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Authors

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Panchalingam, Thadchaigeni
Ce, Shang
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Behavioral Economic Relationship between Cannabis and Cigarettes: Evidence from Hypothetical Purchase Tasks

Michael Cooper[1], **Thadchaigeni Panchalingam**[1], **Ce Shang**[2], **Yuyan Shi**[1,*]

[1]Herbert Wertheim School of Public Health and Human Longevity Science, University of California San Diego. 9500 Gilman Dr., La Jolla, CA 92093, USA

[2]Department of Internal Medicine, The Ohio State University. 281 W Lane Ave, Columbus, OH 43120, USA

Abstract

Background—In the United States (U.S), cannabis policies have been increasingly liberalized whereas tobacco policies have been increasingly stringent. Given the high prevalence of cannabis and tobacco dual use, there are concerns that a policy regulating one substance may unintendedly influence the other. This study examined the responsiveness of the demand for cannabis joints and cigarettes when price varied.

Methods—The study included 338 adult participants (21+) who used both cannabis and tobacco and lived in one of the U.S. states with recreational cannabis legalized by the time of interview in 2019. They completed hypothetical purchase tasks to indicate the quantity desired of cannabis joints and cigarette packs 1) when only one substance was available with escalating prices and 2) when both substances were concurrently available with escalating prices of cannabis joints and a fixed price of cigarette packs. We estimated 1) the own-price elasticity of demand for each substance using nonlinear exponential demand model, and 2) the cross-price elasticity of demand at aggregate level using nonlinear exponential demand model and at individual level using log-linear demand model.

Results—The estimates for the rate of change of own-price elasticity (α) were 0.0011 (SE = 0.000039, p < 0.001) for cannabis joints and 0.00095 (SE = 0.000037, p < 0.001) for cigarette packs. The aggregate-level estimates of cross-price elasticity (I = 13.032, SE = 0.34, p < 0.001; β = 0.0029, SE = 0.0021, p > 0.05) suggest an independent relationship between the two substances. At individual level, 78.70% of the participants treated the two substances as independent, 17.46% as complements, and 3.85% as substitutes.

Conclusions—For most adults who used both cannabis and tobacco in the U.S., cannabis joints and cigarettes had an independent relationship. Policies regulating the price of cannabis may not have large unintended consequences on cigarette use.

Keywords

Hypothetical purchase task; Cannabis; Tobacco; Behavioral economics; Elasticity of demand

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*Corresponding author: Yuyan Shi, 9500 Gilman Drive, La Jolla, CA 92093-0628, USA, yus001@ucsd.edu.

1. Introduction

In the past two decades, cannabis has been increasingly liberalized whereas tobacco has been increasingly controlled in many countries especially in the United States (U.S.). In the U.S., as of August 2022, 37 states and the District of Columbia legalized medical use of cannabis among patients. Among these jurisdictions, 19 states and the District of Columbia further legalized recreational use of cannabis among adults. (National Conference of State Legislatures, 2022) Meanwhile, the U.S. federal government and states implemented comprehensive policies to continuously control the use and sale of tobacco including, for example, raising excise taxes, increasing the minimum legal sales age, prohibiting flavors in certain products, and expanding smoke-free policies to prohibit the use of non-cigarette tobacco in public places. Such diverging strategies to regulate cannabis and tobacco are also seen in other countries such as Canada, Uruguay, and Australia.

An important challenge for public health policymakers is that regulations on one substance may have unintended consequences on health outcomes related to another substance. In the U.S., there have been considerable concerns that cannabis liberalization may jeopardize the progress of tobacco control. (D. M. Dave, Liang, Pesko, Phillips, & Sabia, 2022) Such concerns are valid if cannabis use and tobacco use are positively correlated. At the population level, epidemiologic data have shown that cannabis and tobacco were used concurrently in a defined period of time. From 2003 to 2012, while past 30-day cannabis use increased and tobacco use decreased among adults in the U.S., the prevalence of dual use stayed at about the same rate around 4–5%. (Schauer, Berg, Kegler, Donovan, & Windle, 2015) In late 2010s, nearly a third of adults who used tobacco also used cannabis in the past 30 days. (Cohn & Chen, 2022) In addition to harms associated with the use of a single substance, dual use has been linked to additive health risks such as greater toxic exposure, higher risks of dependence symptoms, more psychosocial problems, and poorer cessation outcomes. (Lemyre, Poliakova, & Belanger, 2019; Meier & Hatsukami, 2016; Peters, Budney, & Carroll, 2012) Epidemiological data also indicated gateway effects between the two substances: the use of one substance was associated with a higher likelihood of the initiation of another substance. (Azagba, Latham, & Shan, 2020; Sun, Mendez, & Warner, 2022; Weinberger, et al., 2020; Weinberger, Zhu, Lee, Xu, & Goodwin, 2021; Wong, Lohrmann, Middlestadt, & Lin, 2020) Few epidemiological studies have observed substitution between the two substances, mainly because of the methodological challenges of measuring substitution behaviors. Most studies suggested that cannabis use was substituted for tobacco use but that tobacco use did not appear to be substituted for cannabis use. (Lemyre, et al., 2019)

