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Behavioral Economic Relationship between Cannabis Flower and Concentrates: Evidence from Simulated Purchase Tasks

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Abstract

Cannabis users use different forms of cannabis, which are associated with distinct public health concerns. Policies that aim to regulate one specific form may have unintended impacts on other forms. This study examined the behavioral economic relationship between flower and concentrates, the two most common forms of cannabis. We surveyed 605 adult cannabis users (21+) who lived in one of the U.S. states that had legalized recreational cannabis by the time of interview in 2019. The participants completed simulated purchase tasks, which asked how much cannabis flower and concentrates they would purchase in the next 30 days at escalating prices. We estimated (1) demand indices and own-price elasticities using nonlinear exponential demand models; and (2) group- and individual-level cross-price elasticities using log-linear demand models. The estimated rate of change in demand elasticity (α) was 0.00066 for cannabis flower (SE=0.00002, p<.001) and 0.00058 for cannabis concentrates (SE=0.00002, p<.001). Group-level cross-price elasticity estimate (slope = −0.075, SE=0.0135, p<.001) indicated that cannabis flower and concentrates were weak complements. Individual-level cross-price elasticity estimates showed that flower and concentrates were treated as independent by 76.2% of the users, as complements by 19.0% of the users, and as substitutes by 4.8% of the users. The findings suggested that cannabis flower and concentrates were overall weak complements and for most adult cannabis users were treated as independent of each other. Price and tax policies regulating either cannabis form may have minimal impacts on the other form.

Keywords

Simulated purchase task; Cannabis flower; Cannabis concentrates; Behavioral economics; Exponential demand model; Elasticity of demand

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Declarations of Competing Interest

None.

1. Introduction

Cannabis has been increasingly liberalized in the United States (U.S.). As of May 2022, 37 states and the District of Columbia legalized cannabis for medical use; among them, 18 states and the District of Columbia also legalized cannabis for recreational use (National Conference of State Legislatures, 2022).

Recreational cannabis legalization facilitates the sales of novel and legally accessible forms of cannabis products. Although cannabis flower (throughout this study we referred to dried flower) remains the most common form of cannabis products in the U.S., alternative forms, such as concentrates (also known as “dabs”, “hash oil”, “shatter”, “budder” or “wax”) have grown in popularity lately. In Oregon, from October 2016 to November 2018, the average market share was around 26% for concentrates but declining for flower (Firth et al., 2020). Similarly, in Washington, concentrate sales increased from 8.6% in October 2015 to 16.8% and 26.2% in October 2016 and 2017, respectively, whereas flower sales decreased from 85.9% to 73.9% to 61.6% in the corresponding years (Davenport, 2021).

Flower is predominantly used via combustion methods such as smoking joints, blunts, and pipes, whereas concentrates are predominately used via non-combustion methods such as vaping and dabbing. Smoking flower and vaping/dabbing concentrates share common health risks such as impaired cognitive and brain development, respiratory and cardiovascular diseases, addiction and psychosis disorders, and motor vehicle accidents (Hall & Degenhardt, 2009; Volkow et al., 2014). They also have distinct health concerns. Smoking is associated with more toxic and secondhand smoke exposures compared to vaping/dabbing (Budney et al., 2015; Russell et al., 2018). Concentrates contain much higher levels of delta-9-tetrahydrocannabinol (THC) than flower (52% to 95% in concentrates vs. 16-21% in flower) (Bidwell et al., 2021; Raber et al., 2015; Stogner & Miller, 2015). The use of extremely high levels of THC is associated with an increased risk of cannabis use disorder (Arterberry et al., 2019; Freeman et al., 2018), increased severity of dependence (Freeman & Winstock, 2015; Meier, 2017), cognitive impairment (Calabrese & Rubio-Casillas, 2018; Pope, 1995; Pope et al., 2001; Ramaekers et al., 2006; Shannon et al., 2010), risk of psychosis (Di Forti et al., 2015; Di Forti et al., 2019; Schoeler et al., 2016), and poor mental health (Chan et al., 2017). Concentrates may appeal to youth more than flower due to the greater discretion of non-combustion methods, larger variety, and novel devices (Budney et al., 2015; Maccoun & Mello, 2015; Russell et al., 2018).

Given the distinct public health concerns associated with recreational use of flower and concentrates, the behavioral economic relationship between these forms has important public health policy implications. Currently some states have regulations to control the price and/or availability of a specific cannabis form. For example, Illinois and New York have separate excise and/or sales tax on flower and concentrates (Schauer, 2021). Illinois taxes cannabis based on the THC content with a higher sales tax rate imposed on the products with a higher THC content (mainly concentrates) (Schauer, 2021). Ten states set separate maximum weight-based limits on the amount of flower and concentrates that can be purchased, ranging from 1.0 ounce to 2.5 ounces for flower and 3.5 grams to 15.0 grams for concentrates (Pacula et al., 2021). If flower and concentrates are substitutes or complements, these regulations that aim to control one form may unintendedly impact the sales and use of the other form, which then may have public health impacts in a favorable or unfavorable way.

To date, there have been no studies providing evidence on the behavioral economic relationship between cannabis flower and concentrates. Such studies would require individual-level demand data. However, existing population surveys lack detailed information on cannabis use forms and aggregate sales data lack detailed information at individual level. In this study, we used simulated purchase tasks (SPTs) to address these limitations. SPT as a tool from the discipline of behavioral economics has been extensively used in substance use research to model changes in consumption of a substance as a function of various policy-related factors such as price and availability of alternatives (Amlung & MacKillop, 2019; Amlung et al., 2019; Aston et al., 2015; Ben Lakhdar et al., 2016; Bergeria et al., 2020; Collins et al., 2014; Dolan et al., 2020; Peters et al., 2017; Vincent et al., 2017). Because SPT assesses within-individual changes in response to exogenous, policy-related factors and avoids between-individual confounding factors, it provides stronger causal inferences compared to studies relying on between-individual changes.

