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Price elasticity of illegal versus legal cannabis: a behavioral economic substitutability analysis

Michael Amlung[1,2], Derek D. Reed[3], Vanessa Morris[1], Elizabeth R. Aston[4], Jane Metrik[4,5] & James MacKillop[1,2,6]

Peter Boris Centre for Addictions Research, McMaster University and St Joseph's Healthcare Hamilton, Hamilton, ON, Canada,[1] Michael G. DeGroote Centre for Medicinal Cannabis Research, McMaster University, Hamilton, ON, Canada,[2] Department of Applied Behavioral Science, The University of Kansas, Lawrence, KS, USA,[3] Center for Alcohol and Addiction Studies, Brown University, Providence, RI, USA,[4] Providence VA Medical Center, Providence, RI, 02908, USA[5] and Homewood Research Institute, Guelph, ON, Canada[6]

ABSTRACT

Background and Aims The evolving legal status of cannabis world-wide necessitates evidence-based regulatory policies to minimize risks associated with cannabis misuse. A prominent concern is the impact legalization may have on the illegal cannabis market, including whether illegal cannabis will serve as a substitute for legal cannabis. Empirical data on this issue are virtually non-existent. This study used behavioral economics to investigate substitutability of legal and illegal cannabis in legalized catchment areas in the United States. **Design** A substitution-based marijuana purchase task assessed estimated cannabis consumption from concurrently available legal (a dispensary) and illegal (a dealer) sources. Prices of the two options were reciprocally either held constant ($10/gram) or escalated ($0–$60/gram). **Setting** US states with legalized recreational cannabis. **Participants** Adult cannabis users who were at least 21 years old (n = 724; mean age = 34.13; 52% female; 74% Caucasian) were recruited using online crowdsourcing. **Measurements** Mean consumption values were used in demand curve modeling to generate indices of price sensitivity and elasticity. Differences in demand indices were compared using extra sums-of-squares F-tests. **Findings** Both legal and illegal fixed-price cannabis options had significant positive cross-price elasticities (Ps < 0.001), indicating that higher prices motivate substitution irrespective of legality. However, the presence of a legal alternative had a substantially greater effect on consumption and elasticity of illegal cannabis ($\Delta_{elasticity} = 0.0019$; $F_{(1,37)} = 160$, $P < 0.0001$) than the presence of an illegal alternative on demand for legal cannabis ($\Delta_{elasticity} = 0.0002$; $F_{(1,37)} = 48$, $P < 0.0001$), indicating asymmetric substitution. Demand for legal cannabis was significantly greater than for illegal cannabis ($P < 0.0001$). **Conclusions** Cannabis users treat legal cannabis as a superior commodity compared with illegal cannabis and exhibit asymmetric substitutability favoring legal product. Cannabis price policies that include somewhat higher consumer costs for legal cannabis relative to contraband (but not excessively higher costs) would not be expected to incentivize and expand the illegal market.

Keywords Behavioral economics, cannabis, demand, legalization, marijuana, price policy, substitutability.

Correspondence to: Michael Amlung, Department of Psychiatry and Behavioural Neurosciences, McMaster University, 100 West 5th Street Hamilton, ON L8N 3K7, Canada. E-mail: amlungm@mcmaster.ca
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INTRODUCTION

Cannabis is the most commonly used federally illegal drug in the United States [1] and its misuse is a substantial public health concern, based on both short-term adverse effects and long-term consequences [2]. However, the legal status of cannabis in the United States is dramatically evolving, with recreational use now legalized in nine states and the District of Columbia. As legalization of recreational cannabis becomes more widespread, the development of evidence-based regulatory and pricing policies to minimize risk is increasingly important. Insufficient price controls could inadvertently encourage consumption or fail to collect revenues to offset the externalities of cannabis use. Excessively high prices could result in many consumers continuing to patronize a less expensive illegal market. Therefore, a prominent concern is the impact legalization may have on the size of the illegal cannabis market and its associated harms [3,4]. These harms include distribution of a cannabis product without rigorous quality control standards (e.g. increased potential for dangerous impurities or contamination by other drugs) and unclear cannabinoid

levels [e.g. unknown potency due to unknown tetrahydrocannabinol (THC) levels], among others. Despite these concerns, empirical data on consumption of legal versus illegal cannabis and the interaction between the two in the market-place is virtually non-existent.

