregon youth and cover topics that include substance use and behaviors specific to cannabis use. During the 2016–2017 school year, 230 schools within 84 of the 191 Oregon school districts participated in the survey; which represented 67.8% of statewide population coverage. Within participating schools, 14,852 8th graders and 11,895 11th graders completed the survey. On average, 116 students (range: 2–406) participated within each school and an average of 3 schools (range:1–10) participated within each school district. We used unweighted survey data in our analysis.

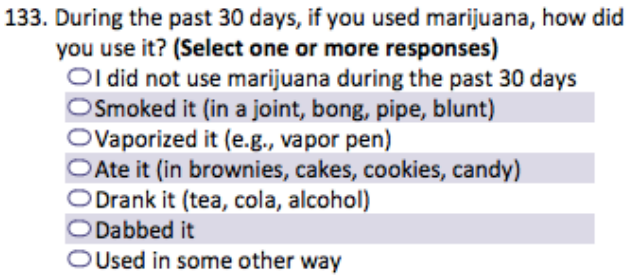
Outcome: High potency cannabis use

Although ideally "high potency use" would be measured objectively, there is no gold standard for assessing high potency cannabis use from biomarkers of cannabinoids in the body. Current research describes the nature of cannabinoids and patterns of detection in the body that are related to mode and frequency of cannabis use. This does not explain the level of product potency or intoxicating effects experienced by the user.[84] Interpreting cannabinoid effects is complex because it is dependent on the onset, peak and duration of physiological impact that are unique to the mode of cannabis use and the individual's history with cannabis.[84] Frequent and chronic cannabis users are known to develop a partial tolerance to some psychoactive effects of cannabis that could make use of high potency products less intoxicating when compared to use among naïve users. [79,80] From a biomarker standpoint, high potency

cannabis edibles would be detectable several hours after consumption as low levels of THC concentration in the blood. The inability to infer reliable cannabis product and mode of use information from biomarker data requires researchers to rely on survey data to assess high potency cannabis use.

In our study, individual-level high potency cannabis use was the **outcome of interest** and calculated from responses to cannabis mode of use questions on the 8th and 11th grade surveys (Figure 1). High potency use was defined based on responses to this question of "Dabbed it" (i.e., "dabbing" or inhalation of vaporized extracted cannabis products) or "Ate it" (i.e., consumption of edible cannabis products) because of the unexpected consequences associated with these modes of use that are especially concerning for naïve users and youth. Both modes of use are seen as high potency because of the high level THC concentration in products used in dabbing (waxes, oils and concentrates),[85,86] and the wide variation in THC concentration in edible products.[87] In addition, states that have legalized cannabis have seen an increase in poison center calls and emergency department visits attributed to ingesting edible cannabis products.[81] Students who reported dabbing or eating cannabis products in the past 30 days were categorized as high potency cannabis users. High potency use was specified as an indicator variable (yes/no high potency cannabis use).

Figure 1. Oregon Healthy Teens Survey, 2017



Source: Oregon Healthy Teens Questionnaires, www.healthoregon.org/oht

Exposures: cannabis retailer proximity environment

We constructed two proximity-based measures to capture two different aspects of exposure to cannabis retailers in June 2017. A school-based metric identified how close cannabis retailers were to schools that participated in the OHT survey as a way of estimating proximity to cannabis retailers while students were

in school or on school property. A second area-based proximity measure was calculated at the school district-level to capture proximity to cannabis retailers in the community or where students lived in the school district.

School proximity

Proximity from school was defined as the minimum distance from the school campus to a cannabis retailer in June 2017 among schools that participated in 2017 OHT survey. Cannabis retailers were identified from the OLCC active retailer list posted on June 16th 2017[74] and accessed through the online Archive Wayback Machine.[88] Retailer addresses were geocoded in ArcGIS Pro and minimum distance between school campus and cannabis retailers were calculated in meters using the Near tool in the Proximity toolkit and subsequently converted to miles.[89] The average distance to the nearest cannabis retailer was 8.7 miles (range: 0.3 miles to 159.6 miles) for middle schools and 8.6 miles (range: 0.3 miles to 159.5 miles) for high schools.

Community proximity (school district)

Our second proximity metric measured the average distance to the nearest retail location at the school district-level. School district was our area-based proximity measure because school policies related to substance use are established at the school district-level and the school district catchment area will capture the geographic area where students live who were included in the OHT survey. To compute proximity, we first applied a grid overlay of 5,000 foot by 5,000 foot cells (0.9 square miles each) to the state of Oregon using ArcGIS 10.5 software (Esri, Redlands, CA) and the Washington State Plane South (ftUS) NAD83(HARN) (EPSG:2927) projection. Using PostgreSQL 10.1 with PostGIS extension 2.4.2 (The PostgreSQL Global Development Group), we determined the direct distance between the center of each grid cell and all active cannabis retailers during June 2017. We selected the shortest distance for each grid cell. We estimated the grid cell-level population distribution for each school district using block-level data from the 2010 U.S. Census which we first apportioned to individual blocks using ratios from the 2010 U.S. Census,[90] then apportioned to grid cells based on area. Using this distribution, we weighted the grid cell-level proximity up to the school district level, resulting in the average distance to the nearest

retailer for residents of each school district. Our area-weighted proximity metric was adapted from the Centers for Disease Control and Prevention (CDC) Guide for Measuring Alcohol Outlet Density.[91] Within school districts, the average distance to the nearest cannabis retailer was 6.3 miles (range: 0.5 miles to 117.6 miles).

In statistical analysis, both proximity measures were combined to describe the cannabis retailer proximity environment for students in four mutually exclusive categories. Proximity measures were converted to indicator variables where "1" was assigned to schools or school districts <1 mile from the nearest cannabis retailer and "0" for those greater than 1 mile. A "1" was designated as a school or school district being near cannabis retailers as opposed to schools and areas further away from cannabis retailers. The school district area-weighted proximity measure was interpreted as community proximity since it is representative of the average proximity for students living within a particular school district (Table 1).