With a series of SPTs, this study aimed to examine the behavioral economic relationship between cannabis flower and concentrates among adult cannabis users in the U.S. We estimated the own demand function of each form as well as cross-product demand function of the two forms. As the first study of this kind, our findings are expected to provide implications for regulating different forms of cannabis in the U.S.

2. Methods

This study was not preregistered. As required by the journal, we report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. Data and study analysis codes are available upon request.

2.1. Data Source and Study Sample

In May 2019, we recruited 3,046 adult cannabis users from online panels through Qualtrics online platform to participate in an online survey. The inclusion criteria included: living in one of the eight states that had legalized recreational cannabis by the time of interview (California, Colorado, Washington, Oregon, Nevada, Massachusetts, Maine, and Michigan); passing the legal age limit of purchasing recreational cannabis (21 years); and having used cannabis at least once in the past 12 months. The District of Columbia, Alaska, and Vermont were excluded because either the state was too small, or the state had not approved retail sale of cannabis by the time of interview. When a state’s population is too small it is difficult to draw an adequate representative sample of cannabis users from that state and make statistical meaningful inferences in that state. We conducted quota-based sampling to obtain a representative sample of adult cannabis users in the U.S. Of the 3,046 individuals surveyed, a third (1,018) were randomized to participate in the SPTs involving cannabis flower and concentrates.

Of the 1,018 participants, 244 were excluded from this study because they demanded zero quantity of cannabis flower and/or concentrates when the price was zero. Even though they used cannabis in the past 12 months, these 244 participants may have stopped using cannabis or use forms other than flower and concentrates at the time of interview. Of the remaining 744 participants, 169 (22.7%) were further excluded due to non-systematic demand behavior (Stein et al., 2015). Demand behavior was considered non-systematic if it met at least one of the three criteria: (a) an insignificant reduction between quantity demanded at the highest price and the lowest price (i.e., less than a 0.025 log-unit reduction in consumption per log-unit range in price), (b) too many increases in quantity demanded as the price increases (i.e., increase in quantity demanded at a higher price by more than 25% of initial demand at the lowest price and more than 10% of such occurrences), and (c) consumption is zero at two or more consecutive prices and followed by a greater than zero consumption at a higher price. The proportion of the 744 participants having each of the three types of non-systematic behavior was 16.8%, 9.6%, and 3.4%, respectively. The overall proportion of the participants having non-systematic behavior (22.7%) fell within the range reported in previous studies (Bergeria et al., 2020; Peters et al., 2017; Schwartz et al., 2021; Strickland & Stoops, 2017). The final study sample therefore included 605 adult cannabis users. Previous SPT studies do not have recommendations regarding the minimum sample size required for statistical analysis, but out sample size 605 was larger than 80% of the cannabis SPT studies summarized in a systematic review. (Aston & Meshesha, 2020)

The online survey was completed in 15 minutes on average. In addition to SPTs, it included questions related to cannabis use pattern, cigarette and other substance use, and sociodemographic characteristics. The survey was approved by the Human Research Protections Program at University of California San Diego.

2.2. Simulated Purchase Task (SPT) Design and Procedure

In the online survey, each participant completed three SPTs: 1) a single-product SPT when only cannabis flower was available, 2) a single-product SPT when only cannabis concentrates were available, and 3) a dual-product SPT where both cannabis flower and concentrates were available. Specifically, the single-product SPT assessed hypothetical purchase of cannabis flower/concentrates at 12 escalating prices. The 12 prices per gram ($/g) of flower were: $0, 3, 6, 9, 12, 15, 18, 21, 25, 30, 45, and 60. The 12 prices per gram ($/g) of concentrates were: $0, 15, 30, 45, 60, 75, 90, 105, 120, 150, 175, and 200. Prices were set based on market prices and prices used in existing literature (Collins et al., 2014; Vincent et al., 2017). The dual-product SPT assessed hypothetical purchases of concurrently available flower and concentrates when flower had the same 12 escalating prices as in the single-product SPT ($0/g to $60/g) and concentrates' price was fixed at $60/g (the average market price at the time of interview).

In all the SPTs, participants indicated how much cannabis they would purchase for personal use in the next 30 days. Participants were told to imagine that their typical budget for cannabis was available; the prices were after-tax prices; they had not used any substances including cannabis before they were making the decisions; the SPT was their only opportunity to purchase cannabis for use over the next 30 days; and there were no other cannabis products available. They were instructed to assume that they would consume all the cannabis they purchased over the next 30 days without any restrictions on where and how they used it; they cannot stockpile the remaining for a later date or share it with anyone else; and the cannabis they would purchase was similar to the strain, quality, strength, and flavor they typically used. A ½ gram of cannabis concentrates were defined as equivalent to 1/8 ounce or 3.5 grams of flower in THC. We did not perform any comprehension checks regarding whether these assumptions apply to participants' real-life scenarios.

2.3. Statistical Analyses

Before estimating demand models, we conducted data cleaning following common practices in literature. We examined the data for unrealistic quantities demanded (e.g., as high as 1,000 grams of cannabis flower/concentrates for use in 30 days at 0 price) and replaced them with the 99^{th} percentiles of quantities demanded in the study sample (Janisse et al., 2014; Siegel et al., 2013). Then, we recoded the extreme outliers, defined as Z score > 3.29, to one unit above the next highest non-outlier (Tabachnick et al., 2007). Outliers were present only at the highest extremes. The maximum values after recoding were 100 grams of flower and 60 grams of concentrates in single-product tasks, and 100 grams of flower and 11 grams of concentrates in dual-product task. In single-product tasks, the proportion of quantities identified as outliers and therefore corrected was 1.71% for flower and 1.21% for concentrates. In dual-product task, the corresponding proportion was 1.63% for flower and 2.41% for concentrates.