Behavioral economics integrates psychological and microeconomic concepts and methods to understand consumption behavior and provides a model system for quantifying the impact of legalization on price elasticity (i.e. price sensitivity) for both legal and illegal cannabis [5]. A behavioral economic demand-based approach examines changes in consumption as a function of market pressures, such as price and availability of alternative reinforcers. Demand is commonly assessed using hypothetical purchase tasks that measure consumption of a commodity at various levels of price (e.g. how many grams of cannabis would you purchase if they cost $4.00 each?). Consumption values from a purchase task are plotted by price to yield a demand curve. Recent research validating a Marijuana Purchase Task (MPT) has revealed robust orderly preferences and significant elevations in cannabis demand as a function of cannabis misuse severity and following exposure to cannabis-related cues [6–8]. The validity of these findings is further bolstered by parallel findings for alcohol demand and tobacco demand (e.g. [9–12]).

Behavioral economics may also help determine whether the utilization of the illegal market will increase or decrease with changes in the legality of cannabis. In economic terms, the question is whether illegal cannabis will be an effective substitute for potentially more expensive legal cannabis. This possibility can be examined using a modified version of the purchase task in which legal or illegal cannabis is available alone or with a legal or illegal alternative is concurrently available. In these paradigms, one commodity is available at an escalating price while the alternative is available at a fixed price. These paradigms characterize the extent to which one option is preferred to another and how price interacts with preferences. For example, when both commodities are available, if consumption of the fixed price alternative (e.g. legal cannabis) increases with increases in price of the other option (e.g. illegal cannabis), then the alternative is considered an economic substitute [13].

Although substitution-based purchase tasks have demonstrated substitutability of other addictive substances (e.g. tobacco products [14–16]), no studies, to our knowledge, have examined the substitutability of legal and illegal cannabis. The purpose of this study was to use a modified MPT to characterize the substitutability of legal and illegal cannabis in simulated markets in which both options are concurrently available. We hypothesized that legal cannabis would be perceived to be a superior commodity compared to illegal cannabis, both because it avoids the 'costs' of being illicit (e.g. legal consequences) and the inherent benefits of a regulated product (e.g. quality control standards; known cannabinoid levels). Asymmetric substitutability favoring legal cannabis would suggest a general preference for the legal market. Furthermore, formal substitutability analysis permits precise characterization of the market prices that bring the competition between preferences for legal versus illegal cannabis into sharpest relief. To maximize ecological validity, we addressed these questions in participants from US states where recreational cannabis was legal using an online crowdsourcing approach.

METHOD

Participants

Participants were recruited via Amazon Mechanical Turk (MTurk; www.mturk.com), which is an online crowdsourcing platform that allows requestors (i.e. researchers) to hire and pay 'workers' (i.e. participants) for the completion of tasks such as questionnaires, experiments, etc. [17,18]. Workers browse available tasks posted by requestors and select those that interest them. They are then paid electronically through their MTurk account upon successful completion of the task. The MTurk platform has been widely used in psychological research in general and behavioral economics research in particular (e.g. [14,19–21]).

To be eligible for the overall study, participants were required to be at least 18 years old. However, as the minimum legal age to purchase cannabis in the states examined was 21, participants under the age of 21 were subsequently excluded from the present analyses. Participants were also required to live in a US state with legalized recreational cannabis use at the time of data collection—including Alaska, California, Colorado, Massachusetts, Maine, Nevada, Oregon, Washington—or the District of Columbia. Although Vermont has also legalized recreational cannabis use, this occurred after data collection was completed. Finally, participants were required to have $> 95\%$ approval rating on > 100 previous MTurk surveys, and only one response per IP address was allowed. To reduce biased responding due to demand characteristics, this study employed a two-stage design. An initial survey open to all MTurk workers who met the above inclusion criteria focused on decision-making and personality with no cannabis-specific information, and a follow-up survey focused on cannabis-related variables. Stage 1 participants who reported any cannabis use during the past 6 months were invited to complete the second stage. In total, 1085 of 3230 stage 1 participants (33.6%) reported using cannabis and 731 (67%) of these participants met inclusion criteria and completed stage 2. Seven participants were excluded for nonsystematic MPT data (see below), resulting in a final 724 participants (see Table 1 for sample

Table 1 Participant characteristics.