Table 1. Cannabis retailer proximity exposures in multivariate analysis

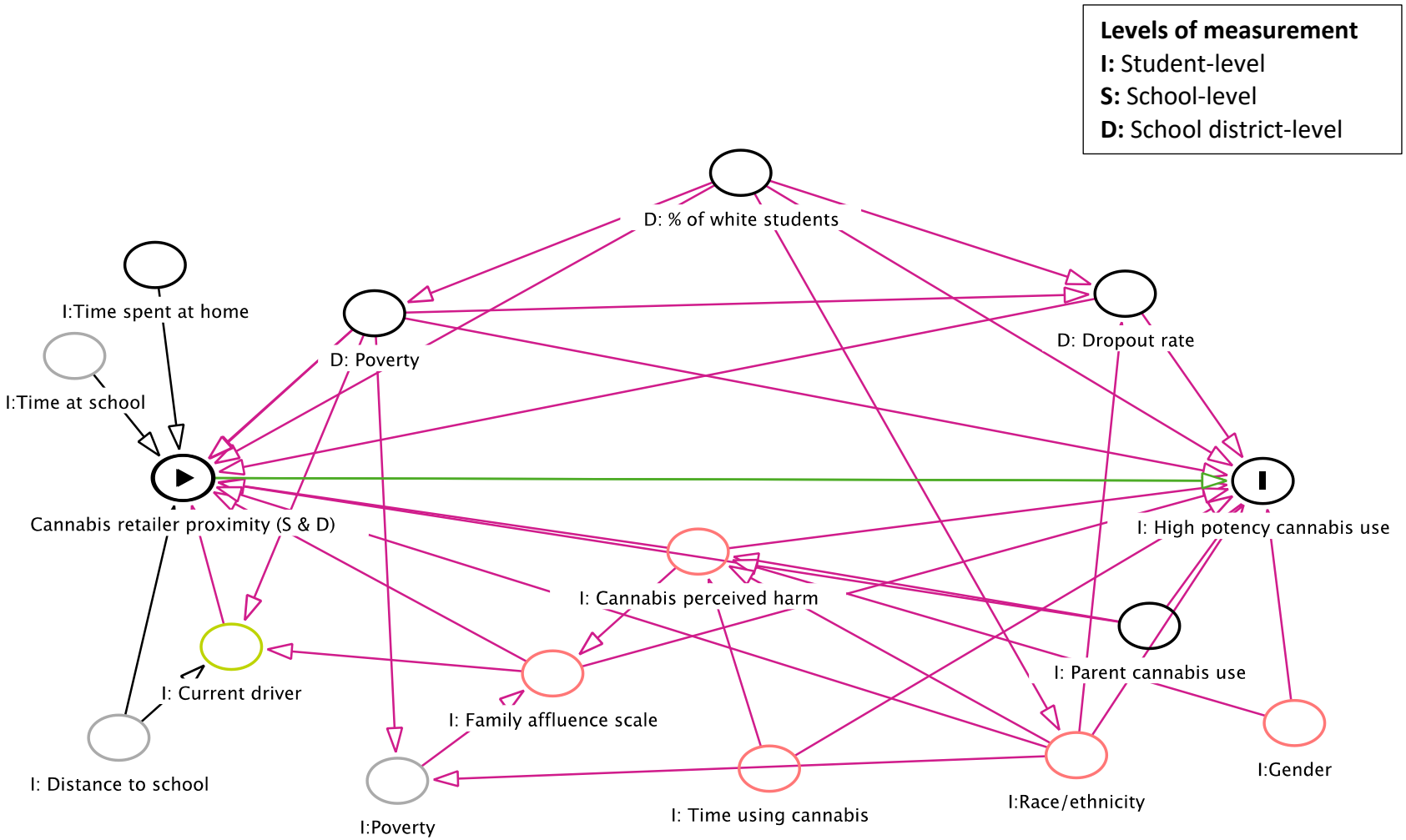
	Community proximity (measured at the school district level)		
School proximity		**< 1 mile**	**1 + miles**
	< 1 mile	Retailers near both school and community *(2,730 students)*	Retailers near school and not near community *(5,752 students)*
	1 + miles	Retailers not near school and near community *(1,093 students)*	Reference: Retailers not near both school and community *(17,173 students)*

Covariates

In statistical analysis, we adjusted for the potential confounding effects of individual and school district-level covariates. Specifically, we were interested in adjusting for socio-demographic characteristics at the individual and school district levels (more information below) that were related to underage cannabis use and geography. In addition, we fit a separate model that included individual-level cannabis environment questions. Student history of cannabis use, perceptions of harm and parental cannabis use could confound the association between cannabis retailer exposure and underage use of high potency products (Figure 2). We presented a Directed Acyclic Graph for 11th graders that incorporate the cannabis

environment questions. The model for 8th graders was similar with the exclusion of school district-level high school dropout rate.

Figure 2. Directed Acyclic Graph of Cannabis retailer proximity and underage high potency cannabis use



Individual characteristics

Individual-level demographic factors that could confound the association between proximity to cannabis retailers and high potency cannabis use were collected from student surveys and adjusted for in multivariate analysis (grade, gender, race/ethnicity, and socioeconomic status). Gender was categorized as three groups (male, female, non-binary/gender nonconforming) and race/ethnicity was categorized as non-Latinx race (White, Asian, Native Hawaiian/Pacific Islander, Black/African American, American Indian/Alaska Native and multiracial) and Latinx ethnicity. Individual-level covariates are labeled with the prefix "I:" in our DAG. In Oregon, underage cannabis use varies by grade, gender and race/ethnicity. In addition, high potency products were relatively expensive and an efficient means of getting high compared to other products and modes of use. Therefore, it is believed that families and youth who have more disposable income may be more inclined to use high potency products. Further, students with more disposable income may be more likely to purchase a variety of products and accessories—including high potency products and equipment necessary for dabbing cannabis. Student socioeconomic status was measured by the Family Affluence scale[92,93] which is determined from a sum of the following four questions: Does the student's family own a car (yes/no)? Does the student have their own bedroom (yes/no)? Did the student travel on vacation with their family in the past year(0: Not at all, 1: Once, 2: Twice, 3: More than twice) ? How many computers does the student's family own (0: None, 1: One, 2 : Two, 3: More than two)? The distribution of the family affluence scale was divided into three even groups "low" "medium" and "high" affluence.