Using the single-product SPT data, we estimated demand indices and elasticities of demand for single-product (cannabis flower and concentrates, respectively) with a nonlinear exponential demand model (Koffamus et al., 2015), which is an exponentiated version of the original Hursh and Silberberg (2008) model (Amlung et al., 2017; Fragale et al., 2017; Strickland et al., 2016; Strickland et al., 2019; Yoon et al., 2021; Yoon et al., 2020). The nonlinear exponentiated demand model was recommended by the recent literature as it accommodates zeros in quantities demanded with improved fit without requiring the log-transformation of zeros (Yu et al., 2014). The model is as follows:

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

where Q is the quantity demanded at price P, Q_0 is the mean quantity demanded as price approaches zero (demand intensity), α is the rate of change in demand elasticity given the span of the demand curve and the base level of demand intensity, and k is the range of quantity demanded in log10 units (a constant specified prior to model estimation). Following Gilroy et al. (2019), we calculated k as follows for each product in the single-product SPT:

$$k = log_{10}(average\ maximum\ quantity) - log_{10}(average\ minimum\ quantity) + 0.5 \quad (2)$$

We calculated the maximum and minimum average quantity demanded at each price. We added 0.5 to minimize the risk of using a k value that did not reflect the full range of observed quantity demanded. We used a single k set at the maximum of the two k values calculated for all analyses (k = 2.7). A single k makes the estimates across different SPTs comparable.

We calculated the following observed and derived demand indices in the single-product SPT: (a) break point (price at which the demand is suppressed to zero), (b) intensity of demand (Q_0) (the quantity demanded at zero price), (c) P_{max} (price at peak expenditure), and (d) O_{max} (peak expenditure). Observed demand indices were calculated as the mean of individual-level demand indices. Derived demand indices were calculated using the fitted parameter values from the demand models. Since there is no closed form solution for P_{max} from the exponentiated demand model, we calculated P_{max} analytically using the lambert W function as suggested by Gilroy et al. (2019). The solution for P_{max} using the W function is:

$$P_{\max} = \frac{-W_0(-1/ln10^k)}{\alpha q Q_0} \tag{3}$$

The derived intensity of demand was an estimate in the nonlinear exponentiated demand model. Following Gilroy et al. (Gilroy et al., 2020), we also produced graphs of changing single-product demand elasticities at different prices using the estimates (Q_0, α) from the nonlinear exponentiated demand models.

Using dual-product SPT, at aggregate group level we regressed the log-transformed quantity demanded on log-transformed price to estimate cross-price elasticity between cannabis flower and concentrates (Amlung & MacKillop, 2019; Amlung et al., 2019; Johnson et al., 2017; Pope et al., 2019; Stein et al., 2018). To facilitate log transformation, a value of 0.01 was added when the quantity demanded was zero. Given the log-log specification, the coefficient can be directly interpreted as cross-price elasticity with the sign of the coefficient indicating whether the two products are complements or substitutes.

In dual-product SPT, we also estimated individual-level cross-price elasticities using the same log-linear demand model. Participants were classified into three categories based on their estimated cross-price elasticities. Participants were classified into “independent” category if 1) they had no variation in concentrates demanded with varying prices of flower or 2) the coefficient of the log-linear model was not statistically significant. Participants were classified into “complements” category if their coefficient was negative and statistically significant. Participants were classified into “substitutes” category if their coefficient was positive and statistically significant.

We did not use an exponentiated demand model to estimate individual-level cross-price elasticity because the model fit in the individual-level model was poor for too many individuals, but we reported the estimated exponential model at aggregate group level as a supplementary analysis. Specifically, we used the cross-product nonlinear exponential demand model provided by Hursh and Roma (Hursh & Roma, 2016): $Q_c = log(Q_{alone}) + Ie^{-\beta P_f}$ where Q_c is the quantity demanded of concentrates when the price of flower was P_f, Q_{alone} is the quantity demanded for flower at infinite price P, I is the interaction constant, and β is the cross-price elasticity. A positive I indicates a complementary relationship between flower and concentrates.

All the analyses were conducted in Stata ME 16.1. P-value < 0.05 was considered statistically significant. Data and analysis codes for this study are available by emailing the corresponding author.

3. Results

3.1. Descriptive Statistics of Study Sample

Before excluding any participants, our survey participants (N=3,046) were overall comparable to adult cannabis users in the entire U.S. according to the 2019 National Survey on Drug Use and Health. (Table S1).

Descriptive statistics of the study sample for this specific study (N=605) are reported in Table 1. Overall, 97.7% and 74.4% of the sample used cannabis flower and concentrates ever in lifetime, respectively, and 67.8% and 45.3% used cannabis flower and concentrates in the past 30 days, respectively. Regardless of cannabis forms, 29.1% of the sample used cannabis on 1-9 days, 10.4% used on 10-19 days, and 46.0% used on 20-30 days in the past 30 days. Regarding purpose of cannabis use, 15.4% of the sample primarily used for medical reasons, 37.7% primarily used for recreational reasons, and 46.9% used for both medical and recreational reasons.

The comparison between the study sample (N=605) and those who were excluded due to non-systematic demand behavior (N=169) was presented in Table S2.

3.2. Single-product Demand Curves and Demand Indices

Figure 1 illustrates the observed demand curves generated from the simple averages of quantity demanded at each price and derived demand curves generated from the fitted parameters for cannabis flower and concentrates, respectively, when each was the only product available. All the observed and derived demand functions had negatively sloped curves, reflecting the decrease in demand as price increased. The derived demand curves appeared to fit the observed demand curves generally well by visual inspection. The R^2 of the derived demand curves for both flower and concentrates was 0.43.