Ecological studies evaluating state-level policy changes suggested that the use of one substance could be unintendedly influenced by policies aiming to regulate the use of another substance. Such evidence, however, was not consistent. For instance, some studies found positive associations between statewide legalization of medical or recreational cannabis and increased prevalence or likelihood of tobacco use, (Coley, et al., 2021; Weinberger, Wyka, & Goodwin, 2022; Weinberger, Wyka, Kim, et al., 2022) but more suggested negative or null associations. (Bailey, et al., 2020; Cerda, et al., 2018; Choi, Dave, & Sabia, 2019; Coley, et al., 2021; D. M. Dave, et al., 2022; Fleming, et al., 2022; Veligati, et al., 2020; Vuolo, Lindsay, & Kelly, 2022; Weinberger, Wyka, Kim, et al., 2022) Tobacco control studies also provided mixed findings regarding the impacts of statewide tobacco control policies on cannabis use. (D. Dave, Feng, & Pesko, 2019; Farrelly, Bray, Zarkin, & Wendling, 2001; Goel, 2009; Pesko, Hughes, & Faisal, 2016)

Aggregate-level population data on substance use prevalence and ecological studies assessing impacts of statewide regulations have limitations for identifying the behavioral relationship between cannabis and tobacco. The major concern is ecological fallacy: the population-level pattern may not represent individual-level behaviors. Causality could be also weak if individual- or state-level confounding factors were not well controlled for. Population data also often lack detailed information on the use of two substances and sufficient variation in policy changes. In this study, we applied hypothetical purchase tasks (HPTs) to mitigate these concerns. HPTs have been used extensively in public health literature to quantify the changes in demand for a substance in response to the changes in price, legality, availability of alternatives, and other policy-relevant product features. (Aston & Meshesha, 2020; Kiselica, Webber, & Bornovalova, 2016; Reed, et al., 2020; Strickland, Campbell, Lile, & Stoops, 2020; Weinsztok, Reed, & Amlung, 2022) In a single-substance HPT, participants are asked to report the quantity of a substance they would hypothetically purchase at various price levels. In a dual-substance HPT, participants indicate the quantity of two concurrently available substances at various price levels of one substance and a fixed price of the other substance. Single- and dual-substance HPTs can be used to estimate own-price elasticity and cross-price elasticity, respectively, hence indicating the behavioral economic relationship between the two substances. Because HPTs exploit within-individual variations in demand, the method is informative about individual perceptions and behaviors rather than only aggregate relationships. In addition, because HPTs isolate the effects of price variation from other aspects of purchase decisions, individual characteristics, and other related policies, the causality of the findings is usually strong. HPTs are usually implemented along with additional survey data collection, so researchers are able to link detailed individual-level information with demand data in a way that is not possible with existing population surveys. We are aware of only one existing study that assessed the economic relationship between cannabis and tobacco. Peters et al. conducted HPTs in a convenience sample of 82 U.S. adults who used both cannabis and cigarettes and found an independent relationship between the two substances. (Peters, Rosenberry, Schauer, O'Grady, & Johnson, 2017)

In this study, we used HPTs to estimate the behavioral economic relationship between cannabis joints and cigarettes, the two commonly used forms of cannabis and tobacco. Compared to non-combustion forms of cannabis and tobacco such as vaping and edibles/ smokeless products, smoking cannabis and tobacco is linked to greater health risks from toxic smoke and secondhand exposure. (Budney, Sargent, & Lee, 2015; Russell, Rueda, Room, Tyndall, & Fischer, 2018). We extended and improved upon Peters et al. (Peters, et al., 2017) by recruiting a much larger sample that was quota-matched to represent adults using cannabis in the U.S. and adopting current best practices for HPT data estimation. Our findings are expected to provide implications regarding possible spillover effects of cannabis and tobacco regulations on use of the other substance.

2. Methods

2.1 Data Source

In May of 2019, we recruited 3,046 participants from online panels administered by Qualtrics, a marketing company in the U.S. The inclusion criteria for the parent survey were adults aged 21 or older, having used cannabis in the past 12 months, and living in eight U.S. states with recreational cannabis legalized at the time of the interview (California, Colorado, Washington, Oregon, Nevada, Massachusetts, Maine, and Michigan) so that responses would be more policy relevant. Sampling quotas were used to recruit a representative sample of adults using cannabis in the U.S. Washington D.C., Alaska, and Vermont were excluded despite recreational cannabis legalized in these jurisdictions because either the state population size was too small or the state had not fully allowed cannabis retail sales by the time of the interview. This survey was approved by the Human Research Protections Program at the University of California San Diego.

Approximately a third of the 3,046 participants (n=1,065) were randomized to complete HPTs involving cannabis joints and cigarettes relevant to this specific study. The other two thirds were randomly assigned to experiments irrelevant to this study and were removed.