Individual cannabis environment measures

Cannabis environment covariates that were included in analysis: student's duration of cannabis use, as calculated from age of first use and current age (>=2 years vs. < 2 years), an adult living in their home uses cannabis (yes/no), and the student's perceived harm of regularly using cannabis ("How much do you think people risk harming themselves (physically or in other ways) if they use cannabis regularly (at least once or twice a week)?").[75]

School district contextual effects

The surrounding environment in which students live can have profound effects on their health behaviors. We used school district-level covariates obtained from the Oregon Department of Education (ODE) School District Report Cards for 2016-2017 to characterize the environments in which students lived.[94] Specifically, we used the proportion of students within the district who are economically disadvantaged (as measured by students who are eligible for free or reduced lunch) for each grade, the proportion of Non-Latinx white students in the district for each grade, and high school dropout rate for the previous year. The high school drop out rate covariate was not included in 8th grade models. Similar to our justification for individual-level covariates, the area-level covariates were hypothesized to confound the association between proximity to cannabis retailers and high potency underage use because cannabis use varies race/ethnicity, areas of economic disadvantage are positively associated substance use and students that have dropped out of high school are at higher risk for substance use and incarceration.[95,96] The ODE Report Card aggregated measures by school district and suppressed small numbers of respondents and coded extreme values as "<1%" or ">95%". For extreme values I replaced "<1%" with 0.5% and ">95%" with 97.5%. School district-level covariates are labeled with "D:" in our DAG.

Age stratification

We stratified our analysis by student grade for two main reasons: strong cross-level confounding effects of age and differences in middle and high school environments (student grade is a proxy measure). Student age has the potential to be a cross-level confounder given that younger students have less access to disposable income, independence to seek cannabis or desire to use substances. Younger students may also be less impacted by contextual exposure to the cannabis retail market in their community. For example, 8th graders may be too young to notice the emergence of cannabis retailers in their environment and thus confound the relationship between community proximity to cannabis retailers and high potency use. Further, student grade is also an indicator of school environment. It encompasses unmeasured confounding factors that distinguish middle schools from high schools. School policies related to after school programs such as open campuses and student parking lots could influence the ability for students to gain access to high potency cannabis products.

Statistical analysis

We used descriptive statistics and multi-level logistic regression models of unweighted survey data to assess whether cannabis retailer proximity was associated with underage high potency cannabis use among middle and high school students in Oregon. We stratified models by grade, as described in the stratification section above. Our analytic data set merged individual-level survey data to our exposure variables that combined school and school district-level proximity to cannabis retailers measures (Figure 1). In models, exposure was measured by three cannabis retailer proximity environment indicators variables (near school and near community, near school and far from community, and far from school and near community) and students attending schools far from retailers and living in districts far from retailers was the referent category. This parametrization allowed us to directly estimate the effects of cannabis retailers on students in environments at greater perceived risk of high potency cannabis use relative to students in environments where the perceived risk was lower because cannabis retailers were further away. The binary outcome of interest was any high potency use reported in the past 30 days among students who responded to the cannabis use questions in the past 30 days. Students who reported high potency use were coded as “1” and students who report other cannabis use or no use at all were coded as “0”. A series of models for each grade were fit 1) an unadjusted model 2) adjusting for individual-level demographic and school district-level factors 3) additionally adjusting for cannabis environment questions. The third model is considered the final. Because cannabis environment questions were missing for 8% of students (1,197 8th graders and 780 11th graders), we conducted a sensitivity analysis by running models 1 and 2 only among students who had responded to the cannabis environment questions to ensure missing data was not associated with high potency cannabis use. Students were nested within schools and a random intercept at the school-level was included in each model to account for clustering within schools. Given that all students are nested within schools within the same school district (no student could be in a different school district from the rest of their peers who attended the same school), the effect of conducting a three-level model and adding a school district-level random intercept was negligible. The structure of the multi-level models followed the two-step approach proposed by Diez-Roux (see Model 1).[97] The results of the analysis were presented as odds ratios and interpreted

as the prevalence of underage high potency cannabis use among students living near cannabis retailers relative to students living in an environment further away from cannabis retailers (Model 1).

Model 1. Multi-level logistic regression model of underage high potency cannabis use and proximity to cannabis retailers

In the first stage, a separate individual-level regression is defined for each school. Unit of analysis is individuals.

$$\log\left(\frac{Y_{ij}}{1-Y_{ij}}\right) = b_{0j} + b_{1j}I_{ij} + \varepsilon_{ij} \qquad \varepsilon_{ij} \sim N(0, \sigma^2)$$

Y_{ij} Individual-level underage high potency cannabis use

b_{0j} Individual-level intercept

I_{ij} Individual-level covariates (proximity, race, gender, family affluent scale, etc.)

In the second stage, each regression coefficient from the first stage (b_{0j} and b_{1j}) are modeled as a function of school district-level variables. Unit of analysis is schools by inclusion of a random intercept at the school level.

$$b_{0j} = \gamma_{00} + \gamma_{01}C_j + U_{0j} \qquad U_{0j} \sim N(0, \tau_{00})$$

$$b_{1j} = \gamma_{10} + \gamma_{11}C_j + U_{1j} \qquad U_{1j} \sim N(0, \tau_{11})$$

$$cov\left(U_{0j}, U_{1j}\right) = \tau_{10}$$

γ_{00} Overall intercept across schools

γ_{10} Overall slope across schools

C_{ij} Cannabis retailer proximity and school district-level covariates (economic disadvantage, high school drop out rate, etc.)

To estimate the contextual effects of the school environment, both an intraclass correlation coefficient (ICC) was calculated to estimate the contribution of the school area-level variance (V_A) on a logistic scale using Merlo et al.'s formula ($V_A/V_A + 3.29$) and the median odds ratio (MOR) was calculated for each model ($\exp(0.95\sqrt{V_A})$) using the Merlo et al. approximation.[98] The MOR corresponds to median value of the area level residuals on the odds ratio scale. The MOR is defined as the median value of the distribution of odds ratio between every pair of persons using area level residuals and the person with the higher odds is always placed in the numerator so that the MOR is never less than one. In this study, the MOR shows the extent to which the individual probability of high potency cannabis use is determined by their school environment. If the MOR is equal to one, moving schools would have no effect on high potency cannabis use. But, if there were strong school level differences in high potency use then the MOR would be large. Both the ICC and MOR are statistically independent of the prevalence of high potency cannabis use.