Table 2 presents the observed and derived demand indices from single-product SPTs. The derived demand intensity (Q_0) for flower was 30.31grams (SE=0.52) and for concentrates was 18.36 grams (SE=0.27). The derived intensity of demand (Q_0) values appeared to be close to the observed values. The derived peak expenditure (O_{max}) and price at peak expenditure (P_{max}) for flower was \$98.69 and \$9.82, respectively, and for concentrates were \$111.48 and \$18.32, respectively; they were all lower than the observed values. The estimated rate of change in demand elasticity (α) was 0.00066 (SE=0.00002; p<0.001) for flower and 0.00058 (SE=0.00002; p<0.001) for concentrates.

Figure 2 presents the derived total expenditure functions using the fitted parameters of non-linear exponentiated demand models. The peak expenditure corresponds to the point in the demand curve where price elasticity is −1 (i.e., unit elasticity with which 1% increase in price decreases the quantity demanded by 1%). The changing elasticity over price is illustrated in Figure 3. As the price increased, the demand for both products moved from inelastic to elastic.

3.3. Cross-Product Demand Curves and Cross-Price Elasticity

Figure 4 illustrates the observed demand curves from the dual-product task. The observed demand curve of flower when it was available alone closely overlapped with the demand curve of flower when it was concurrently available with concentrates. This indicated that the presence of concentrates may have a negligible effect on the demand for flower. The demand curve of concentrates was mostly flat with a negative slope at the beginning.

Table 3 reports group-level cross-price elasticty of demand estimated from the log-linear model. The cross-price elasticity was −0.075 (SE=0.0135; p<0.001), meaning that as the price of flower increased by 1% the demand for concentrates decreased by 0.075%. This indicated that flower and concentrates were weak complements. Table 4 reports the group-level cross-price elasticity estimated from the exponential model, which also indicated a complementary relationship (coefficient = 0.009; $SE = 0.001$; $p < 0.001$).

We also estimated individual-level cross-price elasticities using the log-linear model (Table 5). Of the 605 total participants, 343 did not have enough variation (too few non-zero quantities demanded for concentrates at fixed price to estimate individual-level models) These 343 participants were categorized as treating flower and concentrates as independent. Of the 262 remaining participants, the majority (45.0%) treated both flower and concentrates as independent (the coefficient of log-linear model was not significant), 43.9% treated them as complements (the coefficient was negative), and the remaining (11.1%) as substitutes (the coefficient was positive). Overall, of the total 605 participants, 76.2% treated both products as independent, 19% treated them as complements, and the remaining 4.8% treated them as substitutes. Figure S1 shows a box-whisker plot for the distribution of individual-level cross-price elaticities across the three categories (independent, complements, and substitutes).

4. Discussion

This study is the first to use SPTs to estimate the behavioral economic relationship between cannabis flower and concentrates in adult cannabis users in the U.S. In single-product SPTs, the intensity of demand for concentrates was higher than the flower grams with equivalent THC (½ gram of concentrates were defined as equivalent to 3.5 grams of flower in THC in this study, hence the intensity for concentrates was equivalent to 128.52 grams in THC). The estimated rate of change in demand elasticity (α) for concentrates was slightly smaller than that for flower. Together, these findings suggested that concentrates were demanded in higher quantities (THC equivalent) when unconstrained, indicating that they were considered superior. Demand for concentrates was therefore slightly less price sensitive than flower. These findings were plausible considering that concentrates were more expensive in the market. Breakpoints, the price at which the demand becomes zero, were higher for both products than the average per gram market price of medium quality cannabis in the U.S., suggesting that cannabis was highly reinforcing. Our estimates were comparable to those found in the literature. (Amlung et al., 2019; Vincent et al., 2017)

In dual-product SPTs, cannabis users treated concentrates as a weak complement to flower based on the cross-price elasticity at group level. Based on the cross-price elasticities estimated at individual level, we further categorized three types of cannabis users. The first type accounted for roughly three quarters of the users: those who treated flower and concentrates as independent. This was consistent with the previous studies that found concentrates being used for experimentation rather than for recurrent use (Sagar et al., 2018) and considered to be riskier than flower (Daniulaityte et al., 2017). The second type accounted for nearly 20% of the users: those who treated flower and concentrates as complements. The last type accounted for only a very small fraction (less than 5%): those who treated flower and concentrates as substitutes. The individual-level cross-price elasticities dissected the group-level weak complementary relationship. This implies that the population-level cross-price elasticity may conceal heterogeneities in terms of their individual responses to cannabis policies.

The findings from dual-product SPT may have policy implications. Overall, policies regulating the prices or availability of cannabis flower or concentrates may have minimal impacts on the other. For example, in case of a higher tax rate on flower, only a small minority of users may substitute away from flower to concentrates, a slightly larger proportion may decrease the demand for concentrates, but the large majority may keep the same level of demand for concentrates. In another case of a regulation that restricts the sales of concentrates, the regulation will not substantially influence the demand for flower.

The study has limitations. First, the SPTs assessed demand behaviors in hypothetical scenarios; therefore, the reported demand may not perfectly reflect actual purchases. For example, the participants had more product options in reality than what were offered in SPTs. The participants may not have followed the same conversion rate between quantities of flower and concentrates in reality. The participants who did not use a product type in reality may report unrealistic demand when their preferred products were not available in SPTs. Given the dearth of data from real-world purchases, however, SPTs in general have been extensively used and validated in the literature (Aston et al., 2015; Kaplan et al., 2018). The checks for non-systematic demand behavior also ensured data quality.