2.2 Study Sample

Because this study was intended to investigate the behavioral economic relationship between cannabis and tobacco demand, people who had at least some demand for both substances were relevant. Therefore, we kept only participants who reported having used tobacco in the past 12 months. This reduced the initial sample size of 1,065 to 490. Because one of the inclusion criteria for the parent survey was having used cannabis in the past 12 months, these 490 participants could be therefore categorized as people who used both cannabis and tobacco. We further dropped 83 participants who reported zero demand of either cannabis joints or cigarette packs when the substance was offered for free in single-substance HPTs, as their responses would not contribute to the estimation. These 83 participants could have used cannabis and tobacco in the past 12 months but were not currently using the substances or could have used cannabis and tobacco products other than the forms investigated in this study. The sample size was then reduced to 407.

We then applied the published criteria to drop nonsystematic data. (Stein, Koffarnus, Snider, Quisenberry, & Bickel, 2015) A participant's demand data are considered nonsystematic if they meet one of the following criteria: 1) trend, defined as an insufficient drop in quantity as the price rises (at least 0.025 log-units of consumption per log-unit range in price), 2) bounce, defined as increasing quantity demanded as the price increases in more than 10% of price intervals, and 3) reversal, defined as demanding zero quantity at two consecutive prices followed by a positive quantity at a higher price. The percentage of participants who met at least one of the three criteria in each task was: 10.07% for cannabis joints in single-substance HPT, 9.37% for cigarette packs in single-substance HPT, and 10.32% for cannabis joints in dual-substance HPT (cigarette packs were not evaluated for nonsystematic data in dual-substance HPT because the price was not varying). Overall, 16.95% of participants met at least one criterion in at least one task, within the range of nonsystematic data reported in existing HPT studies. (Bergeria, Dolan, Johnson, Campbell, & Dunn, 2020; Peters, et al., 2017; Schwartz, Blank, & Hursh, 2021; Strickland, Lile, Rush, & Stoops, 2016). After dropping these participants, the final study sample included 338 participants.

2.3 HPT Design and Procedure

In addition to HPTs, the survey also asked demographic characteristics including age, sex, race/ethnicity, education, income, substance use status, and state of residence. The median survey duration was 15 minutes.

The HPTs asked participants to indicate how many standard half-gram cannabis joints or 20-cigarette packs they would purchase at offered prices. Cannabis joint was used as the unit of reporting because it was the most commonly used administration method of cannabis and was most comparable to cigarettes. It has been used in previous research. (Collins, Vincent, Yu, Liu, & Epstein, 2014) Participants were instructed that they would hypothetically be purchasing the substances solely for their own personal use over the next 30 days, that participants could not stockpile for future use, that the amount of money available was the typical amount they would have available for the substances, and that this was their only opportunity to purchase the substances for the next 30 days. They were told that the cannabis joints are similar to the strain, quality, strength, and flavor they typically use and that the cigarette packs are their typically used brand. They were instructed to assume that they did not use cannabis, cigarettes, or any other substances before making these purchase decisions.

Specifically, participants responded to two single-substance HPTs and one dual-substance HPT. The single-substance HPTs asked how many cannabis joints and cigarette packs they would like to purchase at each of the following 11 escalating prices: $0, $1.50, $3, $4.50, $6, $7.50, $9, $10.50, $15, $20, and $30. These prices were selected based on observed market prices and prices used in previous literature. (Collins, et al., 2014; Huang, Tauras, & Chaloupka, 2014; Vincent, et al., 2017). In the dual-substance HPT when both cannabis joints and cigarette packs were concurrently available, participants indicated the quantities demanded for both substances simultaneously. The price of cigarette packs was fixed at $6 (near the average market price at the time of the interview), while the price of cannabis joints escalated through the same list of 11 prices offered in the single-substance HPTs. Each pair of cannabis and cigarette prices was presented simultaneously on the same screen after the quantities for the previous pair were submitted.

2.4 Data Analyses

Before any data analysis was conducted, we identified extreme outliers with z-scores higher than 3.29 following the methods proposed by Tabachnick, Fidell, and Ullman. (Tabachnick, Fidell, & Ullman, 2007) Most outliers occurred at very high quantities demanded when the substances were offered for free. We then applied top-coding to recode these outliers to one unit higher than the next largest non-outlier.

Single-substance HPTs—In the single-substance HPTs, the observed demand curves were visualized by plotting mean consumption at each price. Additionally, we calculated the following observed demand indices: intensity (mean quantity demanded when the substance was free), peak expenditure (mean maximum money spent on the substance), price at peak expenditure, and breakpoint (mean price at which quantity demanded dropped to zero).