RESULTS

Descriptive

During the 2016-2017 school year, 26,747 8th and 11th graders completed the OHT survey and 24,154 responded to question on modes of cannabis use in the past 30 days (11% missing or 1,628 8th graders and 8.1% missing or 965 11th graders). One in five 11th graders reported using any cannabis in the past 30 days (20.3%) compared to 6.5% of 8th graders. One in thirteen 11th graders reported using high potency cannabis products in the past 30 days (7.8%) compared to 2.5% of 8th graders. Among students who engaged in high potency use, dabbing cannabis products was more popular among 11th graders (67.3% of high potency users) whereas consuming edibles was more popular among 8th grades (70.7% of high potency users) (Table 2). For both grades, students who reported high potency use compared to students who reported other modes of cannabis use were more likely to have been cannabis users for a longer period of time. The average duration of cannabis use among 11th graders who reported high potency use was 3.0 years (95% CI: 2.9–3.2) compared to 2.4 years (95% CI: 2.34–2.52) among other current cannabis users. For 8th graders the average duration of use among high potency users was 2.1 years (95% CI: 1.9–2.3) compared to 1.7 years (95% CI: 1.5–1.8) among other current users. High potency use was more prevalent among students who have more experience using cannabis.

Proximity to cannabis retailers varied by level of inference. Twenty nine percent of schools were within one mile of a cannabis retailer (66/230) compared to 9.5% (8/84) of school district average community measure. On average, schools were 8.7 miles from a cannabis retailer (range: 0.3 miles to 159.6 miles) and communities were 6.3 miles (range: 0.5 miles to 117.6 miles). High schools were more likely to be near cannabis retailers than middle schools (30% or 35/117 high schools were within a mile from a retailer compared to 24% or 31/130 middle schools, respectively).

Table 2. Cannabis use among 8th & 11th graders in Oregon, 2017

	8th grade		11th grade	
	n	%	n	%
Current high potency	328	2.5%	853	7.8%
Ate it	128	39.0%	279	32.7%
Dabbed it	96	29.3%	320	37.5%
Ate & Dabbed it	104	31.7%	254	29.8%
Current not high potency	527	4.0%	1371	12.5%
Not current user	12,369	93.5%	8,706	79.7%
Total	13224		10930	

High potency cannabis use varied by demographic groups in 2017. For both grades, more female students report high potency use (172 8th graders and 400 among 11th graders) and non-high potency current cannabis use (299 among 8th graders and 745 among 11th graders) than male or non-binary students (Table 3a and 3b). By race ethnicity, cannabis use and high potency cannabis use were highest among non-Latinx American Indian/Alaska Native students and lowest among non-Latinx Asian students (Table 3a and 3b). Students from less affluent families were more likely to use high potency cannabis and other cannabis products than more affluent families in either grade (Table 3a and 3b).

Table 3a. Demographic characteristics among 8th grade cannabis users in Oregon, 2017

	Current high potency		Current not high potency		Not current user	
Total	328	2.5%	527	4.0%	12369	93.5%
	n	Column %	n	Column %	n	Column %
Gender						
Male	128	39.0%	182	34.9%	5801	47.1%
Female	172	52.4%	299	57.3%	5918	48.1%
Non binary	28	8.5%	41	7.9%	596	4.8%
Missing	59					
Race/ethnicity						
Non-Latinx White	185	59.1%	300	59.3%	7160	60.1%
Non-Latinx Black/AA	9	2.9%	13	2.6%	258	2.2%
Non-Latinx AI/AN	17	5.4%	33	6.5%	443	3.7%
Non-Latinx Asian	<5		<5		510	4.3%
Non-Latinx NH/PI	6	1.9%	6	1.2%	109	0.9%
Non-Latinx Multiracial	11	3.5%	19	3.8%	490	4.1%
Latinx	85	27.2%	135	26.7%	2941	24.7%
Missing	487					
Family Affluent Scale						
1: Least affluence	56	17.6%	86	16.9%	1163	9.7%
2	103	32.3%	179	35.2%	3765	31.3%
3: Most affluence	160	50.2%	244	47.9%	7107	59.1%
Missing	361					

Table 3b. Demographic characteristics among 11th grade cannabis users in Oregon, 2017

	Current high potency		Current not high potency		Not current user	
Total	853	7.8%	1371	12.5%	8706	79.7%
	n	Column %	n	Column %	n	Column %
Gender						
Male	387	45.6%	540	39.5%	4018	46.3%
Female	400	47.2%	745	54.5%	4195	48.3%
Non binary	61	7.2%	83	6.1%	469	5.4%
Missing	32					
Race/ethnicity						
Non-Latinx White	536	64.6%	859	63.9%	5543	65.5%
Non-Latinx Black/AA	21	2.5%	33	2.5%	162	1.9%
Non-Latinx AI/AN	26	3.1%	27	2.0%	171	2.0%
Non-Latinx Asian	26	3.1%	29	2.2%	357	4.2%
Non-Latinx NH/PI	5	0.6%	11	0.8%	76	0.9%
Non-Latinx Multiracial	27	3.3%	42	3.1%	269	3.2%
Latinx	189	22.8%	343	25.5%	1884	22.3%
Missing	294					
Family Affluent Scale						
1: Least affluence	109	13.0%	153	11.3%	728	8.5%
2	319	38.0%	481	35.6%	2922	34.1%
3: Most affluence	411	49.0%	717	53.1%	4923	57.4%
Missing	167					

Multivariate analysis among 8th graders

To assess the association between high potency cannabis use and proximity to cannabis retailers, we conducted a series of multi-level logistic regression models. In an unadjusted model, the prevalence of high potency cannabis use was 21% higher among 8th grade students attending middle schools within a mile from a cannabis retailer (OR 1.21), 51% higher among students living in communities near a retailer (OR 1.51), and 44% lower for students attending schools near retailers and living in communities near retailers (OR: 0.56) relative to students living and attending school farther away from cannabis retailers (Table 4). None of these proximity measures were statistically significantly associated with high potency cannabis use among 8th graders. When individual and school district covariates were entered into the model, proximity metrics were still not significantly associated with high potency cannabis use. The strongest predictors of high potency cannabis use were the cannabis environment indicators (duration of cannabis use, parental cannabis use, and perceived harm of cannabis) and the racial diversity of the school district (percent of white middle-school students).

The proportion of variance in student high potency cannabis use explained by school-level characteristics was 19.06% in the unadjusted model, 17.02% in the demographic model and 14.47% in the demographic

+ cannabis environment model. In the demographic model (Table 4), the median odds ratio (MOR) was 2.18, which means that in the median case the residual heterogeneity between schools doubles the individual probability of using high potency cannabis products when randomly picking out two students from different schools. That is, if a student moves to another school with a higher probability of high potency cannabis use, their risk of using high potency cannabis will (in median) increase more than two-fold. The residual heterogeneity between schools (MOR: 2.18) was of greater relevance than any cannabis retailer proximity metric (OR: 1.33, 1.85 and 0.47) for understanding variations in the prevalence of 8th graders using high potency cannabis products.