Second, the time frame specified in the study was “for personal use in the next 30 days”, which might have been too long for occasional users. The longer time frame may have led some participants to demand extreme quantities when the products were free. We addressed this issue by top coding extreme outliers to the 99^{th} percentiles.

Third, to reduce cognitive burden we only conducted dual-product SPT when price of flower was varying (price of concentrates was fixed) but did not consider the scenario when price of concentrates was varying (price of flower would be fixed). The selection of flower for price variation was because flower was the primary form of cannabis use and the primary target for cannabis regulation. However, the price effects may not be symmetric and the impacts of concentrates on flower remain uncertain. We hope future research could do symmetric dual-product SPTs that also vary cannabis concentrates.

Fourth, during the SPTs we did not specify whether the purchased cannabis would be for recreational or medical use. The heterogeneities by purpose of use were not explored. We did not explore heterogeneities by cannabis use pattern or sociodemographic characteristics, either.

Fifth, we did not consider other substances used concurrently with cannabis.

Further, we used a quota-based convenience sampling due to budget constraints. Although the major characteristics of our survey participants were similar to adult cannabis users in nationally representative surveys, we were not able to account for non-response bias.

Lastly, we restricted the sample to states that had legalized recreational cannabis by the time of interview. Our findings may not generalize to other states in the U.S. or other countries outside of the U.S.

5 Conclusion

This study provides the first evidence in literature that cannabis flower and concentrates may have a weak complementary relationship among adult cannabis users in the U.S. For most users, cannabis flower and concentrates were considered independent of each other. Policies that regulate the price and/or availability of either cannabis form may have minimal impacts on the other form. Future research should focus on the causal mechanisms for such findings. If one product form is preferred due to public health reasons, it is also worth further investigation regarding whether other policies such as marketing regulations and health warning requirements could shift the relationship between the two forms of cannabis.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability statement:

Data and study analysis codes are available upon request.

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Relevance to Public Health

The study findings suggested that cannabis flower and concentrates were overall weak complements and for most adult cannabis users were treated as independent of each other. Price and tax policies regulating either cannabis form may have minimal impacts on the other form.

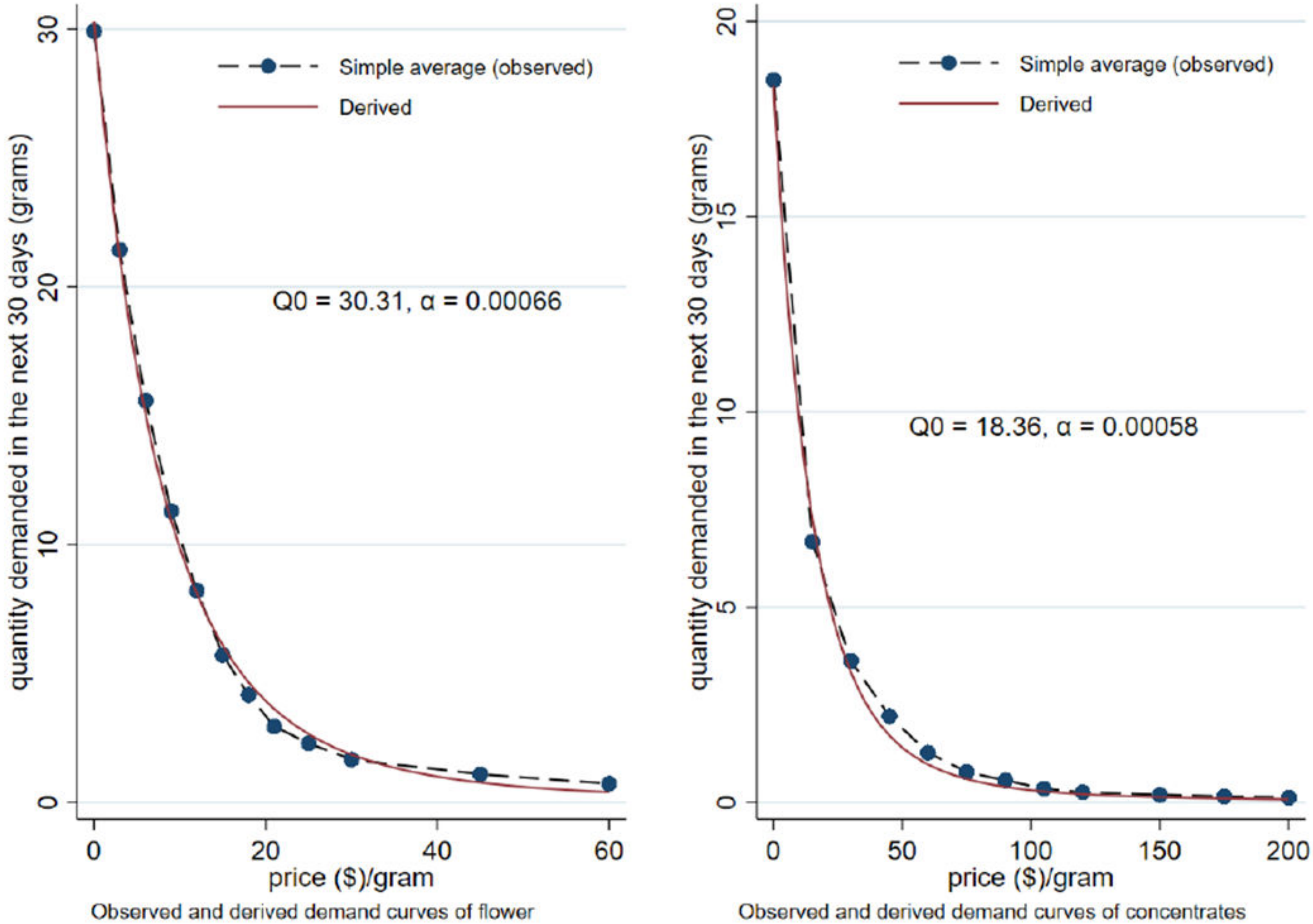

Figure 1. Single-product: observed and derived demand curves of cannabis flower and cannabis concentrates

Notes: Parameters Q_0 and α were estimated from the nonlinear exponentiated demand model. Q_0 is the intensity of demand (i.e., the amount of cannabis purchased when it is free) and alpha is the parameter indicating the rate of change in elasticity along the demand curve.