We fitted the exponentiated version of the exponential demand model. (Hursh & Silberberg, 2008; Koffarnus, Franck, Stein, & Bickel, 2015) The exponentiated version can accommodate zeros and may improve the model fit compared to the standard logged exponential demand equation. (Yu, Liu, Collins, Vincent, & Epstein, 2014). The exponentiated version has been commonly used in recent HPT literature. (Amlung, MacKillop, Monti, & Miranda, 2017; Fragale, Beck, & Pang, 2017; Strickland, et al., 2016; Strickland, Lile, & Stoops, 2019; Yoon, et al., 2021; Yoon, et al., 2020) The specification estimated is:

$$Q = Q_0 * 10^{k\left(e^{-\alpha Q_0 P} - 1\right)},$$

where Q is the quantity demanded of the substance, Q_0 is an estimated parameter of the model representing demand when the substance is free, k is a constant calculated prior to estimation representing the range of quantity demanded in $\log_{10}$ units, P is the price of the substance, and α is an estimated parameter of the model representing the rate of change in own-price elasticity. The precise value of k used was calculated following Gilroy et al. (Gilroy, Kaplan, Reed, Hantula, & Hursh, 2019) as

$$log_{10}(average\ quantity\ at\ highest\ price) - log_{10}(average\ quantity\ at\ lowest\ price) + 0.5\,.$$

The higher value ($k = 2.03$) of the two values calculated from the two single-substance HPTs was used across all analyses so that the estimated parameters were comparable between HPTs.

We also plotted the derived demand curves from the fitted equations. The fitted parameters also allowed us to calculate the following derived demand indices: intensity (Q_0 in the model), peak expenditure, and price at peak expenditure. Note that the derived breakpoint could not be estimated because the fitted demand curves never reached zero quantity demanded. The derived price at peak expenditure had no closed form solution in the model but was estimated analytically using the lambert W function as suggested by Gilroy et al. (Gilroy, et al., 2019)

Dual-substance HPT—In the dual-substance HPT, we implemented the exponential model to analyze cross-price elasticity at the aggregate level. The simpler log-linear model has been used in the literature to estimate a single cross-price elasticity parameter. (Amlung & MacKillop, 2019; Amlung, et al., 2019; Johnson, Johnson, Rass, & Pacek, 2017; Stein, Tegge, Turner, & Bickel, 2018) However, the exponential model was our preferred model for its more realistic assumption that elasticity varies with price. (Hursh and Roma, 2016)

The exponential model for cross-price elasticity is specified as:

$$\log_{10} Q = \log_{10} Q_{alone} + I\, e^{-\beta P},$$

where Q is the quantity demanded of the fixed-price substance, Q_{alone} is the mean quantity demanded of the fixed-price substance when the variable-price substance is at its most expensive price, and P is the price of the variable-price substance. (R. Hursh, 2014) A small constant of 0.01 was added to quantity values prior to model estimation to avoid taking the log of zero. The estimated parameters are I, the interaction constant, and β, which measures the strength of the relationship between the two substances. A positive value of I indicates a complement relationship, while a negative value represents a substitute relationship. Regardless of the value of I, a statistically nonsignificant value of β implies an independent relationship.

In the dual-substance HPT, we also estimated cross-price elasticity for each participant using the simpler log-linear model mentioned above. The log-linear model is an ordinary least squares regression in which the dependent variable is log-transformed cigarette packs demanded and the independent variable is log-transformed price of cannabis joints. A small constant of 0.01 was also added to quantity and price values to avoid taking the log of zero. We reported the percentage of participants displaying each type of economic relationship based on the log-linear model at the individual level: independent, complement, or substitute. Participants were classified as having an "independent" relationship between cannabis joints and cigarette packs if 1) they had no variation in cigarette packs demanded, or 2) the coefficient of the log-linear model was not statistically significant. Participants were classified as having a "complement" relationship if their coefficient was negative and statistically significant. Participants were classified as having a "substitute" relationship if their coefficient was positive and statistically significant. We considered reporting results from the more complex cross-price exponential model fitted to each participant but discovered that the model was either a poor fit or unable to be fit for the vast majority of participants. Among the minority of participants for whom the exponential model was fit, the results were consistent with those from the simpler log-linear model.

Two sensitivity analyses were conducted. Because the results may differ among higher-risk participants who frequently used both substances, in the dual-substance HPT we estimated the exponential model at the aggregate level on the subsample of 256 participants who used both cannabis and cigarettes in the past 30 days. We also estimated the same model on the original sample of 407 participants who used both substances, without dropping participants with nonsystematic data or top-coding outlies.

All the analyses were conducted in Stata SE 17.0. P value < 0.05 was considered statistically significant.

3. Results

3.1 Descriptive Characteristics of Study Sample

We compare our final sample for analysis (N=338) to the population of adults who used cannabis and cigarettes in the past 12 months in the U.S. in the 2019 National Survey on Drug Use and Health (Supplementary Table 1). The two samples had generally comparable demographic characteristics with the exception of our sample having fewer non-Hispanic Blacks and fewer high-income participants.

Descriptive statistics of our study sample (N = 338) are reported in Supplementary Table 2. Supplementary Table 3 compares the characteristics of the study sample (N = 338) with the participants who were dropped due to nonsystematic demand behaviors (N = 69). Independent t-tests show few differences between the two groups.