Sex	52% female; 48% male
Age (mean, SD)	34.13 (10.02)
Race	74% Caucasian
Annual income (median)	$52 500
State of residence (top 5)	CA (45%); WA (14%); OR (12%); CO (10%); MA (10%)
CUDIT-R total score (mean, SD)	8.36 (6.17)

n = 724; mean = mean; SD = standard deviation; CUDIT-R = Cannabis Use Disorder Identification Test–Revised; CA = California; WA = Washington; OR = Oregon; CO = Colorado; MA = Massachusetts.

characteristics). Participants received $2 for stage 1 and $5 for stage 2. The Hamilton Integrated Research Ethics Board approved the study and participants provided informed consent.

Measures

Participants completed a modified MPT for legal and illegal cannabis. Two MPTs assessed hypothetical cannabis consumption in grams from legal ('from a dispensary') and illegal ('from a dealer') sources, separately, at 20 escalating prices from free to $60/g. A substitution-MPT based on a validated tobacco substitution paradigm [14] measured hypothetical consumption of concurrently available legal and illegal cannabis, with one type at adjusting price (free–$60/g) and the alternative at a fixed price of $10/g (the average price per gram in the target states, see Supporting information, Table S1 for supporting data). The fixed and adjusting commodities were counterbalanced within-subjects.

Prior to completing the MPT assessments, participants read a series of instructional vignettes. Participants were first provided with a set of general instructions that have been used with previously validated MPT assessments. Then, participants were provided with descriptions of the two marijuana sources (legal versus illegal) that were developed specifically for this study. Instructional vignettes and MPT task stimuli are provided in the Supporting information. In addition, the full paradigm is freely available for download from Open Science Framework [22].

Cannabis use during the last 6 months was assessed with the Cannabis Use Disorders Identification Test–Revised [23]. Demographic variables were assessed via self-report questionnaire.

Data analysis

Data initially screened for missing values, and it was determined that all participants provided complete data for all variables. Responses on the MPTs were evaluated for non-systematic data using published criteria [24]. Mean consumption data across participants were used in demand curve modeling in GraphPad Prism version 7. Elasticity of demand (α) was modeled using the non-linear exponential demand curve equation provided by Hursh & Silberberg [25]:

$$logQ = \log Q_0 + k\left(e^{-\alpha Q0P} - 1\right),$$

where k is the range of log units consumption (Q), set to 1.8–2.2 for the various curve fits; P is price; Q_0 is demand intensity (fixed to mean consumption at free price); and α is the fitted elasticity parameter reflecting proportionate slope of the demand curve. This equation provided an excellent fit to the adjusting-price consumption values (R^2 values ≥ 0.98). P_{max} was defined as the price at which demand becomes elastic and was defined empirically as the price point at which the slope of the demand equaled −1. Intensity of demand (Q_0) was defined as observed consumption at free price. Finally, breakpoint was defined as the price point at which consumption was suppressed to zero. Substitution was quantified via two indices: (1) cross-price elasticity was calculated as the linear slope of the consumption curve of the fixed-price alternative, with a significantly positive slope indicating substitution [14]; and (2) an exponential cross-price elasticity model. For the second index, we used the exponential cross-price elasticity model provided by Hursh [13]:

$$Q_B = \log(Q_{alone}) + Ie^{-\beta P_A},$$

where Q_{alone} is the level of demand for the fixed-price commodity B at infinite price P for commodity A (zero consumption of commodity A), I is the interaction constant, ß is the sensitivity of commodity B to consumption of price of commodity A, and P_A is the price of commodity A. A negative value for I reflects a reciprocal or substitution relationship between consumptions of the two commodities. Differences in demand indices between conditions were compared using extra sums of squares F-tests with a conventional significance level of $P < 0.05$.

RESULTS

Responses on the MPT revealed prototypical demand curves for legal and illegal cannabis when available alone (Fig. 1). Intensity (Q_0) was greater for legal relative to illegal cannabis, indicated by a 4.5-gram difference in consumption at free price. An extra sums-of-squares test indicated elasticity was significantly higher for illegal cannabis, $F_{(1,37)} = 944$, $P < 0.0001$, suggesting greater price sensitivity compared to legal cannabis.