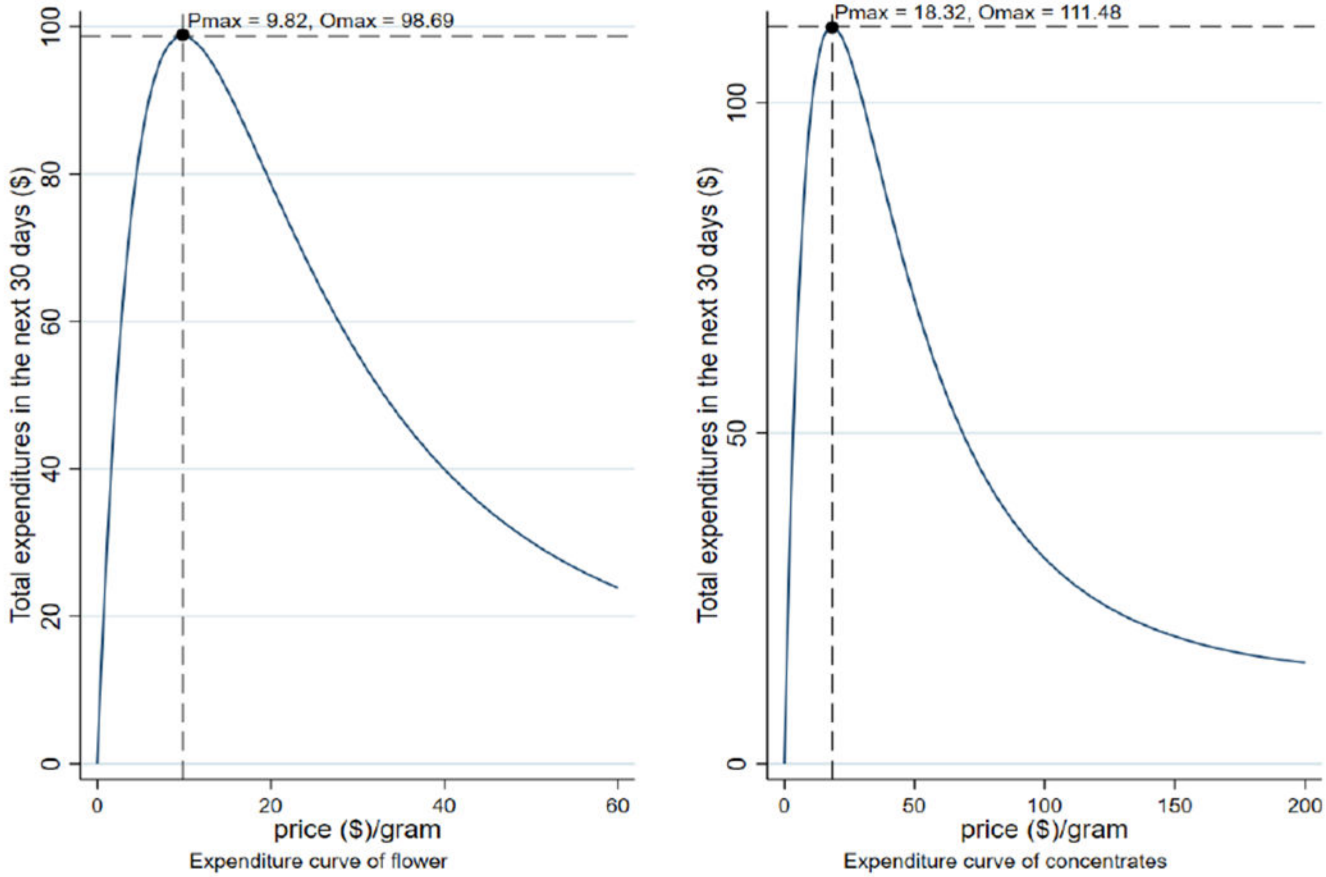

Figure 2. Single-product: expenditure curves for purchase of cannabis flower and cannabis concentrates

Notes: Total expenditure functions were derived using the parameters estimated from non-linear exponentiated demand models for the single-product tasks. P_{max} was the price at maximum expenditure (O_{max}). The estimated O_{max} for flower was $98.69 and concentrates was $111.48.