3.2 Single-substance Demand Curves and Demand Indices

Figure 1 shows the observed demand curve for cannabis joints (left panel) and cigarette packs (right panel) (blue dashed lines). They are downward-sloping as price increases. The observed mean demand indices are displayed in Table 1, Panel A. When the substances were offered for free, participants demanded about 50 cannabis joints and 33 cigarette packs on average. The observed mean peak expenditure was $133.46 for cannabis joints and $152.90 for cigarette packs, observed at prices of $7.58 per cannabis joint and $9.26 per cigarette pack, respectively. The mean prices at which quantity demanded declined to zero were $18.53 for cannabis joints and $18.13 for cigarette packs.

Figure 1 also shows the fitted demand curves derived from the exponential demand model (red solid lines). The derived demand curves appeared to closely match the observed mean data, with the blue dashed line closely overlapping the red solid line. The estimated rate of change in own-price elasticity was $\alpha = 0.0011$ for cannabis joints (SE = 0.000039, $p < 0.001$, $R^2 = 0.43$) and $\alpha = 0.00095$ for cigarettes (SE = 0.000037, $p < 0.001$, $R^2 = 0.44$).

The derived demand indices are reported in Table 1, Panel B. The intensity of demand was estimated to be $Q_0 = 49.92$ for cannabis joints (SE = 1.22) and $Q_0 = 33.32$ for cigarette packs (SE = 0.85). The peak expenditure was $85.30 for cannabis joints and $94.37 for cigarettes packs, occurring at prices of $5.43 for cannabis joints and $9.01 for cigarette packs, respectively.

Supplementary Figure 1 shows the expenditure curves derived from the exponential demand model for each substance. The peak expenditure point occurred when price elasticity turned to −1 (i.e., unit elasticity with which 1% increase in price decreases the quantity demanded by 1%). The changing elasticity over the range of offered prices is illustrated in Supplementary Figure 2. Demand for both substances was inelastic ($|elasticity| < 1$) at prices under the price at maximum expenditure and elastic ($|elasticity| > 1$) at prices above the price at maximum expenditure.

3.3 Dual-substance Demand Curves and Cross-price Elasticity

The observed mean demand curves from the dual-substance HPTs are displayed in Figure 2 (blue dashed line for cannabis joints and black dashed line for cigarette packs). For the purpose of comparison, the mean observed demand for cannabis joints in the single-substance HPT is overlaid on the graph (red dashed line). The two observed demand curves for cannabis joints from the single-substance HPT and dual-substance HPT appeared to closely overlap, indicating that the presence of cigarette packs as an additionally available substance had little effect on the demand for cannabis joints. Further, the average quantity of cigarette packs demanded varied little as the price of cannabis joints changed, staying near 15 packs across all offered prices for cannabis joints. This visual evidence from the observed means indicates that the two substances did not appear to have a strong economic relationship with each other when the price of cannabis joints changed and the price of cigarette packs was fixed.

The cross-price elasticity of demand was estimated at the aggregate level with the exponential model, shown in Table 2 (I = 13.032, SE = 0.34, p < 0.001; β = 0.0029, SE = 0.0021, p > 0.05). While a positive value of I is typically an indicator of a complementary relationship, the statistically nonsignificant value of β along with the very low magnitude indicates no significant relationship between the two substances. The evidence taken together suggests an independent relationship between cannabis joints and cigarettes packs at the aggregate level when the price of cannabis joints changed and the price of cigarette packs was fixed.

In Supplementary Table 4, we replicated the same exponential demand model at the aggregate level but restricted the analysis to the 256 participants who used both substances in the past 30 days. The results did not substantially change among this subsample (I = 14.42, SE = 0.39, p < 0.001; β = 0.0026, SE = 0.0021, p > 0.05).

In Supplementary Table 5, we also replicated the exponential demand model at the aggregate level but included the original sample of 407 participants without the removal of nonsystematic data or the top-coding of outliers. The results again showed an independent relationship (I = 23.46, SE = 6.84, p < 0.001; β = 0.0088, SE = 0.025, p > 0.05), despite a significant loss of explanatory power (R^2 = 0.01 compared to R^2 = 0.52 in our main model in Table 2).

Table 3 shows the log-linear model results of cross-price elasticity at the individual level. We found that the two substances were treated to be independent by 78.70% of the participants, complements by 17.46% of the participants, and substitutes by 3.85% of the participants.