Table 4. Multi-level logistic models of high potency cannabis use among 8th graders in Oregon, 2017

	Unadjusted model		Demographic model		Demographic model + Cannabis environment	
N of students (I)	13224		12371		11334	
N of schools (S)	130		130		130	
N of school districts (SD)	77		77		77	
	OR	**Conf Int**	**OR**	**Conf Int**	**OR**	**Conf Int**
Retailers near school and far from community	1.21	(0.75–1.98)	1.17	(0.74–1.84)	1.33	(0.86–2.06)
Retailers near community and far from school	1.51	(0.67–3.43)	1.92	(0.89–4.11)	1.85	(0.89–3.83)
Retailers near school and community	0.56	(0.18–1.71)	0.58	(0.20–1.64)	0.47	(0.17–1.26)
I: Gender						
Male			ref		ref	
Female			1.30	(1.02–1.65)*	1.48	(1.12–1.97)*
Non binary			2.24	(1.46–3.45)*	1.63	(0.99–2.70)
I: Race/ethnicity						
Non-Latinx AI/AN			1.15	(0.68–1.96)	0.94	(0.51–1.76)
Non-Latinx Asian			0.42	(0.15–1.15)	0.46	(0.15–1.37)
Non-Latinx Black/AA			1.47	(0.73–2.97)	1.10	(0.46–2.61)
Non-Latinx NH/PI			1.98	(0.78–5.03)	1.68	(0.52–5.47)
Non-Latinx Multiracial			0.88	(0.47–1.65)	0.84	(0.40–1.66)
Latinx			1.16	(0.87–1.55)	1.21	(0.87–1.67)
Non-Latinx White			ref		ref	
I: Family Affluent Scale						
1: Least affluence			ref		ref	
2			0.62	(0.44–0.87)*	0.86	(0.57–1.29)
3: Most affluence			0.54	(0.38–0.75)*	1.04	(0.70–1.54)
I: Cannabis use 2+ years					11.55	(8.66–15.41)*
I: Adult uses cannabis at home					2.65	(2.01–3.50)*
I: Perceived harm of cannabis use					0.44	(0.37–0.51)*
SD: % Non-Latinx white students 6th-8th grade			8.82	(2.64–29.52)*	3.86	(1.14–13.05)*
SD: % of economic disadvantage 6th-8th grade			3.92	(1.29–11.91)*	2.32	(0.76–7.07)
School-level variance (SE)	0.77(0.10)		0.67(0.09)		0.56(0.10)	
Intraclass Correlation Coefficient: ($V_A/V_A + 3.29$)	19.06%		17.02%		14.47%	
Median Odds Ratio: exp(0.95√ V_A)	2.31		2.18		2.03	

OR: Odds Ratio
** Statistically significant, p-value <0.05*

Multivariate analysis among 11th graders

In our unadjusted model, the prevalence of high potency cannabis use was 60% higher among students attending high schools near a cannabis retailer and living in communities where retailers are farther away (OR: 1.60, 95% CI: 1.21–2.12). The other two proximity metric were not significantly associated with high potency cannabis use. When individual and school district covariates were adjusted for, the effect of school proximity in the absence of community proximity on high potency use remained unchanged (OR:1.63, 95% CI:1.23–2.16). Though, when cannabis environment questions were adjusted for, the association between school proximity to retailers in the absence of community proximity and high potency cannabis use was no longer significant (OR: 1.24, 95% CI: 0.95–1.62). Similar to 8th grader models, the strongest predictors of high potency cannabis use were the cannabis environment indicators (duration of cannabis use, parental cannabis use, and perceived harm of cannabis). Seven percent of 11th graders were missing responses to cannabis environment questions (780/10,930). To ensure missing values did not bias the effects of cannabis retailer proximity estimates, unadjusted and demographic-adjusted models were rerun using the restricted sample of students who had responded to all cannabis environment questions (n= 9,486). Results indicated that missing values did not have any substantial effect on the cannabis retailer proximity estimates (Supplemental Table 1).

The proportion of variance in student high potency cannabis use explained by school-level characteristics was 12.32% in the unadjusted model, 11.64% in the demographic model and 9.61% in the demographic + cannabis environment model. This suggests that the correlation in high potency use between students within the same school is relatively low. In the demographic model (Table 5), the median odds ratio (MOR) was 1.87. If a student moved to another high school with a higher probability of high potency cannabis use, their risk of using high potency cannabis will (in median) increase by 87%. The residual heterogeneity between high schools (MOR: 1.87) was of similar magnitude to school cannabis retailer proximity (OR: 1.63). The magnitude of residual heterogeneity between high schools was retained in the demographic + cannabis environment model (MOR: 1.75).

Table 5. Multi-level logistic models of high potency cannabis use among 11th graders in Oregon, 2017

	Unadjusted model		Demographic model		Demographic model + Cannabis history	
N of students (I)	10930		10178		9486	
N of schools (S)	122		117		117	
N of school districts (SD)	75		74		74	
	OR	**Conf Int**	**OR**	**Conf Int**	**OR**	**Conf Int**
Retailers near school and far from community	1.60	(1.21–2.12)*	1.63	(1.23–2.16)*	1.24	(0.95–1.62)
Retailers near community and far from school	0.46	(0.18–1.16)	0.51	(0.21–1.26)	0.65	(0.27–1.55)
Retailers near school and community	1.72	(0.62–4.80)	1.52	(0.56–4.12)	1.30	(0.49–3.42)
I: Gender						
Male			ref		ref	
Female			0.94	(0.81–1.09)	0.94	(0.79–1.11)
Non binary			1.19	(0.88–1.61)	1.00	(0.71–1.40)
I: Race/ethnicity						
Non-Latinx AI/AN			1.55	(0.99–2.42)	1.09	(0.64–1.83)
Non-Latinx Asian			0.83	(0.54–1.27)	1.25	(0.77–2.03)
Non-Latinx Black/AA			1.12	(0.69–1.81)	0.84	(0.46–1.41)
Non-Latinx NH/PI			0.69	(0.27–1.72)	0.70	(0.26–1.87)
Non-Latinx Multiracial			1.03	(0.68–1.57)	1.14	(0.71–1.83)
Latinx			1.00	(0.82–1.22)	0.90	(0.72–1.12)
Non-Latinx White			ref		ref	
I: Family Affluent Scale						
1: Least affluence			ref		ref	
2			0.75	(0.59–0.96)*	0.87	(0.66–1.14)
3: Most affluence			0.58	(0.46–0.74)*	0.88	(0.67–1.16)
I: Cannabis use 2+ years					6.48	(5.41–7.76)*
I: Adult uses cannabis at home					1.80	(1.51–2.15)*
I: Perceived harm of cannabis use					0.56	(0.50–0.61)*
SD: High school dropout rate from 2015–2016			0.97	(0.91–1.04)	0.97	(0.91–1.04)
SD: % Non-Latinx white students 9th–12th grade			0.88	(0.33–2.34)	0.40	(0.15–1.03)
SD: % of economic disadvantage 9th–12th grade			0.63	(0.27–1.51)	0.34	(0.15–0.79)*
School-level variance (SE)	0.46(0.06)		0.43(0.06)		0.35(0.06)	
Intraclass Correlation Coefficient: (V_A/V_A + 3.29)	12.32%		11.64%		9.61%	
Median Odds Ratio: exp(0.95√ V_A)	1.91		1.87		1.75	