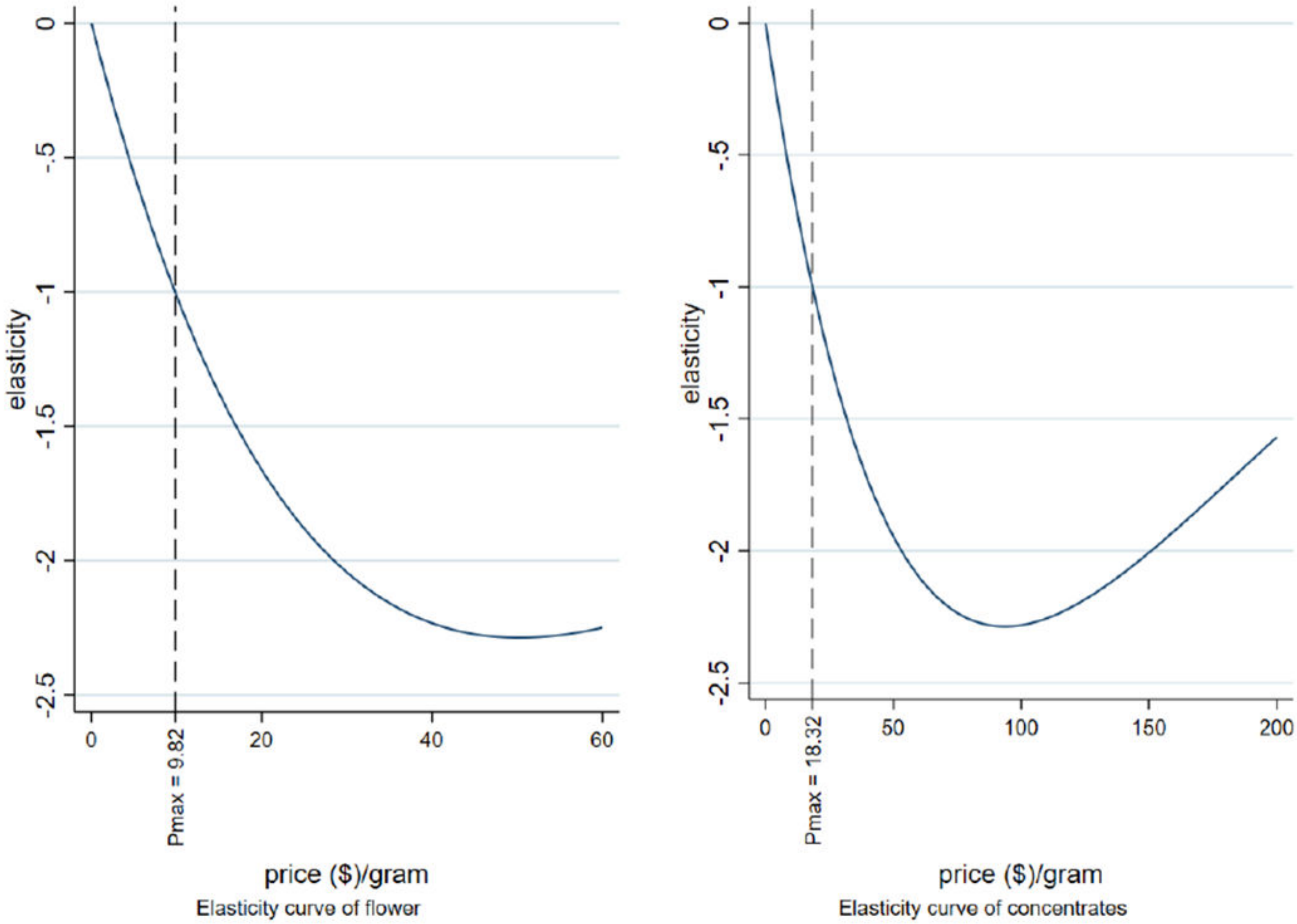

Figure 3. Single-product: elasticity curves for purchase of cannabis flower and concentrates

Notes: Elasticities at different price levels were derived from the non-linear exponentiated demand models for the single-product task. P_{max} indicates the price at which the slope of the demand equals −1.