4. Discussion

This study analyzed the behavioral economic relationship between cannabis joints and cigarettes using HPTs in a sample of people using both cannabis and tobacco in the U.S. We estimated that when cannabis joints and cigarette packs were offered alone in the single-substance HPTs, the [[rate of change of]] own-price elasticity (α) was 0.0011 for cannabis joints and 0.00095 for cigarette packs and the price at peak expenditure was $5.43 for cannabis joints and $9.01 for cigarette packs. Our estimates relating to cannabis demand were comparable with previous HPT studies. For example, Amlung et al. estimated the rate of change of elasticity (α) to be 0.0016 and 0.0028 for legal and illegal cannabis flowers, respectively, with our estimate for cannabis joints of 0.0011 falling just under this range. (Amlung, et al., 2019) Vincent et al. estimated the price at peak expenditure for cannabis joints to be $5.08, $7.28, and $8.99 for low-, mid-, and high-quality cannabis, respectively, similar to our estimate of $5.43 in a scenario that cannabis joints had the usual quality. (Vincent, et al., 2017) Our estimates relating to cigarette demand showed somewhat lower price sensitivity compared to previous studies. For example, Peters et al. estimated a 95% confidence interval for the rate of change of elasticity (α) from 0.0066 to 0.0085. (Peters, et al., 2017) Other examples include Grace et al. estimating α = 0.0056 and O'Connor et al. estimating $\alpha = 0.0084$. (Grace, Kivell, & Laugesen, 2015; O'Connor, et al., 2014) The difference may have to do with differences in study samples: our study focused on people using both cannabis and tobacco whereas these previous studies focused on people only using tobacco/cigarettes. It could be that people who used both substances were more likely to have deeply ingrained substance use habits that were less sensitive to price changes.

When cannabis joints and cigarettes were concurrently available in the dual-substance HPT, our aggregate model estimates were consistent with the hypothesis that the two substances have an independent relationship. This finding was reinforced by the individual-level analysis, which suggests that the two substances had an independent relationship for a large majority of participants (78.70%) and a complementary relationship for most remaining participants (17.46%). Only a very small minority of participants (3.85%) substituted cigarettes for cannabis joints as cannabis joints became more expensive. These findings generally echoed Peters et al., (Peters, et al., 2017) the only existing study examining the same two substances using HPTs. They found evidence of an independent relationship between cannabis and cigarettes at the aggregate level in a small adult sample. Our findings were supported by epidemiological data that suggested tobacco use not being substituted for cannabis use. (Lemyre, et al., 2019) Our findings were also consistent with many ecological studies evaluating state-level policy impacts that reported null associations between statewide cannabis (tobacco) policies and population tobacco (cannabis) use. (Bailey, et al., 2020; Coley, et al., 2021; D. M. Dave, et al., 2022; Pesko, et al., 2016; Veligati, et al., 2020) It should be noted that the cross-price elasticity estimates were based on a dual-substance HPT where only the price of cannabis was varying whereas the price of cigarettes was fixed. The relationship between the two substances remains unknown when the price of cigarettes varies.

Our results may have health policy implications in a global legal landscape moving towards liberalizing and commercializing cannabis. In terms of aggregate demand, our evidence suggests that cannabis joints and cigarettes likely have an independent relationship. This implies that regulating cannabis taxes is not very likely to have an effect on the aggregate demand for cigarettes. In terms of individual-level demand, our analysis suggests heterogeneity that was masked by aggregate-level results. The majority of participants treated cannabis joints and cigarettes as independent. However, a sizeable minority of 17.46% treated the two substances as complements, implying that cannabis taxes may serve a dual purpose of reducing the use of both substances for these people. For a much smaller minority of 3.85% who treated the two substances as substitutes, cannabis taxes may lead to a higher cigarette demand.

This study has limitations. HPTs in hypothetical scenarios may not accurately reflect the purchase decisions of consumers in reality. However, HPTs have been extensively used in literature and validated in comparisons with real purchase or substance use behaviors. (Aston, Metrik, & MacKillop, 2015; Cassidy, Long, Tidey, & Colby, 2020; Kaplan, et al., 2018; MacKillop, Goldenson, Kirkpatrick, & Leventhal, 2019; MacKillop, et al., 2008) HPT is one of the few practical ways to observe behavioral responses to isolated, exogenous variation in prices and to observe prices that may not otherwise occur naturally. Additionally, we used standard methods to remove potentially unrealistic demand data.

An additional limitation is that we only conducted one dual-substance HPT in which the price of cannabis joint was varying and the price of cigarette packs was fixed. This decision was made due to the concern of cognitive burden. The selection of cannabis joints for price variation was because of the relatively limited literature on cannabis demand compared to tobacco demand and the policy relevance with the current evolution of international laws liberalizing cannabis. We found that cannabis price had minimal impacts on cigarette demand. However, the price effects may not be symmetric and the impacts of cigarette price on cannabis demand remain uncertain. We hope future research could do symmetric dual-substance HPTs that also vary tobacco price.

Some settings in our HPTs may not reflect the real-world situations. Our HPTs used a 30-day reference period, which is longer than typical HPTs that occurred over hours or one day. The benefit of this longer reference period is seeing more variation in quantity demanded, particularly among people who only occasionally used the substances and who might not plan to use the substance within a short time period. However, a drawback is that some participants may have struggled to predict and quantify their demand over this longer time period, perhaps leading to some extreme quantities when the substances were free or very cheap. We addressed this limitation by top-coding extreme outliers. We followed previous research to ask participants to consider their usual amount of money available to spend on these substances. (Amlung, et al., 2019; Johnson, et al., 2017) However, the budget constraint was not binding, which could have made the purchase less realistic. The participants may use other substances in addition to the ones assessed in this study. For example, our results may not extend to other modes of consuming cannabis such as edibles or concentrates or other tobacco products such as e-cigarettes. We asked participants to assume that they have not used any substances before making purchase decisions, but this may not capture the effects that real abstinence may have on purchase behaviors such as resorting to other substances during withdrawal if one becomes prohibitively expensive.