Substitution curves are presented in Fig. 2, price-level consumption data are provided in Supporting information, Tables S2 and S3 and complete statistical results are

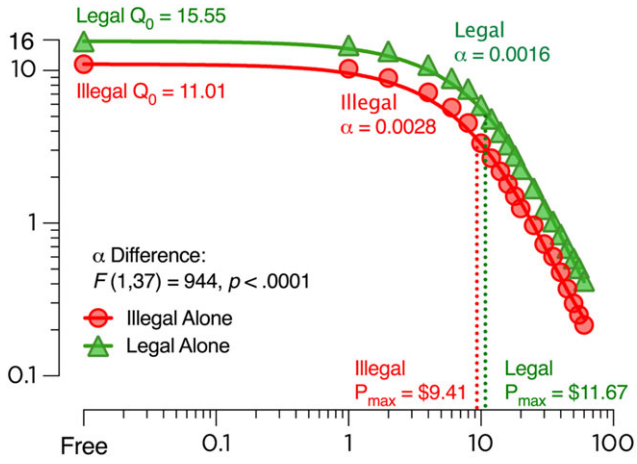

Figure 1 Consumption of legal and illegal cannabis available alone [Colour figure can be viewed at wileyonlinelibrary.com]

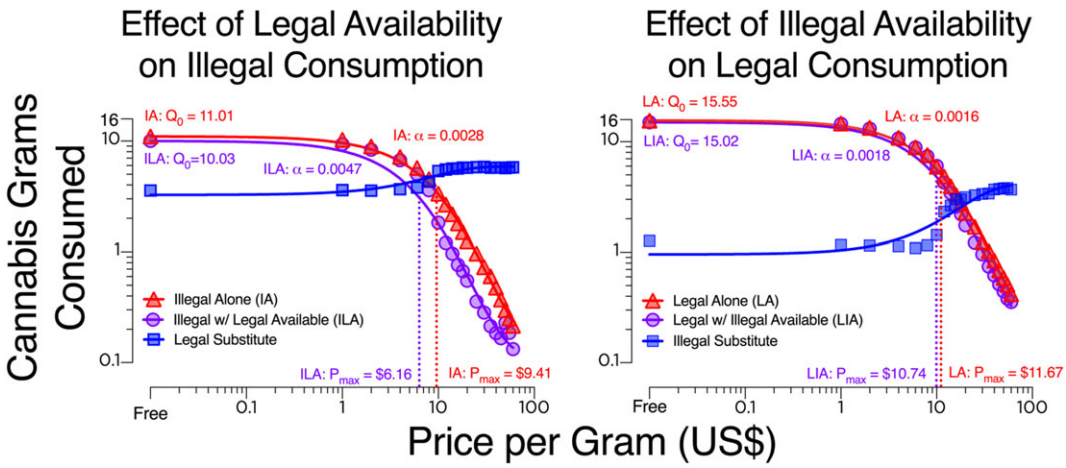

Figure 2 Demand and substitution curves depicting effects of legal and illegal cannabis alternatives on consumption [Colour figure can be viewed at wileyonlinelibrary.com]

presented in Table 2. Both fixed-price alternatives had significant positive linear cross-price elasticities (*P*s < 0.001), indicating substitution, and the slope of the illegal alternative was significantly greater than legal alternative, $F_{(1,36)} = 5.24$, $P = 0.03$. Similarly, both fixed-price alternatives had negative *I* values (illegal = −0.64; legal = −0.26) that significantly differed from each other, $F_{(1,34)} = 13.94$, $P < 0.001$. Examination of the own-price elasticities (α) in Fig. 2 indicated that the presence of a legal alternative had a substantially greater effect on the elasticity of illegal cannabis ($\Delta\alpha = 0.0019$; $F_{(1,37)} = 160$, $P < 0.0001$) than the presence of an illegal alternative had on legal elasticity ($\Delta\alpha = 0.0002$; $F_{(1,37)} = 48$, $P < 0.0001$). A similar pattern was evident for P_{max} (ΔP_{max}: illegal = $3.25, legal = $0.93). Finally, the mean breakpoint price for illegal cannabis available alone was $17.89, but this decreased to $8.38 when the legal alternative was available. The breakpoint for illegal cannabis alone was $28.98, and $23.43 when illegal was available. Therefore, there was a 2.4-fold larger effect of the legal alternative on illegal breakpoint than the opposite situation. Thus, for all of the demand indices examined, we observed asymmetrical substitutability.