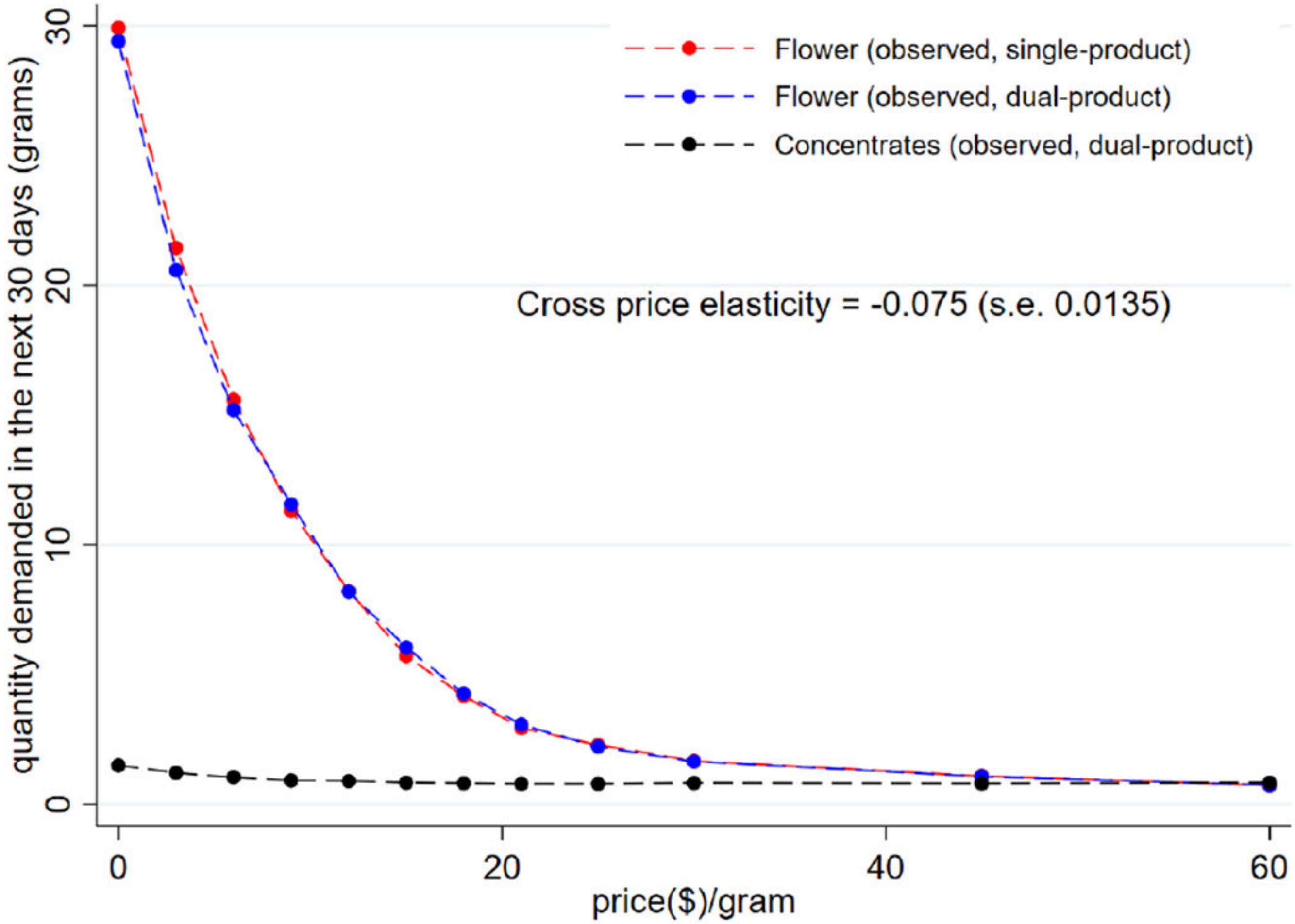

Figure 4. Dual-product: observed demand curves and derived cross-price elasticity

Notes: Cross-price elasticity was estimated from a log-linear demand model where the dependent variable was the log transformed concentrate demanded and the independent variable was the price of flower per gram in the dual-product task.

Table 1.

Sample Characteristics (N = 605)

Characteristics	(%)
Age:	
21-29 years	37.7
30-44 years	37.7
45+ years	24.6
Sex:	
Male	57.7
Female	42.3
Race/Ethnicity:	
White	74.5
Hispanic	11.2
Non-Hispanic Black	6.94
Other Non-Hispanic	7.27
Education	
High school or less	30.7
Some college, Associate's, or Bachelor's Degree or above	69.3
Income	
Less than $10k	8.4
$10k-25k	17.7
$25k-50k	29.1
$50k-75k	17.0
$75k+	23.1
Unknown	4.6
State	
California	23.5
Colorado	13.7
Massachusetts	12.7
Maine	2.64
Michigan	15.0
Nevada	8.26
Oregon	9.75
Washington	14.4
Overall cannabis use status	
Used less than 12 months but more than 30 days ago	14.5
Used 1-9 days in the past 30 days	29.1
Used 10-19 days in the past 30 days	10.4
Used 20-30 days in the past 30 days	46.0

Characteristics	(%)
Cannabis use status by form	
Flower:	
Used more than 12 months ago	7.6
Used less than 12 months but more than 30 days ago	22.3
Used in the past 30 days	67.8
Concentrates:	
Used more than 12 months ago	9.1
Used less than 12 months but more than 30 days ago	20.0
Used in the past 30 days	45.3
Purpose of cannabis use:	
Medical	15.4
Recreational	37.7
Both medical and recreational	46.9
Other substance use	
Smoked cigarettes in the past 30 days	40.3
Had 5 or more alcoholic drinks in one occasion at least once in the past 30 days	46.6

Table 2.

Single-product: observed (mean) and derived demand indices

Demand Index	Cannabis Flower	Cannabis Concentrates
Panel A: Observed: mean (standard deviation)		
Intensity of demand (Q_0) (gram)	29.93	18.50
	(31.24)	(19.44)
Peak expenditure (O_{max}) ($)	145.83	153.55
	(170.27)	(216.93)
Price at peak expenditure (P_{max}) ($)	15.59	35.50
	(15.17)	(39.21)
Breakpoint ($)	32.90	75.33
	(20.06)	(54.73)
Panel B: Derived		
Intensity of demand (Q_0) (gram)	30.31	18.36
Peak expenditure (O_{max}) ($)	98.69	111.48
Price at peak expenditure (P_{max}) ($)	9.82	18.32
Rate of change in demand elasticity (α)	0.00066	0.00058

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.

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Table 3.

Cross-product: cross-price elasticity estimate in log-linear model – group level

	Log-Linear model
Log(flower price)	−0.0752***
	(0.0135)
Constant	−1.0161***
	(0.0181)
Number of price-demand pairs	7260
Number of Participants	605

Notes: Cross-price elasticity was estimated from a log-linear demand model where the dependent variable was the log transformed concentrate demanded and the independent variable was the price of flower per gram in the dual-product task. Standard errors in parentheses.

*** $p < 0.001$.

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Table 4.

Cross-product: cross-price elasticity estimate in exponential model – group level

	Exponential model (1)
I	1.2148***
	(0.03879)
β	0.009469***
	(0.001507)
Number of price-demand pairs	7260
Number of Participants	605
R^2	0.20

Notes: Cross-price elasticity was estimated from a nonlinear exponential demand model provided by Hursh (2014): $Q_C = log(Q_{alone}) + Ie^{-\beta P_f}$ where Q_C is the quantity demanded of concentrates when the price of flower was P_f, Q_{alone} is the level of demand for flower at infinite price P, I is the interaction constant, and β is the cross-price elasticity. A positive I indicates a complementary relationship between flower and concentrates. Standard errors in parentheses.

*** $p < 0.001$.

Table 5.

Cross-product: proportion of participants who treated flower and concentrates as independent, complements, or substitutes – individual level

Estimated relationship between cannabis flower and concentrates	All users (%) (N = 605)
Independent	76.2
Complements	19.0
Substitute	4.8

Notes: Participants were classified into "independent" category if 1) they had no variation in concentrates demanded with varying prices of flower or 2) the coefficient of the log-linear model was not statistically significant. Participants were classified into "complements" category if their coefficient was negative and statistically significant. Participants were classified into "substitutes" category if their coefficient was positive and statistically significant.