We used quota-based convenience sampling approach to make our sample comparable to the population of adults using cannabis in the U.S. However, this method was unable to account for non-response bias. In addition, because we only retained participants who used both cannabis and tobacco, the final study sample may no longer represent the population using cannabis or the population using both cannabis and tobacco. In particular, our sample had fewer non-Hispanic Blacks and fewer high-income participants compared to national surveys. Our findings may not generalize to youth population or population in other countries, either. Future research may also further increase the sample size as it is possible that with a larger sample, we may have found evidence in support of a weak complementary relationship at the aggregate level rather than our current evidence on an independent relationship.

5. Conclusion

Our study estimated the behavioral economic relationship between cannabis joints and cigarettes among the population of adults using both substances in the U.S. Our results suggest that the aggregate demand for cigarettes is independent of the price of cannabis joints when only the price of cannabis was varying. However, at the individual level, a sizeable minority treated the two substances as complements, and a very small minority treated the substances as substitutes. Our findings imply that regulating prices of cannabis may have little effects on the aggregate demand for cigarettes, but that there may be important distributional effects on subpopulations to consider.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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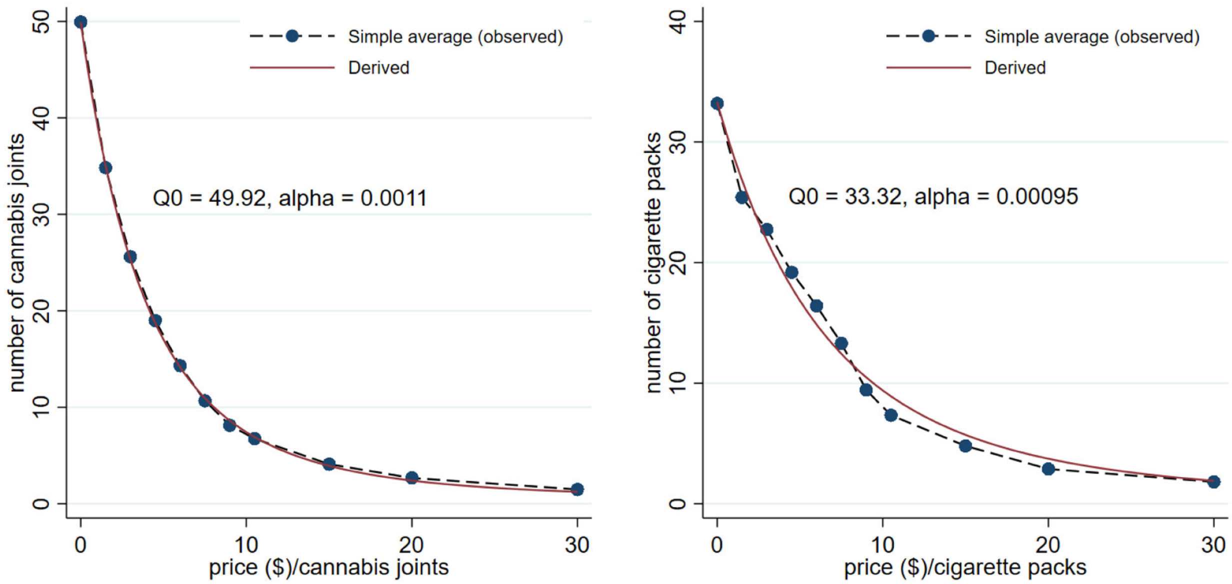

Figure 1. Observed (simple average) and Derived (exponentiated demand function) Demand Curves of Cannabis Joints (left) and Cigarette Packs (right)

Notes: Parameters Q0 and alpha were estimated from the non-linear exponentiated demand model. Q0 is the intensity of demand (i.e., the amount purchased when it is free) and alpha is the parameter indicating the rate of change in elasticity along the demand curve.