A series of sensitivity analyses were conducted to determine whether the results obtained differed as a function of demographic factors, including age, income and sex. Demand and substitution indices were calculated separately for younger versus older participants (median split), higher versus lower income (median split) and males versus females. The results of these analyses are presented in Table 2. Although the absolute amount of cannabis consumption on the MPT varied in expected ways (e.g. younger participants reported consuming more cannabis than older participants; males reported greater consumption than females), the pattern of asymmetric substitution was universally present in all subgroups. In each case, the presence of the legal alternative increased the elasticity of illegal cannabis to a greater extent than the effect of illegal alternative on legal cannabis consumption.

Table 2 Overall results and sensitivity analyses examining patterns of substitutability between legal and illegal cannabis by age, income and sex.

		Alone			*Alternative available*			*Elasticity comparison*		
Group	*Source*	Q_0	P_{max}	*Elasticity (α)*	Q_0	P_{max}	*Elasticity (α)*	*Δα*	*F*	*p*
Total sample	Illegal	11.01	9.41	0.0028	10.03	6.16	0.0047	0.0019	160.0	< 0.0001
	Legal	15.55	11.67	0.0016	15.02	10.74	0.0018	0.0002	48.0	< 0.0001
Age < 32	Illegal	11.24	9.93	0.0028	11.68	6.86	0.0039	0.0011	73.0	< 0.0001
	Legal	15.73	10.90	0.0014	16.73	8.97	0.0016	0.0002	41.0	< 0.0001
Age ≥ 32	Illegal	9.35	10.48	0.0026	8.54	5.23	0.0057	0.0031	175.0	< 0.0001
	Legal	14.44	12.02	0.0018	13.42	11.08	0.0021	0.0003	46.0	< 0.0001
Income	Illegal	12.11	9.22	0.0026	10.89	5.79	0.0046	0.0020	104.0	< 0.0001
< $45 k	Legal	16.60	10.23	0.0015	15.99	8.85	0.0018	0.0003	47.0	< 0.0001
Income	Illegal	10.45	9.58	0.0029	9.63	6.55	0.0046	0.0017	178.0	< 0.0001
≥ $45 k	Legal	14.93	12.15	0.0016	14.49	11.13	0.0018	0.0002	44.0	< 0.0001
Male	Illegal	13.88	9.77	0.0020	12.74	7.10	0.0030	0.0010	109.0	< 0.0001
	Legal	17.46	11.21	0.0013	16.82	10.09	0.0015	0.0002	49.0	< 0.0001
Female	Illegal	8.77	8.91	0.0040	7.89	4.83	0.0082	0.0042	89.0	< 0.0001
	Legal	14.10	11.66	0.0019	13.69	10.37	0.0022	0.0003	34.0	< 0.0001

Group	*Source*	*Slope*	*P*	*F*	*P*	*I*	*F*	*P*
Total sample	Illegal substitute	0.183	0.0004	5.24	0.028	−0.64	13.94	0.001
	Legal substitute	0.805	< 0.0001			−0.26		
Age < 32	Illegal substitute	0.169	0.0002	5.50	0.025	−0.58	19.85	< 0.0001
	Legal substitute	0.076	< 0.0001			−0.25		
Age ≥ 32	Illegal substitute	0.208	0.0007	4.98	0.032	−0.74	8.75	0.006
	Legal substitute	0.088	< 0.0001			−0.28		
Income	Illegal substitute	0.219	0.0002	9.05	0.005	−0.73	11.37	0.002
< $45 k	Legal substitute	0.074	< 0.0001			−0.24		
Income	Illegal substitute	0.160	0.0009	2.75	0.106	−0.59	16.09	< 0.001
≥ $45 k	Legal substitute	0.088	< 0.0001			−0.28		
Male	Illegal substitute	0.169	0.0004	3.48	0.070	−0.59	21.30	< 0.0001
	Legal substitute	0.089	0.0001			−0.29		
Female	Illegal substitute	0.221	0.0005	7.70	0.009	−0.77	6.42	0.016
	Legal substitute	0.072	< 0.0001			−0.23		

Age and income groups based on a median split.