OR: Odds Ratio
** Statistically significant, p-value <0.05*

DISCUSSION

Cannabis retailer proximity

Our multi-level study used school-based survey data and cannabis retailer license data to assess the relationship between proximity to cannabis retailers at two spatial scales and underage high potency cannabis use for Oregon 8th and 11th graders in Oregon. Furthermore, this study is the first to examine the implications of high potency cannabis products largely introduced by the commercialized cannabis industry on underage high potency use. Our study provides limited evidence that proximity to cannabis retailers significantly contributes to the use of high potency cannabis products among Oregon youth. Specifically, students in high schools within a mile from a cannabis retailer were statistically more likely to

have 11th graders report high potency cannabis use than students attending schools with retailers farther away regardless of community-level (school district-level) proximity in the unadjusted and demographic-adjusted models. Among 8th grade students, proximity to cannabis retailers at the school or school district-level were not associated with high potency use. The absence of an association between proximity to cannabis retailers and high potency use among 8th graders seems reasonable given their lack of disposable income and exposure to substance use. Still, over a third of the 855 8th grade cannabis users reported high potency use in the past month which suggests that high potency cannabis use is common among this young and price sensitive cannabis using population. High potency cannabis use among 8th graders warrants further monitoring to better understand the use of these products in order to mitigate unintended consequences that include accidental poisoning and emergency department visits.[6,9]

High school proximity to cannabis retailers was associated with an increased prevalence in underage high potency cannabis use in unadjusted and demographic adjusted models. Currently Oregon state law requires all cannabis retailers are at least 1,000 feet or 0.19 miles from school grounds.[54] In 2017, the closest cannabis retailer was 1500 feet or 0.3 miles from a participating school and an increased prevalence in high potency cannabis use was observed among high schools within a mile from any cannabis retailer. *This finding has direct implications for policy makers of existing cannabis regulatory agencies and states looking to implement a retail cannabis market.* Increasing the required buffer between schools and cannabis retailers may reduce the prevalence of underage high potency cannabis use. Our proximity measures considered cannabis retailers within a mile as a “nearby retailer” because a mile was believed to be a realistic distance for students to travel on foot during a school period or after school.

Our results did not find community proximity—as measured by average proximity to cannabis retailers at the school-district level—to be associated with an increased prevalence of underage high potency cannabis use among 8th or 11th graders. This could be attributed to the different aspects of proximity and spatial scales that the two metrics represent. The school-based metric was seen as exposure to retailers during school or after school where as the community metric was the population-weighted area-based

average that represented proximity to cannabis retailers when students were at home. School environments play a critical role in access and use of high potency cannabis products. Substance use on school grounds and purchasing substances at school is common among high schoolers. One nationally representative survey found that over half of high school students identified a place on school grounds where students could use illegal substances during the school day and over a third of students reported it was easy to get away with using substances on school grounds.[99] Our results support this narrative that high school students may obtain cannabis near schools as opposed to their homes.

Lastly, cannabis history characteristics were the strongest factors associated high potency cannabis use. Students who reported using cannabis for at least two years and had a parent at home who used cannabis were more likely to report high potency use and students who perceived cannabis as harmful were less likely to use high potency products.

Alternative explanations

The contribution of the contextual effects of the school environment on high potency cannabis use exceeded the contributions of proximity measures in each multivariate model. The school-level median odds ratio was larger than the effects of proximity measures in models for both 8th and 11th graders. This indicates that unmeasured confounding factors or inadequate confounding adjustment had a strong effect on high potency cannabis use. Inadequate adjustment of confounders was plausible given school-level covariates were not adjusted for in analysis (individual-level and school district-level covariates were adjusted for). Though, we included a school-level random intercept to alleviate some of variability between schools and results of the ICC indicated that there was little correlation between students from the same school (ICC was 10% in the demographic + cannabis environment model among 11th graders). As previously discussed, students commonly report using and acquiring substances on school grounds. Therefore, students may be purchasing black market cannabis at school or illegally accessing products from nearby cannabis retailers.

Black market cannabis is difficult to monitor given the legality of growing cannabis at home in Oregon state. As part of Measure 91, the voter initiative to legalize cannabis in Oregon, all person 21+ years are allowed to grow up to four cannabis plants in their home and store eight ounces of usable product.[54] Access to homegrown cannabis and homemade edible products are additional unmeasured confounding factors that could contribute to underage high potency product use. This is supported by the strong contribution that cannabis environment indicators had on high potency use in all models. The perceived harm of cannabis, duration of use and parental use of cannabis could all contribute to underage use of cannabis independently from proximity to cannabis retailers.

Limitations

The cross-sectional design of our study limits the ability to infer a causal relationship between cannabis retailer proximity and underage high potency cannabis use. The strongest predictor of high potency use was student duration of cannabis use. In order to determine whether proximity to cannabis retailers is causally related to underage high potency use, longitudinal studies will be needed. An additional concern was that our study may have been underpowered to detect a meaningful relationship between retailer proximity and high potency use given the rare occurrence of high potency cannabis use among 8th graders. Further, we were reliant on student self-reported cannabis use and students may be less likely to report substance use given the illegal nature of their use. Using school-based survey data limits the generalizability of findings to Oregon youth still in school since youth who have dropped out of school or are institutionalized are excluded from the OHT survey and are also at higher risk of substance use. Oregon ranks third in the country for the lowest percentage of young adults who complete their high school education within four years and 7% of Oregonians have dropped out and never completed their high school education by the age of 24.[100] In addition, the National Survey on Drug Use & Health reported that 28% of 12th grade aged youth who had dropped out of high school reported current cannabis use compared to 16% of 12th graders who remained in school.[101] Therefore, there is reason to believe that using OHT data may have underestimated high potency cannabis use among all Oregon youth. Further, our study was restricted to 230 schools that participated in 2017 OHT survey –representing 68% of the

statewide student population—and our results may not be representative of high potency cannabis use or proximity to cannabis retailers for all students in Oregon.