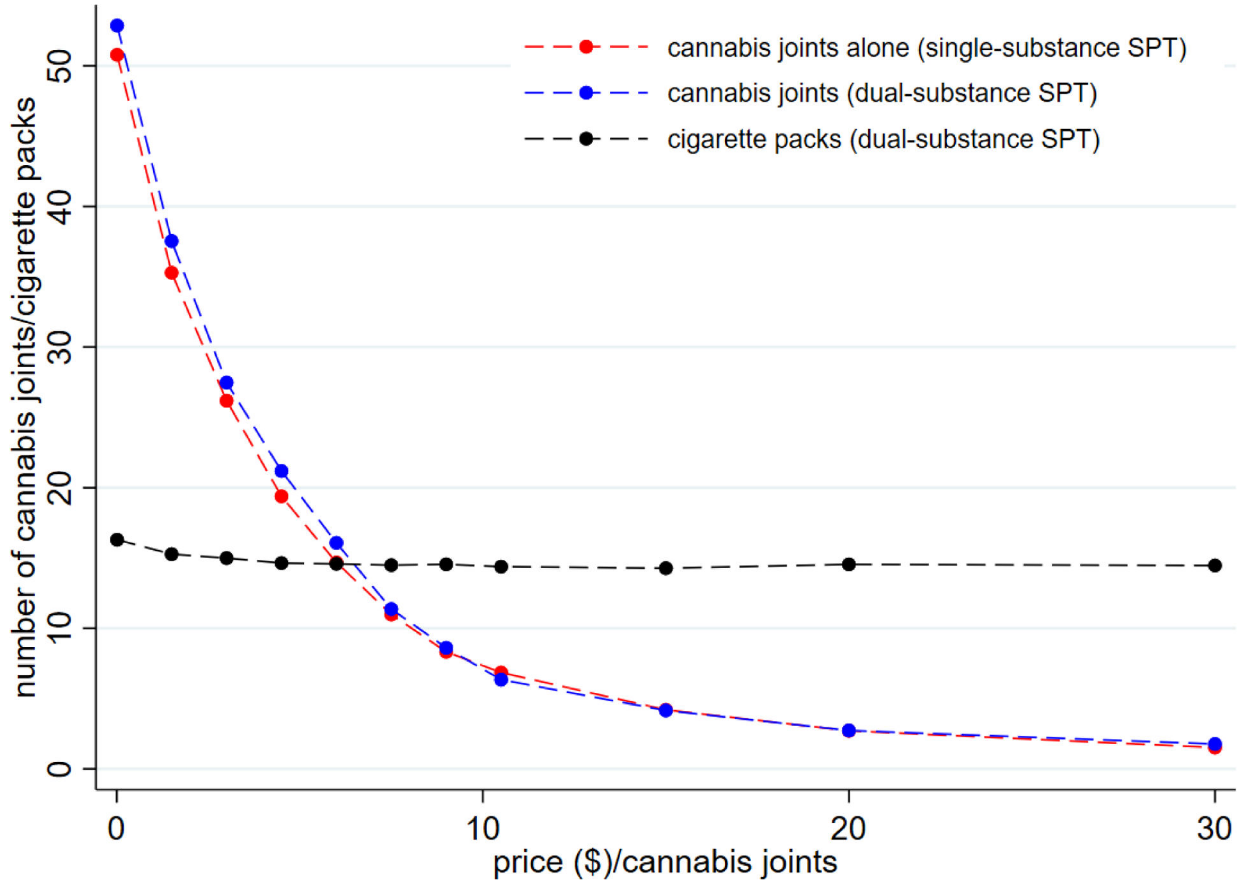

Figure 2. Dual-substance HPT: Observed Demand Curves

Notes: Figure shows observed mean quantity demanded at each price point of cannabis joints, connected by dotted lines.

Table 1.

Single-substance HPT: Observed (mean) and Derived Demand Indices

Demand Index	Cannabis Joints	Cigarette Packs
Panel A: Observed, mean (standard deviation)		
Intensity of demand	49.94	33.20
	(54.03)	(42.88)
Peak expenditure ($)	133.46	152.90
	(165.72)	(156.34)
Price at peak expenditure ($)	7.58	9.26
	(7.38)	(7.18)
Breakpoint ($)	18.53	18.13
	(10.50)	(9.80)
Panel B: Derived (standard error)		
Intensity of demand	49.92	33.32
	(1.22)	(0.85)
Peak expenditure ($)	85.30	94.37
Price at peak expenditure ($)	5.43	9.01
Number of Participants	338	338

Notes: Observed demand indices were calculated by taking the mean of the individual demand index values. Derived demand indices were calculated using fitted parameter values from the exponential demand model. Breakpoint could not be calculated for derived demand indices because the specified functional form never reached 0 quantity across the range of prices offered. Standard deviations are reported in parentheses in Panel A. Standard errors are reported in Panel B for directly estimated parameters.

Table 2.

Dual-Substance HPT: Exponential Model at the Group Level

Parameter	Estimate (Standard Error)
I	13.032***
	(0.34)
β	0.0029
	(0.0021)
Number of Price and Quantity Pairs	3,718
Number of Participants	338
R^2	0.52

Notes:

*** $p < 0.001$.

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Table 3.

Dual-Substance HPT: Log-linear Model at the Individual Level

Relationship between Cannabis Joints and Cigarette Packs	Percentage (%) (N = 338)
Independent	78.70
Complement	17.46
Substitute	3.85

Notes: Individual-level cross-price elasticity was estimated from a log-linear model estimated separately on one participant's data at a time. Participants were classified as having an "independent" relationship between cannabis joints and cigarette packs if 1) they had no variation in cigarette packs demanded, or 2) the coefficient of the log-linear model was not statistically significant at 0.05 level. Participants were classified as having a "complement" relationship if their coefficient was negative and statistically significant at 0.05 level. Participants were classified as having a "substitute" relationship if their coefficient was positive and statistically significant at 0.05 level.