DISCUSSION

This study used a behavioral economic approach to inform price policy for legal cannabis by investigating the effects of cannabis legalization on use of cannabis from illegal sources. As predicted, legal cannabis was considered a superior commodity to illegal cannabis, as indicated by increased unconstrained demand (Q_0) for legal cannabis that was 29% higher than illegal cannabis and price elasticity that was 43% lower for legal cannabis (less elastic) compared to illegal cannabis. Furthermore, the results provide converging evidence of asymmetrical substitutability such that the presence of legal cannabis substantially decreased demand for illegal cannabis, but the reverse effect was significantly different and much smaller. The presence of illegal cannabis increased price sensitivity for legal cannabis by 13%, but the presence of legal cannabis increased price sensitivity for illegal cannabis by 68%. The results of the sensitivity analyses further indicate that this pattern was independent of demographic factors. Taken together, these data that introduction of legal cannabis into the market is likely to disrupt and potentially reduce illegal purchases.

Importantly, these data also imply that the specific pricing of legal cannabis will determine the extent of this disruption. This can be seen most clearly via examination of the crossover points in Fig. 2, or the price points at which procurement of the adjusting-cost commodity shifted from the majority to the minority of consumption. The crossover points suggest that $10/gram of illegal cannabis was roughly equivalent to $15/gram of legal cannabis, while $10/gram of legal cannabis was roughly equivalent to $7/gram of illegal cannabis, an approximately twofold difference. These data suggest that a price of $10/gram for legal cannabis would not be expected to substantially motivate illegal consumption (81% legal/19% illegal) and

that prices up to $14 would also not be expected to push consumers toward the illegal market. However, the relative consumption from illegal and legal sources also suggests that at substantially higher prices for the legal product, the overwhelming majority of cannabis purchase would be from illegal sources (e.g. at $20/gram the average consumption was 36% legal/64% illegal; Supporting information, Table S3). Thus, over-pricing legal cannabis could potentially backfire to the extent that the majority of purchases would effectively come from the contraband market. If a goal of legalization is reducing the contraband market as much as possible, competitive pricing is necessary. However, a last nuance to these findings is that underpricing may also be problematic, as excessively low prices of legal cannabis may actually spur greater overall consumption (see Fig. 2; Supporting information, Table S3). Lawmakers will need to 'thread the needle' of identifying the best prices to both suppress the contraband market and not inadvertently encourage greater use. This will vary across regulatory regions and over time, but the current data suggest prices ranging from $8–$14/gram would optimize the balance.

The most significant consideration for these findings is the use of simulated measures of behavioral economic demand on the MPT assessments. It is critical to acknowledge that these data reflect self-attributions about purchase preferences, not actual purchases, although there are several factors that bolster confidence in the findings. Hypothetical purchase tasks have been extensively validated in previous research (e.g. [12,26,27]), the high variance accounted for by the demand models increases confidence in the MPT data, and several inclusion criteria and data integrity checks ensured high-quality data [14].

More importantly, however, in the absence of observational field studies or large-scale data on actual purchases, the purchase task approach provides a robust platform for developing evidence-based policy decisions and designing future studies that will provide more definitive tests of substitutability. These data also pertain to cannabis users in US states with legalized recreational cannabis, and findings may not generalize to other states where cannabis remains illegal. The results may also vary in other countries where the legal status of cannabis is different, such as the impending federal legalization of cannabis in Canada. As a final consideration, it is also important to emphasize that these findings are situated in the context of the MPT, meaning that a regulated recreational cannabis environment would need to provide the corresponding features (e.g. quality control, clear constituent information) for these findings to pertain. The MPT also did not specify whether cannabis was used for recreational or medicinal purposes, although all participants in the present sample reported using cannabis for recreational purposes. Finally, the MPT paradigm used here cannot address the possibility that participants may shift preferences to other substances as the price of cannabis increases, including increasing their use of alcohol, tobacco or other drugs. Investigating these cross-commodity relationships is an important area for future research.

In sum, this study provides empirical evidence that cannabis users treat legal cannabis as a superior commodity compared to illegal cannabis, and exhibit asymmetric substitutability that supports the use of price policy that results in higher consumer costs for legal cannabis relative to contraband product. These findings suggest that availability of legal cannabis generally does not incentivize and expand the illegal cannabis market, unless the price of the legal product is too high. Pricing policy will need to be optimized to maximize the benefits of a legally regulated cannabis marketplace. More broadly, the study provides important support for using hypothetical purchase tasks to simulate cannabis demand under different policy manipulations.

Declarations of interests

None.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1 Average cannabis prices in target US states.
Table S2 Price-level consumption data on substitution MPT—part 1.
Table S3 Price-level consumption data on substitution MPT—part 2.