Future research

There are inherent limitations in the interpretations of our findings given the cross-sectional nature of our study. Future studies should expand on the knowledge generated from this analysis to understand youth perception of risk of using high potency products, how youth access high potency products, the relationship between high potency product sales and underage use, and how this relationship changes over time. Understanding the specific mechanisms that relate cannabis retailers to underage high potency product use will aid in developing specific policies that incorporate this unintended consequence of cannabis legalization.

Conclusion

Cannabis legalization and the opening of commercial cannabis retailers can affect underage high potency cannabis use through several mechanisms. Our results suggest that among 11th grade students attending high schools within a mile from cannabis retailers is associated with 63% greater odds of underage high potency cannabis use in Oregon. This finding has direct implications for policy makers that are establishing rules for the siting of cannabis retailer locations. Though, the impact that the emergence of cannabis retailers has had on trajectories of underage high potency cannabis is unknown. Going forward, longitudinal studies are needed to monitor changes in cannabis use, perceptions of harm and means of accessing high potency products in order to better inform policies. Examining multiple mechanisms that can impact high potency underage use can better inform cannabis business regulations and policy options in order reduce unintended consequences, including accidental poisonings, attributed to high potency cannabis use among youth.

Supplemental Table 1. Sensitivity analysis of high potency cannabis use among 11th graders in Oregon who responded to all cannabis environment questions, 2017

	Unadjusted model		Demographic model		Demographic model + Cannabis history	
N of students (I)	9486		9486		9486	
N of schools (S)	117		117		117	
N of school districts (SD)	74		74		74	
	OR	**Conf Int**	**OR**	**Conf Int**	**OR**	**Conf Int**
Retailers near school and far from community	1.58	(1.18–2.12)*	1.59	(1.19–2.13)*	1.24	(0.95–1.62)
Retailers near community and far from school	0.49	(0.19–1.25)	0.59	(0.20–1.27)	0.65	(0.27–1.55)
Retailers near school and community	1.55	(0.54–4.46)	1.50	(0.53–4.26)	1.30	(0.49–3.42)
I: Gender						
Male			ref		ref	
Female			0.94	(0.80–1.09)	0.94	(0.79–1.11)
Non binary			1.18	(0.87–1.62)	1.00	(0.71–1.40)
I: Race/ethnicity						
Non-Latinx AI/AN			1.42	(0.88–2.31)	1.09	(0.64–1.83)
Non-Latinx Asian			0.75	(0.48–1.19)	1.25	(0.77–2.03)
Non-Latinx Black/AA			1.02	(0.61–1.71)	0.84	(0.46–1.41)
Non-Latinx NH/PI			0.75	(0.30–1.88)	0.70	(0.26–1.87)
Non-Latinx Multiracial			1.07	(0.69–1.64)	1.14	(0.71–1.83)
Latinx			1.00	(0.82–1.23)	0.90	(0.72–1.12)
Non-Latinx White			ref		ref	
I: Family Affluent Scale						
1: Least affluence			ref		ref	
2			0.75	(0.59–0.97)*	0.87	(0.66–1.14)
3: Most affluence			0.58	(0.45–0.75)*	0.88	(0.67–1.16)
I: Cannabis use 2+ years					6.48	(5.41–7.76)*
I: Adult uses cannabis at home					1.80	(1.51–2.15)*
I: Perceived harm of cannabis use					0.56	(0.50–0.61)*
SD: High school dropout rate from 2015–2016			0.97	(0.91–1.05)	0.97	(0.91–1.04)
SD: % Non-Latinx white students 9th–12th grade			0.70	(0.26–1.95)	0.40	(0.15–1.03)
SD: % of economic disadvantage 9th–12th grade			0.55	(0.22–1.35)	0.34	(0.15–0.79)*
School-level variance (SE)	0.46(0.06)		0.43(0.06)		0.35(0.06)	
Intraclass Correlation Coefficient: (V_A/V_A + 3.29)	12.32%		11.64%		9.61%	
Median Odds Ratio: exp(0.95√ V_A)	1.91		1.87		1.75	

OR: Prevalence Odds Ratio

** Statistically significant, p-value <0.05*

IN CONCLUSION

The body of evidence produced by my dissertation justifies the need to formally address equity in cannabis policies to ensure that indirect harms of adult cannabis legalization are not borne by youth and communities that have been disproportionately impacted by the war on drugs. Results from my dissertation on Oregon's cannabis regulations identified the inequitable distribution of cannabis retailers across neighborhoods in the City of Portland, Oregon; an increase in juvenile cannabis criminal allegations after adult legalization of cannabis in Oregon; and high school students attending schools near cannabis retailers may be more likely to use high potency cannabis products. Each of these findings have generated new knowledge and has implications for future research and policy makers to implement equitable cannabis policies that aim to mitigate unintended consequences of cannabis legalization.

Policy Implications

At the **neighborhood-level**, more exposure to cannabis retailers in disadvantaged areas could alter the perceived safety and social cohesion within neighborhoods and increase underage access to cannabis. As more states continue to liberalize cannabis-related laws, the emergence of cannabis retailers in more U.S. neighborhoods seems inevitable. Local policy efforts should evaluate the spatial implications of their cannabis business regulations. A solution to correct the disproportionate spatial distribution of available property that can operate as cannabis retailers would require addressing the underlying structural inequities in zoning policies (e.g. changing the spatial distribution of available commercial property in the city). A more realistic solution may be to engage cannabis regulatory agencies, local officials and community organization to address the spatial density of cannabis retailers and mitigate potential harms that retailers may cause within neighborhoods. Such regulation as imposing a cap on the number of licenses within a neighborhood or ensuring a proportion of businesses are owned and operated by neighborhood residents could reduce the potential negative impacts of cannabis businesses. Having neighborhood residents as stakeholders in the cannabis industry may result in better collaboration between community members, the cannabis industry and regulatory agencies. Currently, all newly licensed cannabis businesses in Portland are required to submit Marijuana Control Plan to the city for publication on their website.[37] These control plans serve as an introduction for cannabis businesses to the neighborhoods and address concerns related to on-premise consumption, noise complaints and safety.

However, neighborhoods experiencing deprivation and with less social capital may not have the resources to advocate to local government officials or partner with cannabis business owners to place restrictions on storefront advertisement, location or the number of cannabis retailers that operate within their neighborhoods. Particularly in neighborhoods experiencing the greatest disadvantage, local officials and cannabis industry representatives should seek the input of community members. This engagement is necessary in order to ensure that the voices of communities who have been historically excluded from political decision-making, targeted by the tobacco industry, and devastated by the war on drugs do not go unheard.

Vulnerable populations remain at greater risk for the indirect consequences of adult cannabis legalization. For youth, specifically youth of color, adult legalization has resulted in an increase in referrals from law enforcement for cannabis-related allegations. To address these inequities, an interdisciplinary approach that pulls substance use out of the purview of criminal justice and acknowledges it as a matter of public health could have a large societal impact. A recent study among California teens found that after decriminalization of cannabis possession for all ages in 2011, the rate of teens arrested for cannabis plummeted along with violent crime and school dropout.[68] This finding supports the interconnectedness of social systems and the mutual benefit that criminal justice policy reforms can have. Since most juvenile cannabis allegations in Oregon are for low-level possession or cannabis consumption status offenses, a coordinated effort between law enforcement and school discipline (since schools can refer youth to juvenile departments for crimes including low-level possession/consumption) will be needed in the absence of decriminalization. The goal would be to implement community-based interventions for youth who use cannabis and are at risk of substance abuse without engaging the juvenile justice system which has been shown to have negative health consequences for youth.[69,70] In addition, addressing the spatial inequities in the siting of cannabis retailers and reconsidering the proximity of cannabis retailers to school environments will also help reduce the susceptibility of youth being arrested for cannabis-related crimes.

Outside of Oregon, initiatives have been proposed to address the historic criminalization and inequities in cannabis-related criminal justice involvement in the implementation of cannabis legalization. The

governor of Illinois recently proposed their state bill for legalization would include the automatic expungement of all low-level cannabis crimes and explicitly addressed expunging criminal convictions accrued in juvenile court.[102] Other states like New Jersey and California have also considered automatic expungement, though the feasibility of executing this process is still being discussed.[103] Policies that incorporate automatic expungement are an equitable solution that begin to address the restitution owed to communities disproportionately impacted by the war on drugs.

The underlying inequities in the distribution of cannabis retailers may contribute to further inequities in underage cannabis use, being arrested and their subsequent health impacts (e.g. long-term outcomes of criminal justice involvement and adverse health effects of high potency cannabis use). Access (as quantified by proximity to the nearest cannabis retailer) may increase underage high potency cannabis product use through a couple mechanisms: 1) youth illegally accessing cannabis products from retailers or patrons of retailers, or 2) storefront retailer presence and advertisement changes social norms around high potency product use. Understanding the implications of these mechanisms on youth use will be essential to informing policies. In the absence of this evidence, using a precautionary approach could help mitigate the potential harms that access to cannabis retailers may have on youth. Currently, the state of Oregon requires cannabis retailers to be a minimum of 1,000 feet from primary and secondary schools. Our analysis demonstrated an increase in underage high potency use for 11th graders attending schools with a retailer within a mile from campus. Policy makers could consider increasing this buffer as well as buffers around other places frequented by youth (e.g. community centers, parks, movie theatres) as an option to reduce access to high potency cannabis products to students. In addition, targeted education and prevention campaigns should address use of specific cannabis products and the risks of unexpected consequences like accidental poisonings and ER visits. Further, campaigns should engage community participation and be tailored to the specific needs of communities, particularly in areas most burdened by cannabis retailers. Public health messaging can be displayed on cannabis retailer storefronts and near school campuses. Implementing equitable cannabis policies will require engagement from the cannabis industry, local governments, public health officials, school administrators and community stakeholders to

incorporate the relevant needs of communities in order to reduce unintended harms of adult cannabis legalization on youth.

In Summary

Environmental effects

- The effect of legalization on public health and societal outcomes is not uniform across the state of Oregon. This is evident from differences in rates of juvenile justice allegations by county urbanicity, by neighborhood deprivation and by proximity to cannabis outlets.
- Neighborhoods experiencing disadvantage are more likely to have cannabis retailers in Portland, Oregon.
- The distribution of cannabis retailers by neighborhood deprivation may change over time as the cannabis retail market matures.
- Future research should focus on other measures of cannabis retailer access beyond proximity (such as spatial density and clustering) to understand the impacts that access to cannabis markets have population health outcomes.

Vulnerable populations

- Adult legalization of cannabis may have caused increases in the rate of youth arrested for cannabis-related crimes in Oregon.
- Future research should examine mechanisms that are contribution to increased rates in juvenile justice allegations, particularly in regards to the persistence of racial/ethnic disparities.

Individual-level effects

- Future research should explore other modifiable mechanisms of underage high potency cannabis use (e.g. understanding how student obtain high potency products, impact of retailer price promotion, and storefront advertisement).

Recommendations/Contributions to public health practice

- Educational and prevention campaigns for youth should address both the health and criminal justice implications of underage cannabis use.
- Legislation should modify criminal law definitions to avoid increasing juvenile justice involvement.

- Legislation should advocate for policies that treat substance use as a matter of public health and not criminal justice and acknowledge the cumulative impacts of juvenile justice involvement on the health and wellbeing of youth.
- Equitable cannabis policies should incorporate provisions that address the unintended consequences of legalization preemptively, require monitoring of public health and societal outcomes for unintended effects, and revise policies in a timely manner if inequitable effects are observed.
- Cannabis policies should encourage local community participation to engage with cannabis business owners, law enforcement and school administrators on issues related to underage access of cannabis, community-based substance use treatment and education campaigns.

Contributions to the field of Epidemiology

- Site suitability assessments should be regularly incorporated into epidemiologic studies that assess the distribution of built environment features.
- Geographic boundaries that are meaningful to the environments of study populations should be formally integrated into public health research.
- Careful consideration should be used when considering who is truly at risk and susceptible for developing the disease—or societal outcome—–when modeling changes in rates over time.

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